Characterization and Groundwater Modelling of a New Block-Caving Project

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Abstract

The Tujuh Bukit Project is operated by PT Merdeka Copper and is located in East Java, Indonesia. A block cave operation is planned beneath the existing open pits. An extensive campaign of deep exploration drilling is being carried out from the surface and underground. Consequently, hydrogeological conditions and future water management requirements are well understood and dewatering of the first underground production level has already been achieved.

A 3D FEFLOW groundwater numerical model has been constructed to help evaluate groundwater level variations above and around the proposed block cave, with the objective to assess the interaction between the planned underground workings and the surrounding environment. The numerical model is flexible enough to evaluate different mine plans.

Keywords: Block-cave, underground, groundwater, mine dewatering, numerical model

Introduction

The mining area is located on the slopes of Mount Tumpang, about 55 km southwest of Banyuwangi in southeast Java. The climate of southeast Java is tropical. Mean annual rainfall on the higher ground at the site is about 2 m, with about 80% of the rainfall typically occurring in a 7-month wet season.

Recent volcanic rocks dominate the site geology, predominantly dacite, and volcanic breccias. The project area is centered in and around a nested tonalite porphyry complex, with a structurally controlled advanced argillic alteration. Several primary and secondary geological structures offset the lithological units and create hydraulic boundaries in the non-weathered bedrock. There is a distinct upper weathered zone around 100 to 150 m in thickness, although weathering may extend deeper adjacent to fault zones.

The existing surface mining operation commenced in 2016 with three main pits (Pits A, B, and C), a heap leach operation (HLO), waste rock areas, and support facilities. The current plan is for a 6-year sub-level caving (SLC) operation mining downward from about 300 m depth, with concurrent development of a 20-year block caving (BC) operation starting at about 800 m depth (Figure 1). Planned access from the surface is by multiple declines.

Surface water drainage is radially outward from the high ground towards the west and south flank, and towards the Katak Creek drainage to the northeast and north. There are no major watercourses within the project area.

Groundwater levels are mostly near the ground surface and exhibit a natural seasonal fluctuation of a few meters. Under natural conditions, most active groundwater flow occurs within the weathered zone. The only source of groundwater is infiltration and recharge in the wet season. All groundwater movement is localized. There is no regional-scale groundwater flow in the project area. Although there are zones of interconnected fracture permeability that may extend several hundreds of meters laterally, the groundwater

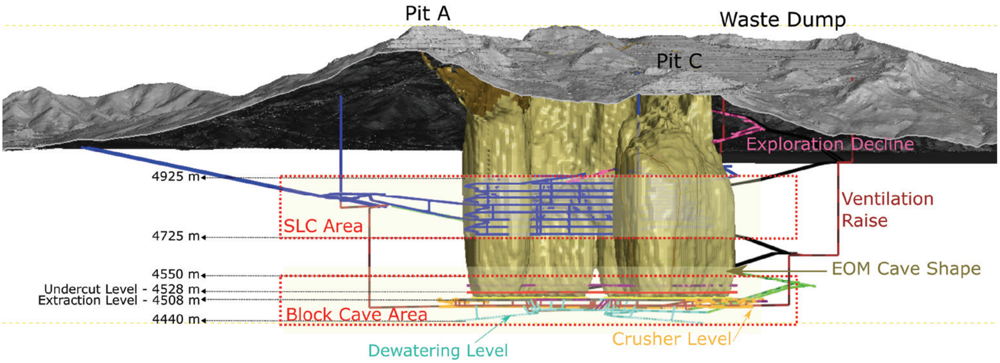

Figure 1 Sub-level cave and block cave details (looking Northwest)

system in the non-weathered (fresh) bedrock is compartmentalized by the lithological contacts and geological structures. As a result, widespread groundwater movement does not occur.

Dewatering is being achieved by allowing selected underground exploration drill holes to permanently flow (Figure 2). In the dewatered area, groundwater levels in the non-weathered (fresh) bedrock have become decoupled from the overlying weathered zone groundwater levels with two distinct phreatic surfaces. Multi-level piezometers typically show a strong dewatering response in the fresh bedrock but little to no drawdown in the overlying weathered zone.

