Paste 2013 — R.J. Jewell, A.B. Fourie, J. Caldwell and J. Pimenta (eds)

doi:10.36487/ACG_rep/1363_34_Cavalcante

Paste fill – a safety solution for pillar mining

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Abstract

MINERAÇÃO CARAÍBA S.A. has been a pioneer in the field of mining and metals processing for 43 years. A key contribution to the field of mining in Brazil has been the use of paste fill in underground mines. Its use has produced extremely successful results, increasing the stability of the rock mass as well as improving the recovery of mineralised bodies. Recovery increases as paste fill allows ore to be recovered which would previously have been left as pillars for the purpose of ground control.

Furthermore, paste fill reduces the environmental impact of mining efforts. Paste offers a higher placement density than alternative backfill methods, meaning more tailings can be placed underground. This results in reduced tailings being sent to the surface tailings placement facility, and ultimately reduces the size and cost of the tailings disposal site.

This paper describes the background and success of the paste fill system implemented by MINERAÇÃO CARAÍBA S.A., as well as on-going plant modifications. Current improvements to the paste system are being implemented to meet the mine expansion to maximum depths and to reach the most remote mining areas, while simultaneously minimising capital expenditures.

1 Introduction

MINERAÇÃO CARAÍBA S.A. headquarters are located in the north-east of the State of Bahia (**A**), Brazil, as shown in the image below. Caraiba Mine has been producing copper since 1979, and is situated about 500 km from Salvador, the capital of the State (**B**).

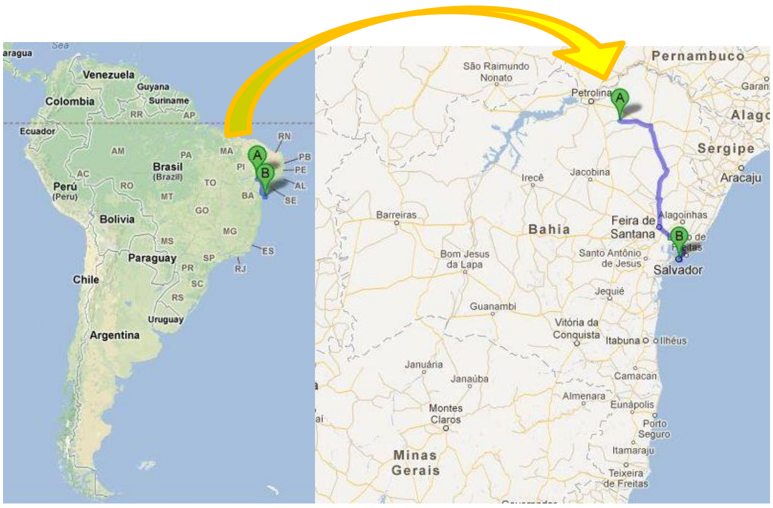

Figure 1 Headquarters and Caraiba Mine locations

The current annual production of MINERAÇÃO CARAÍBA S.A. is approximately 2.7 million tons of copper ore, constituted mainly by chalcopyrite and bornite. This amounts to 27,000 tons of metal annually. Mining originally commenced as an open pit operation, with final pit dimensions of approximately 1,200 m long by 700 m wide and a maximum depth of 300 m.

The mineralisation extends and mining continues below the open pit limits as shown in Figure 2.

