Geomechanical features of the exploitations of Iscaycruz mine (Peru)

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ABSTRACT: The Iscaycruz mining area is located in the western range of the Andes in Peru. Within an area of 50 square km, four zinc economic deposits have been identified and are being mined. The deposits are sub-vertical seams of poly-metallic ores presenting grades up to 14% zinc. The geomechanical country rock conditions vary from bad to good quality country rocks. In this context, the developed geomechanical program has shown to be a basic tool to design, plan and operate the mines. As a result a wide variety of mining methods are performed in the different deposits, including underground techniques such as cut-and-fill, open stoping with fill and sublevel caving; and open pit mining for the exploitation of the upper parts of two orebodies. In this paper we present a summary of the rock mass conditions encountered and the different mining methods selected and put into practice for the different orebodies mined at Iscaycruz.

1 INTRODUCTION

The Iscaycruz mining area is located in the western range of the Andes, 320 km NNE Lima, in Peru. The owner is the mining company Los Quenuales S.A., belonging to the Glencore Group. The deposits are sub-vertical seams of poly-metallic ores with grades up to 14 % zinc. These seams are located in sedimentary rock formations, formed by pelitic Jurassic sediments followed by Cretaceous sediments, being more clastic on the wall and limier at the top. The intrusion of igneous rocks in these formations originated metallic deposits in metasomatic and skarn areas.

The company started with the mining of the Limpe Centro orebody by means of underhand cut-and-fill method from sublevels with long-holes and back-filling the stopes with cemented aggregate fill, achieving a production of 1,000 tons per day. Presently, three new orebodies are under exploitation: Chupa, Tinyag & Rosita, consisting of sub-vertical seams ranging from 8 to 35 m thick. In this way, a production of 3,700 tons per day has been recently reached. The Chupa orebody is mined with sublevel open stoping with cemented aggregate fill. The upper parts of the Tinyag and Rosita orebodies have been open pit mined. The lower part of Tinyag has just started by sublevel caving. In Limpe Centro, the mining strategy has changed to overhand cut-and-fill with cemented aggregate and also paste fill.

In the following a general view of Iscaycruz is presented, highlighting the rock mechanics topics on the production and the different mining methods applied to each deposit.

2. REGIONAL GEOLOGICAL SETTING

The Iscaycruz area is found in a sedimentary environment, belonging to the Andean cretaceous basin. This basin is structurally characterized by a series of folds and thrusts very representative of western range of the Peruvian Andes. The Cretaceous rock series are composed in their lower parts by clastic rocks including sandstone, siliceous sandstone and limestone, belonging to the formations Oyón, Chimú, Carhuáz and Farrat. The upper part consists of a sequence of limy rocks together with some bituminous shale corresponding to the formations Pariahuanca, Chulec, Pariatambo y Jumasha. Igneous rocks, including tonalite, dacite and granite porphyry, have intruded these sedimentary rocks formations. Finally, tertiary age volcanic rocks, corresponding to the Calipuy formation, have discordantly covered the sedimentary formations.

During the Andean orogeny, the sedimentary sequence was intensely folded, mainly in the direction N-20º-W. In the Iscaycruz area the dip of bedding is 75 to 80 º NE. The anticlines and synclines extend for various tens of miles, intertwined with thrust areas parallel to the principal strain axis. Various sets of faults –in directions parallel and normal to the orebodies- complete this complex geological picture of the mine area.

3. INITIAL DEVELOPMENTS AT LIMPE CENTRO MINE

Limpe Centro mine started operating in 1996. This deposit comprehends two poly-metallic massive sulphide orebodies, ‘Estela’ and ‘Olga’. The initial output was 1,000 tons per day, coming from the underground mining of both bodies and from the open pit mine of the upper part of ‘Olga’.

These bodies formed due to metasomatic replacement of two limestone beds, separated 20 to 30 m and located within a large massive pyrite mass. The orebodies are tabular and parallel, being ‘Estela’ the most important one. This body is parallel to bedding (N-20º-W & 80-85º NE), it is 5 to 35 m thick, it is 250 long m and it was studied up to 630 m deep.

