Dewatering strategy for a copper mine in the Democratic Republic of Congo

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Abstract Mining at the site is carried out in three pits and is located along a faulted overturned syncline composed of siltstones, argillites, sandstones and shales and covered by laterite. The operational problem at the mine site is the control of inflows of groundwater into the pits. This has resulted in failure of pit walls and flooding of mine operations during the wet season. Reducing these impacts requires a dewatering strategy which is cost effective. A detailed conceptual hydrogeological model was used to develop a site specific dewatering strategy to reduce pore pressures in the pit walls.

Keywords Conceptual model, dewatering strategies, permeability, faulting, management

Introduction

High-grade copper-cobalt mineralisation of the Central African Copperbelt and the scale of available ore bodies in the Democratic Republic of Congo (DRC) and Zambia are fast becoming the global 'hotspots' for international mining investment and exploitation activities (Lydall and Auchterlonie 2011). The mine, located in the Katanga Province, has a concession area of 15.7 km^2. Mining began in 2006 and is taking place in three pits from where copper ore is ferried to the mine plant while cobalt ore is stockpiled for processing in Zambia. The three pits are expected to reach terminal depth of 180 meters below ground level (mbgl) by year 2024.

Since the start of open pit operations in 2006, the single major problem at site has been the control of large inflows of groundwater into the pits. The rise of groundwater level at the mine site not only causes increases in water influx into the pit but also results in pit wall failures (fig. 1). The pit wall failure is due to increased pore water pressure behind the face of the wall and eventually results in the collapse of some pit walls.

The copper deposit occurs within the north east dipping layers of siliceous dolomitic schist in the local overturned syncline. Laterite deposits which cap the underlying formations at the site form a variable weathered residual overburden (regolith) layer which varies in thickness. The thickness of the regolith has an important effect on the occurrence of ground-

Fig. 1 *Rotational slide failure of Pit 2 walls at the mine site. Photo taken during dry season.*

water in both the fractured zones and above basement formations (Acworth 1987). Groundwater occurrence in the region can be correlated to the regional stress pattern that created faulting and folding (Acworth 1987).

The central African region had repeated episodes of compressive tectonism, involving at least four periods of wrench faulting separated by relaxation and dyke emplacement (Acworth 1987). Most lineaments in the region are faults or tectonically related joints forming as planes of tectonic shearing and hence could be considered as compressive features at the time of inception. The primary stress orientation in the region is along a NW-SE direction.

Groundwater flow in such deformed zones occurs both by matrix seepage and as fissure flow in discrete fracture channels, which could be part of an interconnected system. Open fractures below the water table surface have the capacity to store and channel water. Fractures that are under tensile and shear stresses are good targets for groundwater (Kellgren and Sander 2000).

The main focus of this paper is to evaluate the developed conceptual hydrogeological model. A numerical groundwater flow model was also developed but it will only be incorporated if required. A secondary objective is the achievement of pit slope stability by dewatering of the main fractured and weathered aquifer systems associated with the pit wall. Identification of groundwater flow from available remote sensing data and combining it with knowledge of the regional stress orientation, aquifer thickness from geophysical results (resistivity and drilling) results enabled groundwater quantification and design of dewatering strategies to be developed for the mine site.

The dynamic nature of a mine environment coupled with the heterogeneous and anisotropic distribution of hydrogeological parameters, make groundwater studies complex. The problem necessitates a well-planned programme of investigations. The programme should be tailored to suit the problem at hand.

Site description

The mine site is located in the Katanga Province of the Democratic Republic of Congo (DRC). Layout of the mine site is shown in Fig. 2. In the central part of the mine area are three pits located along the SE-NW striking Roan series aquifer. There are three waste rock dumps to the south-east, north-east and north-west of the pits. The tailings storage facility (TSF) and Coffer dam are located in the north-east corner and north-west of the area respectively, underlain by predominantly less transmissive sandstones and shales of the Kundelungu formation. The processing plant and mine offices are located between the TSF and the north-eastern waste rock dump.