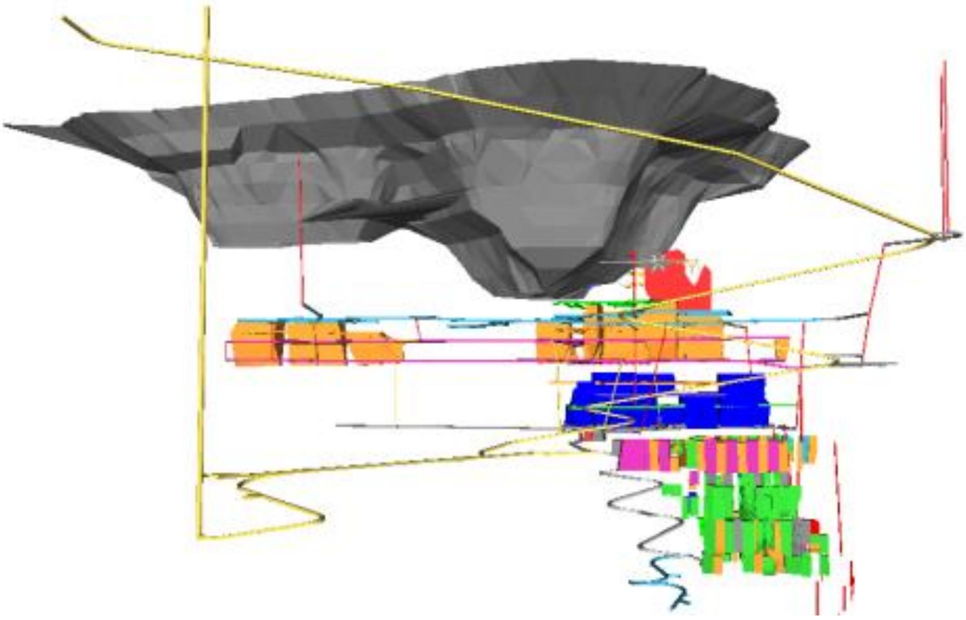

Figure 2 Layout of open pit and underground workings

Underground development at Caraiba Mine began in 1986. This was accomplished with an inclined ramp of around 17° and with a cross-section of 5.5 x 4 m. A vertical shaft with a diameter of 6 m was sunk to a depth of 640 m. Two skips with a capacity of 15 tons each were installed in the shaft.

The underground mining started with top-down extraction in Panels I and II utilising the sublevel open stoping mining method. Excavations measured 95 m high, 20–30 m wide and 60–100 m long (according to the mineralised body), and contained more than 100,000 tons of ore per stope.

In order to ensure the stability of the underground excavations, a 25 m wide crown pillar was put in place between the open pit and Panel I, as well as a 20 m sill pillar between Panels I and II. Additionally, rib pillars were also placed between the stopes of each panel. While the pillars were mineralised, engineering and geology departments worked together to ensure that where possible, pillars would be located in low grade areas to reduce the impact on revenue.

By 1996 Panel I was completely mined out, and extraction of Panel II was expected to be exhausted by 1998. Nevertheless, a diamond drilling exploration project commenced in 1996 which increased reserves considerably to 14.5 million tons of ore, with an average copper grade of 2.67%. Based on these results, Caraiba invested funds to expand the mine. While mining of Panels I and II continued with the expansion, several ground stability issues began to arise, including high dilution and low recovery of ore. Instability resulted in loss of ore within stopes and pillars. Caraiba commenced detailed rock mechanics and economic assessment in 1996 with a Canadian consultancy for the Caraiba Mine expansion. Recommendations included substitution of the existing sublevel open stoping mining method with the vertical retreat mining (VRM) method, with the implementation of a paste backfill system.

2 Methodology

Up until 1996, the mining of the underground Caraiba Mine was performed by open stopes (sublevel stoping). Even prior to the discovery of substantial reserves below Panel II and the mine expansion, Caraiba was considering revising the mining method and mine design due to the poor performance as follows:

- High levels of rock stress developed while mining.
- High dilution of ore (greater than 30%).

- Occurrence of large falls of ground and rock bursts.
- Loss of production.
- Ground falls generated large boulders requiring secondary drilling and blasting.
- Compromised stability aggravated over time by exposure, since the excavations remained open.
- Increased seismicity.
- Occurrence of induced seismic activity.
- Loss of ore reserve (recovery reduced to 50% of the measured reserve).

The Caraiba Mine team along with the Canadian consultants commenced a number of studies in order to develop a number of solutions and find a path forward. Based on the studies and brainstorming sessions that took place, the following measures were taken:

- A review of the geomechanical parameters and criteria for geotechnical rock mass in Caraiba.
- The geometry of the excavation was optimised in order to reduce dilution and facilitate greater recovery of ore.
- The mining method was modified to VRM.
- A paste fill system was implemented.