The drift and fill method was selected and pre-designed for ‘Estela’ in investigation stages and due to the bad rock mass conditions. Before the operation started, a painstaking rock mechanics program was implemented and performed in order to re-asses and optimise the mining method selection efficiently. As a result it was decided to implement the mining method ‘sublevel retreat under consolidated fill mining’. This method has improved recovery, productivity, safety standards and the stability of excavations.

The implemented rock mechanics program comprehended the following activities:

1) The basic geomechanic information was gathered by means of geotechnical zoning to characterize the rock masses affected by mining and mapping of the rock masses.

2) Different tools including analytical and numerical techniques were used to model the mining method to assess various mining strategies, arrangements and sequences.

3) The operational response of the rock mass to the mining activities was featured by means of displacement monitoring and other measurements and observations.

4) In-place information regarding the behaviour of the rock masses and their response modes to the main structure excavation was recovered to fine-tune the mining method.

5) Standards related to geomechanical parameters estimate and quality control procedures were stated.

6) An education program for mine staff was implemented.

This program has been continuously maintained as a part of the mining process. As a result of the preliminary application of the rock mechanics program a new mining method was tailored for the mining of ‘Estela’, whose main features are summarized as follows and which offers the view of the mine presented in Figure 1.

The main access is a ramp excavated in the hanging wall, for it is in this part where the rock masses present the best geomechanical quality. From the ramp, the ore body is entered by means of a main level drift; from which a direction access and haulage drift parallel to the ore body is excavated. From this direction drift 3.5 m x 3.5 m section crosscuts are excavated entering and crossing the orebody up to the footwall. One sublevel including a main direction drift and crosscuts are excavated every 12 m. The stopes were 3.5 to 4 m wide. Once the crosscuts in two consecutive sub-levels were built, a slot raise is open, the intermediate ore is blasted by means of long-holes and the mineral is recovered by LHDs. The stopes are back-filled from the upper crosscut. Mining proceeded horizontally up to the completion of the sub-level, acting the back-fill as a freestanding vertical wall. Mining continued in the lower level so back-fill acted as the crown of the lower stopes.

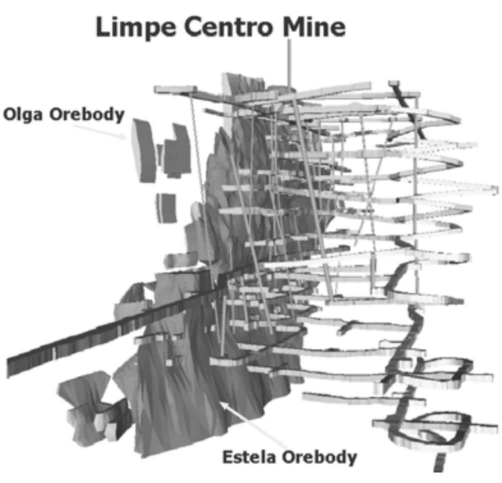

Figure 1. General structure of Limpe Centro mine.

Cemented aggregate back-fill was used to fill the stopes. This is a fill with graded aggregates obtained by simple classification of mountain talus slope quarried close to Limpe Centro mine. The thicker materials (smaller than 5 cm and larger than 1 cm) constitute 50 % of the stone material, whereas the rest was smaller than 1 cm. The binding agent was standard Portland cement in a proportion of 5% with a water/cement ratio around 1:1. The measured unconfined strength reached 2 and 6 MPa after curing times of 4 and 28 days. With these strength levels, adequately stable and safe walls and crowns were achieved.

4. UPDATING OF LIMPE CENTRO MINING METHOD

With the information gathered by means of the rock mechanics program, it has been possible to improve the mining method in various ways. This updating has cut the mining costs, keeping the stability of the excavations and safety standards in the operation. Presently the direction haulage drift is no longer excavated in the hanging wall, but in the inside of the orebody, where from, crosscut are made to both ends of the seam (Figure 2). The height between sublevels has been increased up to 17 m and now the stopes are 4 to 5 m wide. A topic to be remarked is that, even if the rock mass quality is low, mining is no longer going down-dip, but it is going up-dip as shown in Figure 3. All in all, an important change in the geometry and sequence of mining has been performed, resulting in a method specially tailored for Limpe Centro and unique in South America.