Climate and drainage

The study area climate is typical of sub-tropical to tropical rainforest characterised by warm winters and hot and humid summers. Daily minimum and maximum temperatures vary from 15 °C and 26 °C (July) to 17 °C and 36 °C (October), respectively. The hottest months are September to November, when the mean daily temperature is typically in the region of 31 °C to 32 °C. Daytime temperatures can reach 36 °C which can fall to 34 °C at night. The rainfall sea-

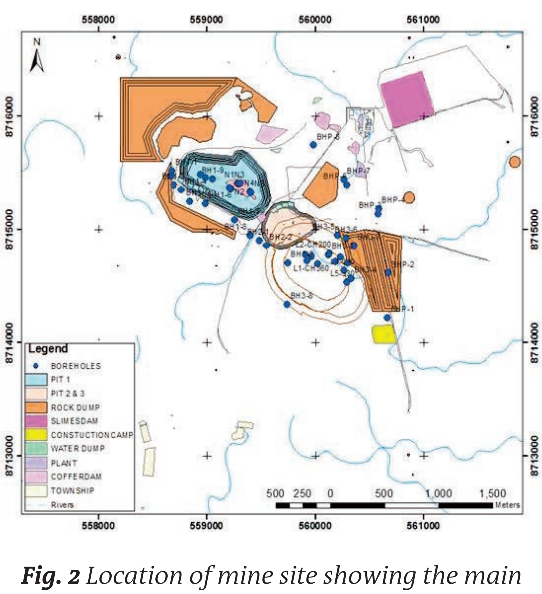

***Fig. 2** Location of mine site showing the main pits and tailings infrastructure.*

son stretches from late October to April at the site and annual rainfall ranges from 1000–2200 mm per annum.

The study area is drained by Luano River to the North West and Kebumba River to the North East. Groundwater has a short residence time after recharge as it discharges as baseflow into surface water. This phenomenon is proven by immediate water level rises and decline during the rainfall season and dry season, respectively. The catchment area of the Luano and Kebumba rivers is 5.1 km^2.

Regional geology

The mine site ore bodies are hosted by metasedimentary rocks of the 7000 m thick Neoproterozoic Katanga System. The area sits on the south end of the Katangan Copperbelt which together with the Zambian Copperbelt are located within the deformed SE-NW trending a fold-and-thrust belt called the Lufilian Arc which stretches into Namibia. This Copperbelt is 600 km long extending from Luanshya (Zambia) in the south-east to Kolwezi (DRC) in the north-west.

In the DRC, the Katangan Supergroup is preserved both as tightly folded, but relatively intact sequences and as complexly deformed dolomitic rocks namely the Roan strata (Straskraba 1991). The Katangan system is composed of sedimentary rocks of the late Proterozoic era, a succession of interbedded quartzites, sandstones, conglomerates, shales, siltstones, dolomites, limestones, argillites and dolomitic shales.

The mine site structural features are typically folded and brecciated, forming tight, steeply dipping synclinal and anticlinal structures. The vergence of the folds is variable; this is consistent with the interpretation of chaotic fragments within the breccia zone. The dip of the limbs is mainly steep from vertical to 85°, but also shallow down to 45° (GCS, 2006). In some places very shallow to sub horizontal dips occur. Fault displacements vary between 15–45 m.

Results

Hydrocensus and drilling campaign

A hydrocensus was carried out during the month of February 2010. Parameters that were collected during the hydrocensus include position of borehole; existing water supply equipment; current use; borehole status; reported yield; reported or measured borehole depth, static water level and photographs. The hydrocensus data was used in planning the next phase of the hydrogeological investigation, notably drilling, aquifer testing and water quality sampling. The highest hydraulic heads (1250–1272 mamsl) was observed on the southern side of the pits which coincided with the south west regional groundwater flow direction. The deepest hydraulic head (1222 mamsl) was recorded in Pit1 showing effects of continuous pumping for dewatering of the pit floor.

The objective of the drilling phase was to initially characterise rock units in terms hydrogeological properties. The hydrogeological properties of the rock units would then guide in establishing a dewatering plan for the mine. Blow yields were measured at 5 m intervals and the final blow yield at the end drilling. Groundwater physicochemical parameters were also measured during drilling which included water strikes (fig. 3). The top water strikes identified during drilling were also sealed off in some boreholes in order to measure the actual water strike yields in the lower formations.