3 Data

Initially the mining method consisted of descending or 'top-down' mining, with vertical pillars separating the open stopes on each level (panels), while horizontal pillars (sill pillars) separated the panels from level to level. These pillars were permanent and the stopes were kept open, unfilled after the completion of mining. This approach compromised the stability of the excavation to the point that one pillar failed completely. As a climax, failure of the crown pillar below the open pit occurred, requiring rapid and extensive filling. The location of this pillar is shown in Figure 3.

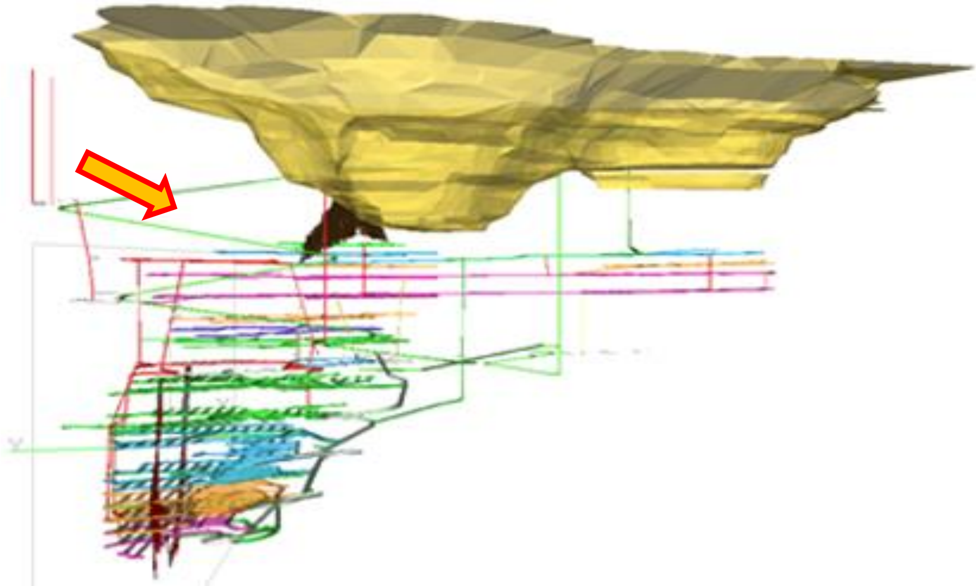

Figure 3 Crown pillar failure

Figure 4 shows a schematic representation of underground mining as of 1996 and prior to the concept of deepening the mine.