From a mine planning scope, mine blocks are defined containing 5 sublevels each of them. The mining of the block starts in the lower sublevel and moves upward in the shape of a column up to reach the fifth level. Then, the adjacent panel is mined in the same way, and the mining proceeds in this way up to the completion of the block. The mining of the block finishes when all the panels are extracted. According to this mining sequence, the cemented backfill only acts as the crown in the upper sublevel of the lower block when mining below, in all the rest of cases it only works as a free standing vertical wall.

In what the aggregate cemented fill concerns, there have also been significant improvements, thanks to the research performed in the concrete and fill laboratory of the Iscaycruz mine. It has been possible to reduce the cement consumption significantly, and at the same time the back-fill strength has been kept to reasonable values. Presently, with 3.5% cement, back-fill strengths of 4 MPa are achieved after 28 days of curing times and for 2.5% 3 MPa are measured for the same time. This has been possible by improving the gradation of aggregates and reducing the water content in the mixture up to water cement ratio of 0.75. Presently, the thicker materials constitute the 62% of the stone material, whereas 38% were smaller than 1 cm. Moreover, as the mountain talus slope quarries are getting closer to its depletion, the owner has built a paste-fill plant to use concentrator tailings from the plant. In order to study paste-fill behaviour, some tests have already been performed, including the backfilling of some stopes with paste fill and the construction of freestanding walls. So far 0.6 MPa with 6% cement have been achieved in 28 days. A research program is being carried out, in order to optimise strength keeping the cement consumption at a discrete level.

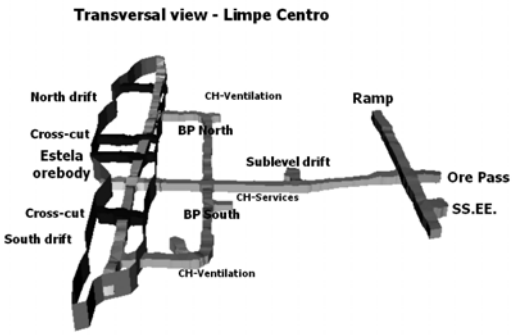

Figure 2. Transversal view of access to the stopes in Limpe Centro mine.

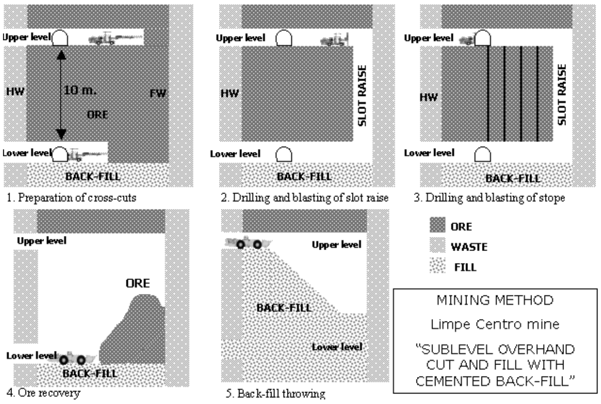

Figure 3. Different activities in the stopes to perform the sublevel cut and fill mining method at Limpe Centro mine.

Reinforcement and support are also important issues in excavation development at Limpe Centro, since bad quality rock masses are found in the mine, except in the hanging wall. In all the rest of excavations, stopes included, a combination of rockbolts (split-sets and corrugated bars), mesh and (plain or reinforced) shotcrete is used. In the footwall, where bad quality rock masses are found, light steel arches are needed. In standard stopes a 2" shotcrete layer is usually enough. Reinforcement and support are part of the daily work of the rock mechanics staff, which is responsible for controlling the quality of the support and reinforcement and for their installation and performance.

Since the operation set up, the larger part of production has come from Limpe Centro mine. Presently 3,700 tons of ore per day are entering the plant with a 14 % Zinc grade. 55 % of this mineral still comes from this mine. Due to the high grade of this deposit, reserves should be carefully treated, in order to complete the production from less rich mines in terms of mineral quality.