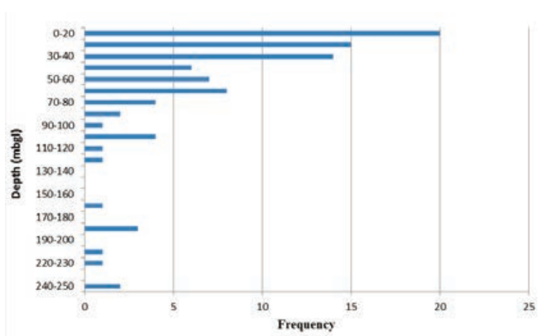

Fig. 3 *Water strike frequency during drilling campaign.*

The drilling data indicated multiple water strike positions, with shallower and less prolific water strikes in the depth range of 5–40 mbgl, mostly within the Kundelungu Formation and at depth range of 35–220 mbgl in the Roan Formation. The average yield of the Laterite aquifer was calculated to be 10 m^3/h. Blow yields for the Roan aquifer ranged between 15 and 400 m^3/h. It was noted that high yields were associated with the Roan lithologies located in the centre of Pit 1 and Pit 2. The southern side of the pits is underlain by predominantly semi-permeable and lowly yielding (<3 m^3/h) roches argillaceous talceus (RAT) and calcareous mineral noirs (CMN) formations.

Site Geology

Siliceous dolomitic shale (SDS) is the predominant rock type intersected in the deep boreholes. The weathered and altered dolomite namely the Black Ore Mineralised Zone (BOMZ) occurs as compartments in contact with the SDS.

Pit 1 intersected SDS and roches siliceuses feuilletees (RSF) of the Roan Formation and compartments of BOMZ. Difficult drilling conditions were encountered in the collapsing zones of the loose BOMZ. The SDS is separated into compartments by geological structures as evidenced by the presence of pockets of BOMZ. Drilling results indicate that periods of folding and associated faulting could have pushed the less permeable and older formations (*e.g.* RAT) closer to ground surface. Boreholes in Pit 2 intersected CMN, siliceous dolomitic siltstone and BOMZ. High blow yield in the BOMZ resulted in back-pressure and subsequent reduced penetration rates. Pit 3 area intersected Laterite underlain by RAT breccia. Below the RAT breccia is 15–20 m thick RAT underlain by 80–40 m thick SDS.

Weathering and associated alteration was encountered from ground surface to depths of approximately 80 mbgl in most boreholes. Fracturing was encountered at various depths and was encountered at 200 m depth in the deepest borehole at the mine. It was also noted that fracturing and weathering was associated with contact zones and bedding planes.

Hydraulic parameters

A graphical summary of estimated hydraulic conductivity values are given for Pit 1 in Fig. 4. The main features of each unit are briefly described below as it relates to permeability and storativity values.

The weathered regolith consists of weathered laterite in the pits area. Results from dewatering and groundwater monitoring drilling show that depths of weathering reach approximately 100 mbgl. The depth of weathering increases towards the south reaching 120 mbgl, where the topography is flat promoting infiltration during rainfall events. The estimated hydraulic conductivity of the upper weathered zone is approximately 7–15 m/d.

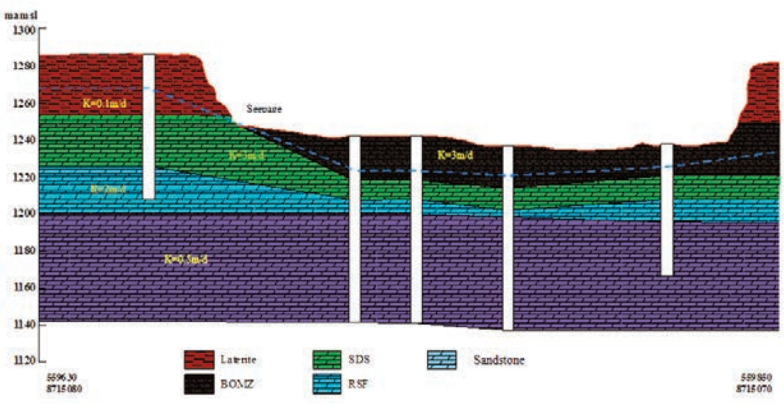

Fig. 4 *Pit 1 NE-SW cross section indicating the hydraulic conductivity zones.*

Weathered and altered dolomite (WAD) unit consists of 40 m thick highly weathered and decomposed dolomite and becomes moderately weathered to fresh with depth. Porosity for the unit was estimated to be 20–25 %, with moderate to high permeability within the weathered zones. Transmissivity of the unit was estimated to be 256 m^2/d with a storage coefficient of approximately 2.2×10^{-3}.