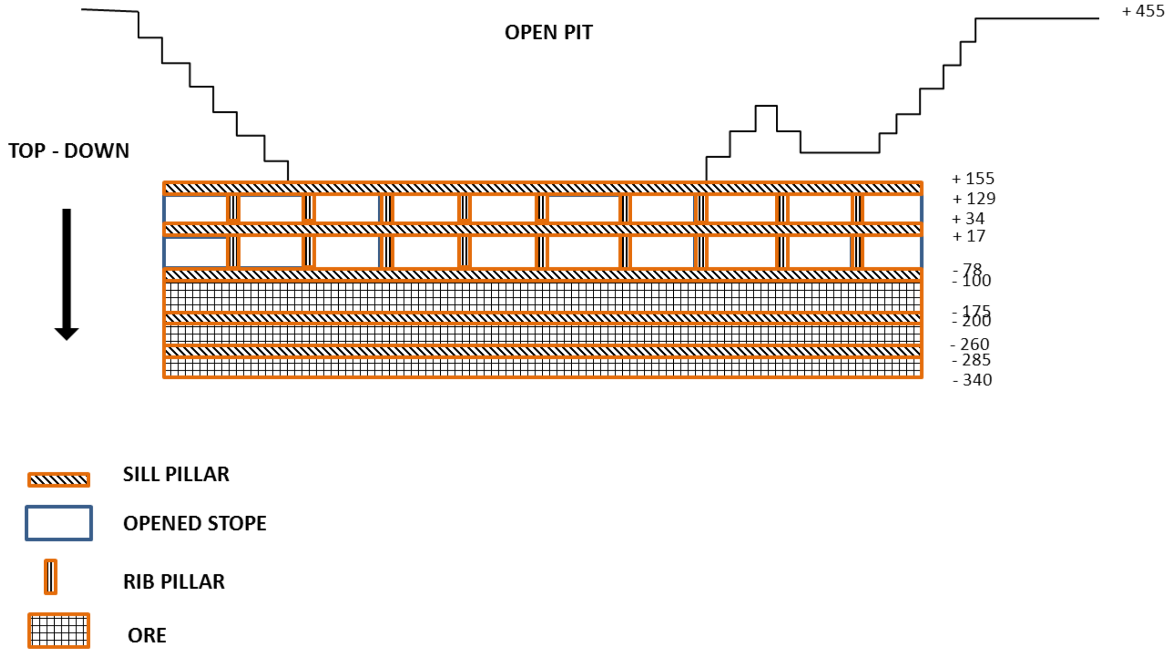

Figure 4 Initial concept for deepening the underground mine

In 1996, as the diamond drilling campaign got underway, indicated ore reserves were identified to a depth of 800 meters. At that time, the deep mine expansion project was developed to a concept level, which retained the open stopes, rib pillars between panels and sill pillars.

Meanwhile, the mining of panels I and II was difficult, although several key aspects were identified to resolve key issues. The geology of the Caraiba Mine is within a fold, with regions of high to low stress conditions when crossing the fold.

The following solutions were accepted and implemented:

- Development of a revised set of geomechanical parameters and of the geotechnical criteria of the rock mass of Caraiba Mine was carried out.
- The geometry of the excavations was optimised in order to reduce dilution and ensure greater ore recovery.
- Re-orientation of development and production stopes from a north-south to an east-west orientation, perpendicular to the regional structures (fault, fold axis) rather than in line with the structures.
- A higher degree of flexibility obtained by adopting a 'bottom up' approach to mining.
- VRM was adopted.
- A paste fill system was implemented.

With new geomechanical model and the mine design completed, and with changing the mining method from sub-level open stoping to VRM, significant improvements were realised. Furthermore, the implementation of the paste fill system in 1997 enabled the bottom-up approach to mining sequence as well as increasing recovery through the ability to recover permanent pillars. This increased the mineable reserve, dramatically improved the stability of underground excavations and, as a result, minimised the dilution of ore.

Figure 5 shows a schematic diagram of the concept of upwards extraction.

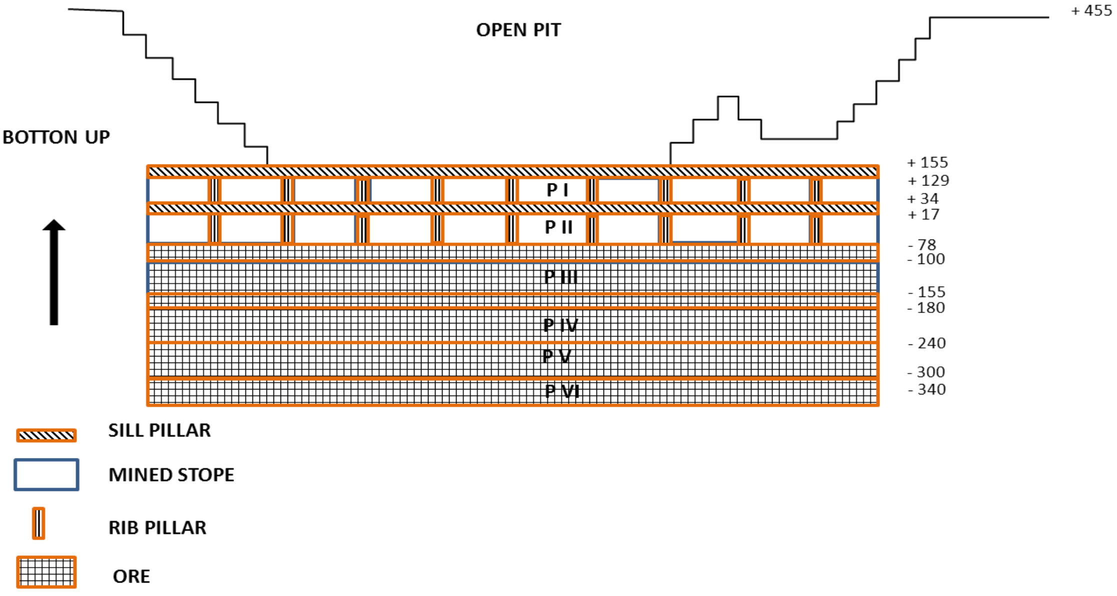

Figure 5 A new concept for deepening the underground mine

4 Implementation of the VRM method

The implemented VRM method is very versatile, having the ability to be applied in varying ore widths, dips and thickness. Caraiba experienced a higher degree of control over mining limits, improved recovery while reducing dilution through flexibility in blast hole layout and provided better stability of the rock mass.