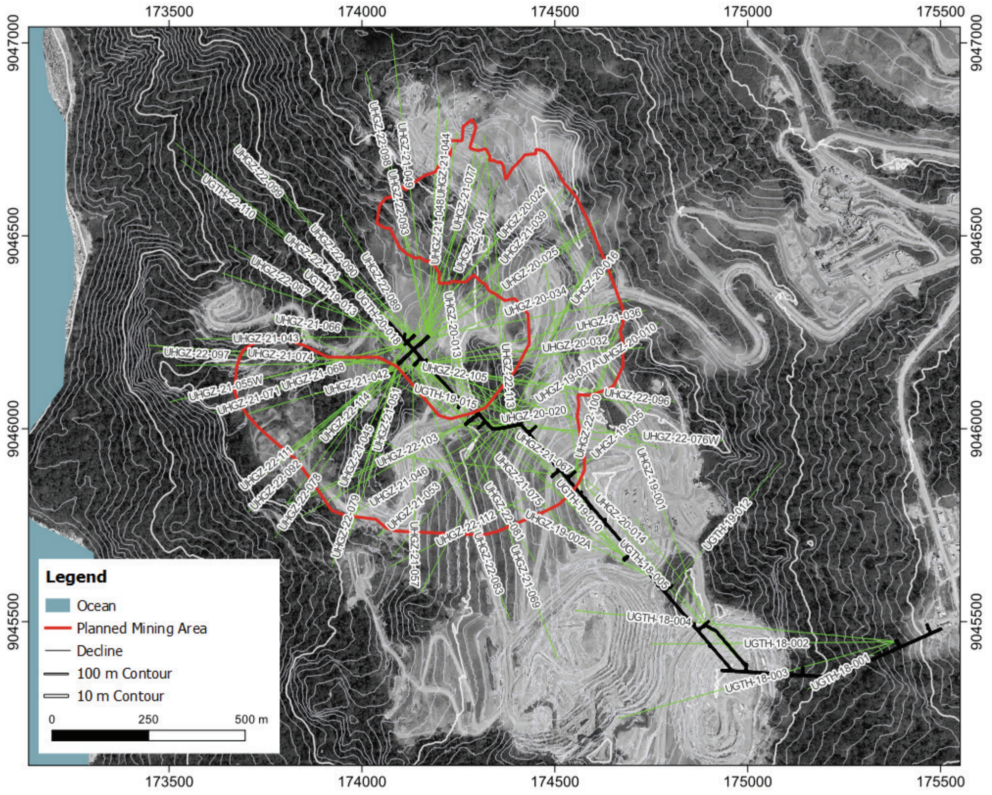

Figure 2 Underground drill holes used for dewatering the decline

The extensive collection of hydrogeological data from the surface and underground resource drilling represents global best practices. Consequently, hydrogeological conditions and future water management requirements are well understood. The decline has been successfully dewatered since 2019. Over 250 m of drawdown has already been achieved at a dewatering rate of between 30 and 35 L/s. Water management infrastructure for the current underground and surface mining is already in place.

Numerical Model

The numerical model is built to evaluate potential impacts on the local water resources and is designed to evaluate different designs of the underground mine. At this stage, model predictions are focused on the construction of underground infrastructure, extraction activities and development of a cave zone from the sub-level caving and block-caving operations. Model predictions are supported by a strong conceptual model which is underpinned by a large amount of field observations and testing. The currently available dataset guarantees that the main concepts characterizing the local groundwater system are included in a numerical model that reasonably simulates the site-specific conditions.

1. Model domain and construction

The domain, or area of coverage, of the numerical groundwater model is populated within FEFLOW by a finite element mesh which defines all stratigraphic and structural features plus existing mine voids which are likely to exert control on groundwater flow. The spatial limits of the model were determined primarily on a natural catchment boundary basis. The overall area of coverage of the model domain is 22 km². This encompasses all major mine facilities in the centre of the model area. The model is distributed vertically in 14 layers, with the upper layer defined with a maximum thickness of 5 m.

Development of the FEFLOW model was undertaken using discrete time-steps, within which either the physical conditions prevailing within the model domain or the 'operational rules' applicable to variables such as underground mine dewatering, were considered likely to remain reasonably constant.

2. Model calibration

Calibration of the FEFLOW model was performed by running simulations for the current period and comparing the results of simulated groundwater head elevations against recorded groundwater levels across the model domain. Iterative adjustments were successively made to recharge and model hydraulic parameters until optimum replication of measured water level distributions was obtained.

A total of 73 points within Tujuh Bukit's empirical database were considered to provide