The RAT unit is interpreted to be a product of brittle failure when the Roan series was pushed over the Kundelungu series during the Katangan deformation. Yields within the RAT breccia range between 5–40 m^3/h. SDS unit consists of moderately weathered dolomitic shale, although highly weathered and friable horizons have been observed within the upper weathered zone. Sub-horizontal fracturing is dominant with estimated transmissivity values of approximately 252 m^2/d and a moderate-to-high porosity of 20–25 %. The RSF unit consists of relatively thin impersistent layers of foliated siliceous dolomite at the base of the Roan Formation. Porosity was estimated to be 15–25 % and transmissivity in the range of 200–400 m^2/d.

CMN was intersected by most boreholes drilled in the north-west of pits 1 and 2. Water logging conditions were observed in pit 2 north east areas underlain by CMN. Permeability is estimated to be low in orders of less than 0.001 m/d.

The water levels follow topography to a large extent indicating unconfined conditions. This could be an indication of a high degree of interconnectivity between shallow and deep aquifers and the system acts like a single aquifer.

Dewatering Strategy

At the current stage the magnitude of collapse of pit walls and flooding at the mine site depends primarily on the groundwater levels, the hydraulic conductivity of the rock units in the high walls and the local recharge to the groundwater system. The majority of modern mines use a combination of sump pumping, grouting and strategically designed active pumping and water interception systems.

The analysis of hydrogeology data gathered at the mine site demonstrates that an effective dewatering system for Pit 1 should consist of a combination of elements.

Recharge interception

The planned dewatering methods should cut off recharge from sandstones and from Luano River. However boreholes drilled in the sandstones south of the pit had low blow yields of approximately 5 m^3/h. Seepage mapping in Pit 1 identified a spring like type of flow with a flow rate of approximately 1 m^3/h. This represents significant recharge flow through fractures/conductive zones from the south. It is necessary to install a dewatering well along this fracture on the perimeter of the pit and intercept flow along the fracture/conductive zone.

Wells

Vertical in-pit and pit perimeter wells will be required for active dewatering. The wells will lower the phreatic surface below the working pit floor, and will have significant local effects on heads at the toe of the slope. The most prolific aquifer, the SDS, dips towards the North-East. Groundwater flow is expected along the bedding planes. Seepage mapping identified heavy seepage from the south-west of the pit.

Pumping wells located around the periphery of the pit may prove practical and economical. The wells should be installed to a depth in excess of 200 m and large diameters to accommodate bigger capacity pumps. The numerical model predicted a maximum inflow of 11000 m^3/d during the final year of mining in Pit 1. A total of six wells pumping on average of 100 m^3/h will have a total pumping volume of 14000 m^3/d. As of 2011 and early 2012 the water level had been maintained at approximately 5 m below the pit bottom, whilst pumping at an average rate of 9000 m^3/d. Monitoring wells located 25 m away from the pumping well showed quick response to pumping. As such borehole spacing of 25–30 m between pumping wells will be sufficient to create a compound cone of depression below the pit floor.

Three in-pit wells should be installed, one in the centre of the pit and the other two wells at about 30 m west and east of the central well. The wells should be screened in the BOMZ which deepens towards the east.

One pit perimeter well will be required on the north side of Pit 1 as it will be used to intercept any recharge from Luano River and its basin. The other pit perimeter well should be installed on the southern side of the pit preferably close to the high seepage/spring zone. The third perimeter well should be installed on the BOMZ-breccia contact zone and intercept flow along this zone. All the pit perimeter wells should be screened in the SDS, BOMZ and sandstone lithologies, which indicated a high hydraulic conductivity.

Pit sumps and drainage canal

In addition to drainage control within the pit itself, the control of surface drainage outside pit boundaries is necessary to ensure that surface water does not flow directly into the pit. If extra pumping capacity required, water flowing into the pit percolates into surface fractures and openings, many of which have been created by blasting, develops cleft water pressures. This aggravates pit wall collapse and the occurrence of local slides between benches.

As seepage and significant flow from the perched zones is expected in Fig. 4. Pit floor sumps should be constructed and harvest passive flow from the saturated perched zones. The sumps should be deep enough to accommodate submergible pumps. Pipelines from the sumps should preferably be connected to the pipelines from dewatering wells and discharge water to storage facilities like the Coffer Dam.

Conclusions

A full hydrogeological assessment of the mine site and surrounding environment was performed. A combination of dewatering methods has been implemented on site to address specific issues relating to mining and high wall stability. The site is located in a high rainfall area with high infiltration rates and overland flow, a combination of interception and higher pumping rates have proven to decrease the rate of influx into the mine site. In all instances an ongoing monitoring of strategies employed should be maintained as the mine floor is lowered over the next 10 years.

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