Figures 6 and 7 display the concept of VRM method, with division of the stope in three parts:

- Free-face – Determined by the cross cuts developed at the end of the drifts, in the 'top-sill' and 'bottom-sill'. A slot raise to establish a free-face over the height of the stope is completed along the footwall contact of the ore and within the ore. The slot raise is drilled using an in-the-hole (ITH) drill on a nine-hole pattern with 165 mm diameter holes.
- 'Over cut' – The upper section of the stope is drilled with downholes up to 35 m in length and having a diameter of 114 mm. Holes longer than 35 m are drilled with the ITH drill rig at 165 mm diameter.
- 'Under cut' – The lower section of the stope is drilled with upholes with 89 mm diameter holes.

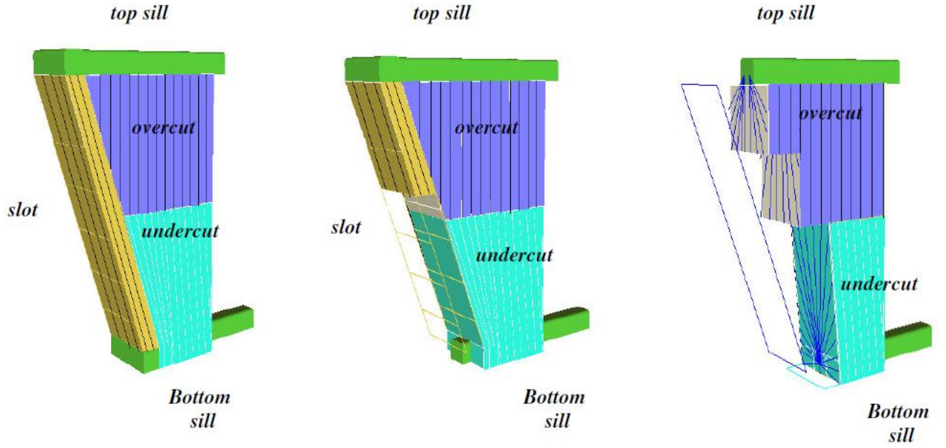

Figure 6 VRM mining method

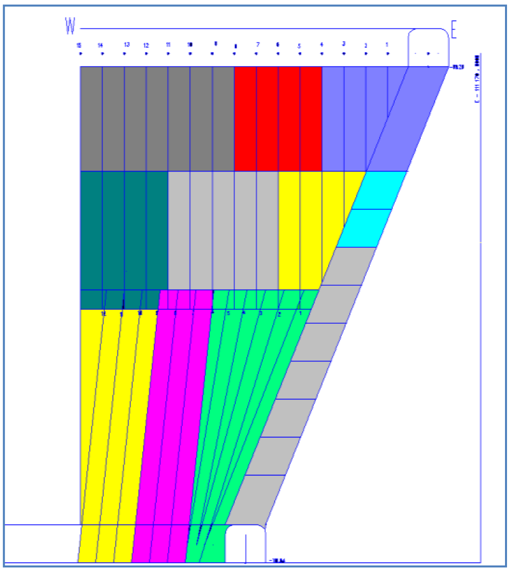

Figure 7 Blast sequence in VRM

5 Implementation of the paste fill system

With significant improvement in reserves following the exploration campaign, concerns were heard regarding the stability of the mine with depth. As mentioned above, the need for backfill was identified, and three options were considered:

- *Classified hydraulic filling* – Cyclone classified tailings used as hydraulic fill did not meet the strength requirement in order to contain the walls that measured from 1,500 to 2,400 m². The drainage requirement for the stopes as well as the added infrastructure and energy needed to pump the water back to surface further limited its potential. Tailings gradation was acceptable and available.
- *Cemented rockfill (CRF)* – Less capital expenditure is needed initially, however it has the highest operational costs. CRF demands a larger fleet of equipment in the mine, and interferes directly with production by increasing the need for additional mobile haulage equipment, labour and congestion of ramps. An increased fleet would also constrain the mechanical availability of mobile equipment. Further costs are encountered with additional ventilation requirements for the mine.
- *Paste backfill* – This option was selected due to the fact that it was more economically feasible than CRF. It was also perceived to be the best option for minimising any interruption/interference-free operation of the mine since backfill would be delivered within a pipeline, rather than requiring additional mobile fleet and labour. The strength is such that fill is capable of supporting the large stopes. Almost all the water from the plant is recovered with the filtering of solids, in addition to greatly reducing the amount of both water and solids sent to the tailings damn.

The capital investment for the paste backfill system was US$4.8 million, with an average operating cost of US$2.40 per ton of ore.

The success obtained by Caraiba Mine in the expansion of the underground mine was largely due to the implementation of the paste backfill system. The mining of the pillars essentially doubled the mineral reserve. The payback period on the paste fill system was slightly more than two years.

Figure 8 shows the stopes to be mined and filled with paste.

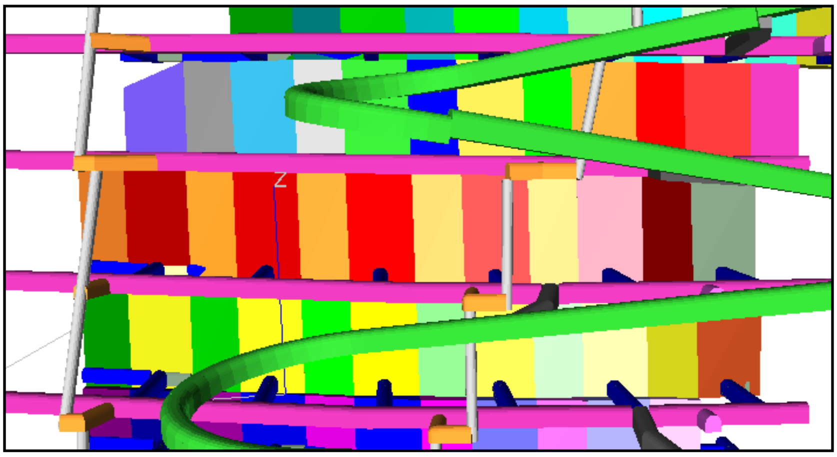

Figure 8 Stopes to be mined (by João Guilherme Travassos)

The ability of the paste backfill to be self-supporting within 28 days of curing results in rapid turnaround. Due to the grind and mineralogy of the tailings at Caraiba, test work showed a minimum content of 4% Portland cement in order to provide the required strength of 0.37 MPa. The paste consistency must be monitored in order to avoid deposition within the distribution lines.

Table 1 presents the annual paste production since the start-up of the paste plant in 1998.

Table 1 Annual production of paste

Year	Paste production
1998	74,356
1999	622,502
2000	419,506
2001	673,450
2002	739,127
2003	606,154
2004	746,900
2005	346,477
2006	268,795
2007	482,126
2008	268,429
2009	260,643
2010	254,644
2011	257,636
2012	128,951
Total	**6,149,696**

6 Results

The modifications implemented by Caraiba Mine allowed the mining of pillars between panels (sill-pillars) and the rib-pillars between the stopes, increasing the ore recovery from 50% to more than 70%.

The improvement in the stability of the excavations ensured a higher degree of safety in development and mine workings. The duration that stopes are left open decreased considerably as paste backfill allowed a high rate of filling with low utilisation needs, leaving ample time for plant maintenance, piping modification and barricade construction.

Furthermore, the paste backfill improved the degree of control over the mining, with improved ore recovery, and improved the ability to schedule and produce ore reliably to meet production targets.

Currently Caraiba Mine is preparing for further development to a depth of 1,600 m, which will require the paste backfill distribution system to be extended to meet production requirements. The deep mining will require more rapid filling and higher strength to facilitate safe and efficient mining environment.