5. CHUPA MINE

Chupa mine is located in the south zone of Iscaycruz premises. The mineral occurs in the intersection of two faults and it is a sub-tabular body 10 to 30 m thick, with direction N-32-W and dipping 70º NE. The hanging-wall consists of sandstones and the footwall is formed by limestones (Figure 4). The span of the body varies form 100 to 150 m and the investigated depth is 500 m so far. The average grade of zinc is 10.5%, with minor lead, copper and silver contents.

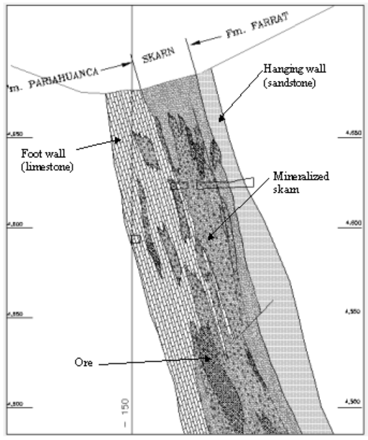

Figure 4: Geological section of Chupa mine.

In the investigation stage by means of exploration drifts and core drilling, the basic geomechanical information was gathered and the conditions of the different rock masses were assessed. The 3D geomechanical zonation carried out with the help of code Datamine (MICL, 1999) indicates average to good rock mass qualities. According to these qualities it was possible to propose sublevel open stoping as the more economic mining method for this deposit. In this case, open stoping requires the use of long parallel blast-holes and cemented rock-fill, in order to permit the recovery of the adjacent mineral.

In open stoping, the dimensioning of stopes is a key issue. A multi-approach method was applied, including empirical and numerical methods, together with mining experience and some full-scale testing. The stability graph method (Hoek et al., 1995) was particularly of great help. Finally, the height between sublevels was set to 33 m and the width of stopes to 8 m. Once excavated the upper and lower rooms, the intermediate bridge of rock is drilled and blasted with parallel blast holes.

Initially, the mining sequence was horizontal, that is, it must be first completed the mining of a sublevel before starting the mining of the upper one. In these conditions, in the mining advance, to recover the ore adjacent to a stope the cemented rock fill should behave as a self-standing wall. This mining sequence needed to let open the crown rooms in order to continue with mining enlarging progressively the unsupported roofs, which need, to be reinforced with cable-bolts. As mining advanced and experience was gained, the rock mechanics program focused on optimising the method. The orebody was divided into three horizontal 5 sublevel blocks separated by sill pillars 12 to 15 m wide, which will be recovered later. Mining advanced in vertical direction in every block, sparing the use of cable bolting. Stopes were enlarged to 16 m wide whereas in the fault influence areas to 10 m wide. A mine section is shown in Figure 5.

The cemented rock-fill was rejected due to the low strengths obtained and its high cost. This fill was replaced by cemented aggregate fill, coming from the same plant as Limpe Centro. With this new fill 30 m high self-standing walls were achieved with 3.5% cement. The cement content was raised up to 5% in the base of the mining block to be able to withstand stable roofs up to 10 m long when mining below. To estimate the back-fill strength requirements, different approaches are combined including those by

Stacey & Page (1986), Cai (1983), Mitchell & Roettger (1981) and the gained experience. With the new method, Chupa mine contributes with 20% of the output of the mine.

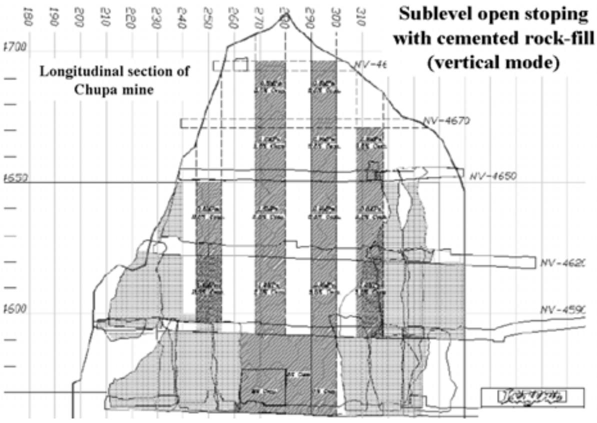

Figure 5: Longitudinal view of the upper part of Chupa mine. Some blocks are mined and back-filled, others only mined and some are not yet mined.