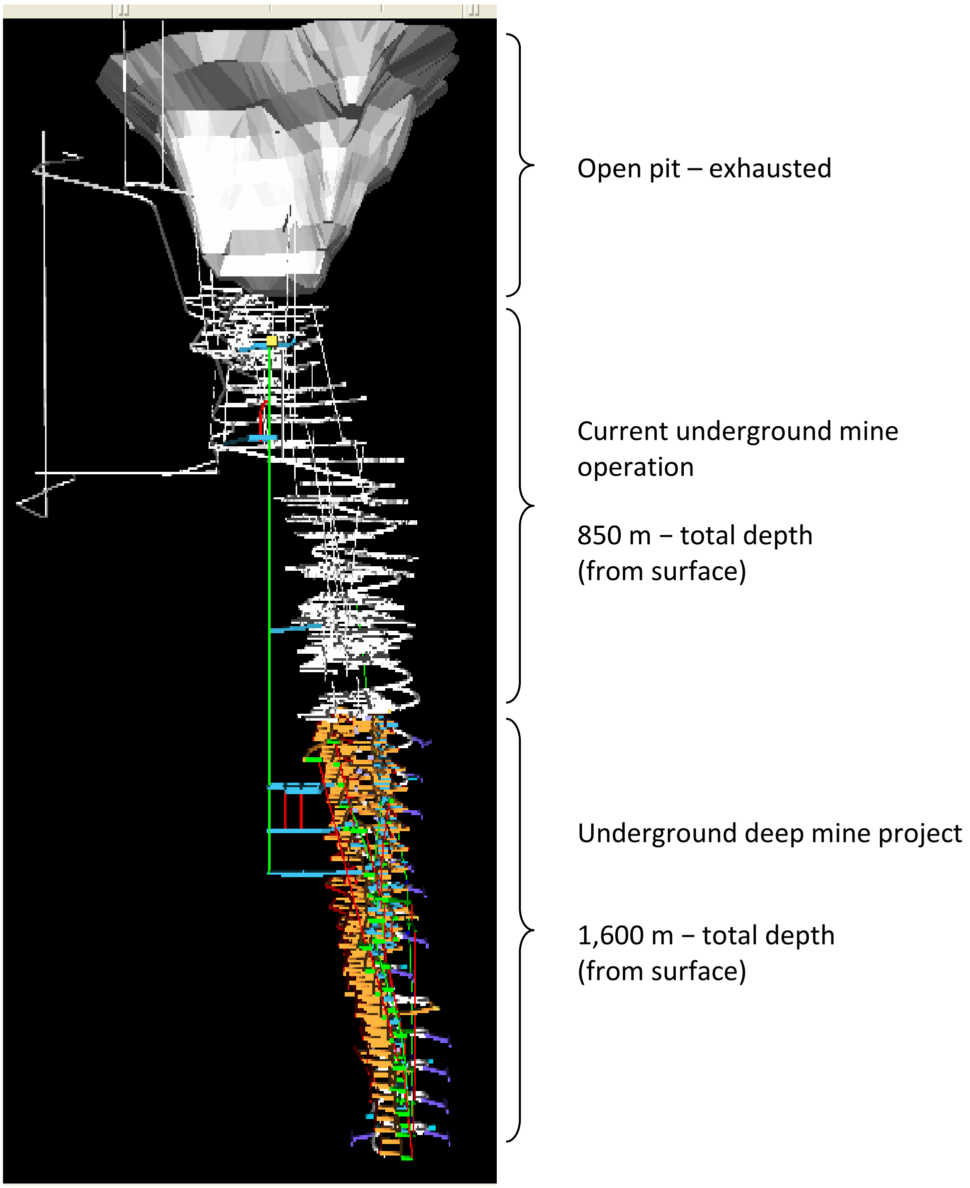

Figure 9 New deep mine project

The following pictures of the paste backfill system at Caraiba Mine are offered to provide insight into the system and the results it has achieved.

Figure 10 Paste fill plant

The paste prepared on the surface is composed of 78% solids (tailings), 4% Portland cement, and water. From the plant on the surface, the paste is gravity fed through lines to fill stopes in underground.