6. TINYAG & ROSITA MINES

Tinyag and Rosita orebodies represent the continuation towards south of the Limpe Centro deposit. Rosita is the southernmost area of the reserves identified. Both bodies are around 200 m long. Tinyag is 15 to 25 m thick. Rosita shows two parallel bodies, the eastern one is 7 to 12 m thick and the western one 2 to 5 m thick. The ore is disseminated in a skarn and it forms massive sulphide bodies. The grades are 7.7 % zinc for Tinyag and 9.5 % zinc for Rosita.

In what concerns the country rocks: pyrite, oxides and silica horizons with quartzite and marl appear sequentially in the hanging-wall. Beds of pyrite, shale, altered shale, dolomitic shale with sandstone and shaly sandstone appear sequentially in the footwall. The geomechanical quality of the ore is average to bad, and that of the hanging wall is very bad. The footwall presents average rock mass quality.

Since these bodies were almost outcropping, its mining has been performed by means of open pit mining, representing together 25 % of the ore entering the plant. The rock mechanics program focused on the design and on the control of open pit slopes. Final general slopes varied between 42 to 49 ºdip, with 6 m high benches inclined between 55 and 60º. In the western walls of those pits, it has been necessary to use cable-bolts in order to reinforce the stratified rock dipping toward the slope. The Tinyag pit has already been mined out up to its economic bottom. Rosita pit is in its third stage of development (Figure 6).

Since there is still ore below the pits, the underground mining of the lower parts of these orebodies is being planned. For the Tinyag orebody, and according to the bad quality of the hanging wall, the sublevel caving (SLC) method has been selected and designed according to the conditions encountered. By means of the rock mechanics program the transversal SLC has been established with 12 m sublevels and draw-point spacing 11 m, also, the mining sequence has been proposed. Presently, a pilot project of this method is being carried out with satisfactory results. So far, 90 % recovery of the ore has been achieved with dilution in the range of 15 to 20 %, which is a reasonable figure for SLC. The mining method for Rosita is presently being assessed.

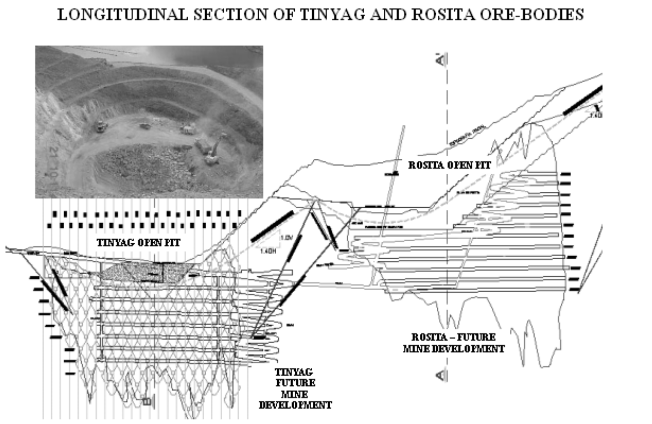

Figure 6: Longitudinal section of Tinyag and Rosita open pits and future underground development and picture of the Tinyag pit.

7. FINAL COMMENTS AND CONCLUSIONS

We have highlighted the different topics of the rock mechanics work developed in Iscaycruz. Geomechanics has been of paramount interest to design and fine-tune mining methods, to determine the strength requirements for the back-fills and also to design the support and reinforcement of the mining excavations. The rock mechanics studies have been an important help for the daily mining process as well.

As a result of the practical experiences carried out so far, it has been possible to improve the local and general stability conditions of the excavations associated with mining, and therefore the safety standards in the mines. A wide experience has been gained in the difficult task of appropriate mining method selection for Andean sub-vertical metallic seams, according to the country rock geomechanical conditions.

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