Figure 11 Stopes filled through horizontal pipes (left) and boreholes (right)

Figure 12 Barricade at stope bottom

Figure 13 Stope filled with paste

Figure 14 Contact of cemented paste and footwall rock

Figure 15 Measuring paste slump

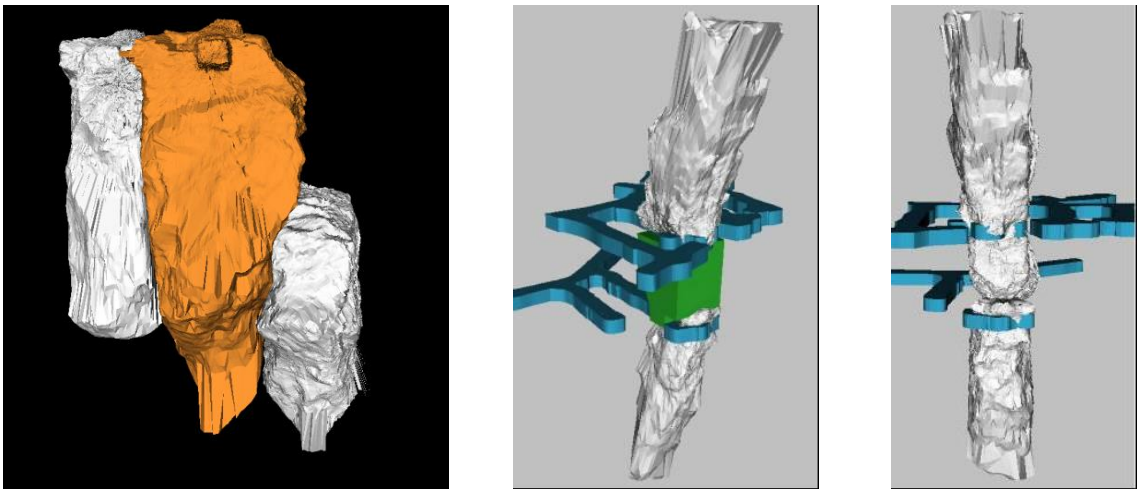

Figure 16 Cavity surveys of mined and filled with paste, which improves mining practices through knowledge of reconciliation between recovery, dilution and fill quantity

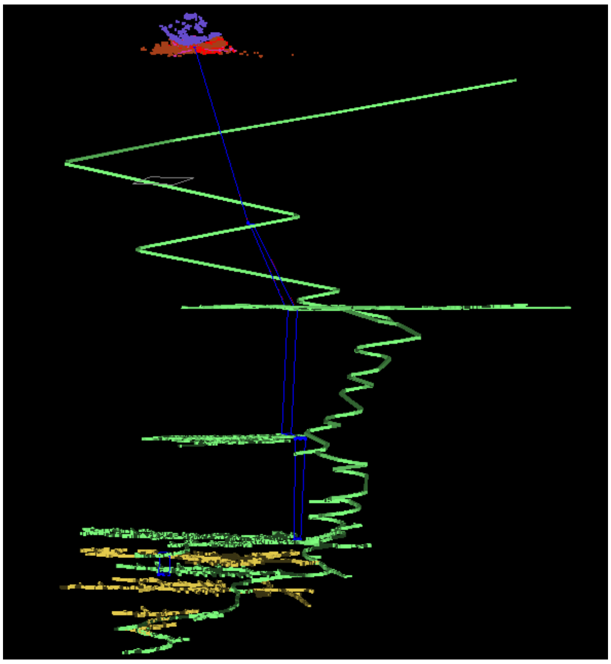

Figure 17 New piping route to transport paste to future mining areas (by Jordan Menezes)

7 Conclusions

MINERAÇÃO CARAÍBA S.A. has had significant success since its implementation of the paste backfill system, which allowed a significant recovery of the ore reserve and decreased the dilution of ore. Furthermore it has increased safety in development works and provides a higher degree of control in the stability of the excavations. As well, the use of paste has resulted in the reduction of tailings and water disposed on the surface.

Acknowledgements

We would like to thank MINERAÇÃO CARAÍBA S.A., who allowed the release of this work, as well as their team that has been performing excellent work in ore production. This work includes improvements to mining techniques and the development of outstanding professionals in several areas of the company.