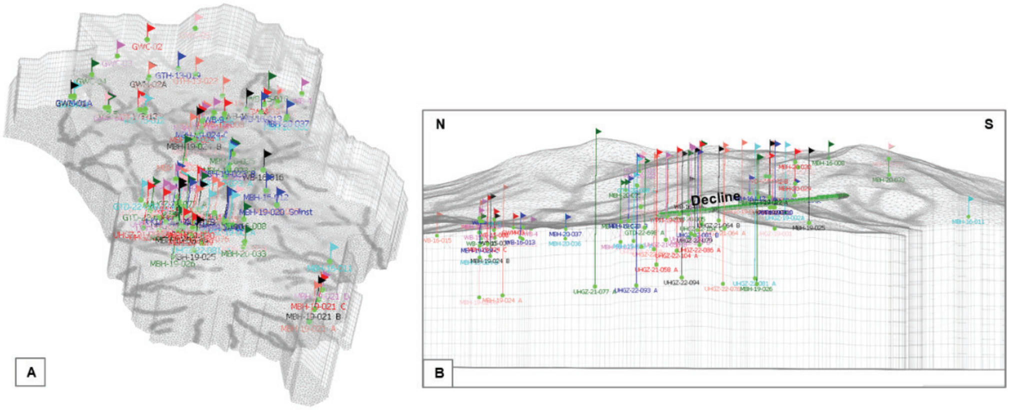

Figure 3 Monitoring network currently included in the FEFLOW model. A) spatial distribution of monitoring points in the model domain. B) Cross-section view with the decline and VWP sensors

reliable groundwater level measurements for use in calibration. Different types of monitoring points have been included in the numerical model (Figure 3).

The long-term simulated inflow into the decline (which currently includes the discharge from 72 underground exploration (UHGZ) holes) is equivalent to 25 L/s. The numerical model simulates a groundwater inflow of 20 L/s to the exploration decline. The simulated inflow into the decline is slightly below current groundwater extraction measured from the decline, but the model scenario is considering a steady-state simulation representative of a long-term equilibrium for the groundwater system with a total depletion of water available in storage. It, therefore, appears that the flow simulated in the drain holes is of the same order of magnitude.

UHGZ holes drilled as part of the drilling program have the potential to dewater the area of the cave zone if they are left open. The numerical model indicates that the depletion on the near-surface phreatic level in the Weathered Zone over the cave footprint is limited, but the UHGZ holes effectively depressurize the fresh, unweathered bedrock to the level of the exploration tunnel (Figure 4).

3. *Model prediction*

Once the numerical model was calibrated, a series of predictive simulations were executed from the calibrated model to predict the potential effects of the project development.

The predictive simulations are based on assumed dates adopted for the purpose of modelling and which may change as the mine plan is refined. The total duration of the predictive scenario is 28 years including all the major developments provided in the mine plan. It is divided into monthly and yearly stress periods to follow the current (January 2023) mine plan.

Underground infrastructures: The extraction level is represented with a series of seepage nodes at an elevation comprised of between 400 and 1,000 mbgl. The use of modulation functions enables the progressive activation of seepage nodes representing the underground infrastructure and mine expansion. The project will start with the construction of SLC infrastructures enabling the first ore to be extracted in 2025. By 2031 BC infrastructure will be fully developed below the SLC. Similar to the existing decline, seepage nodes are used to represent the drainage caused by the linear underground infrastructure (Figure 5). The exact location

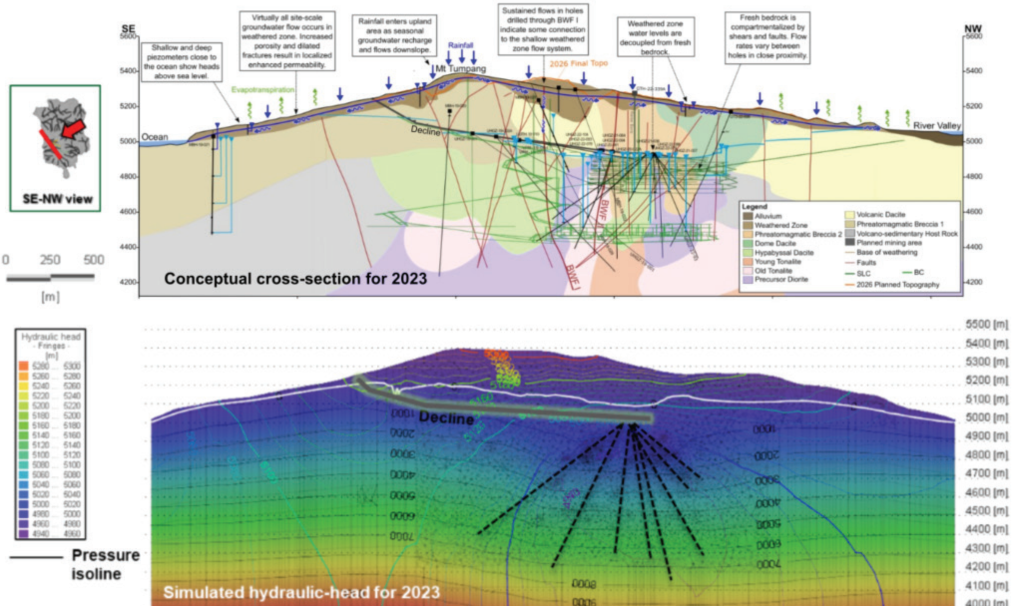

Figure 4 *Effects of the UHGZ drilling program on pressure and hydraulic head distribution*

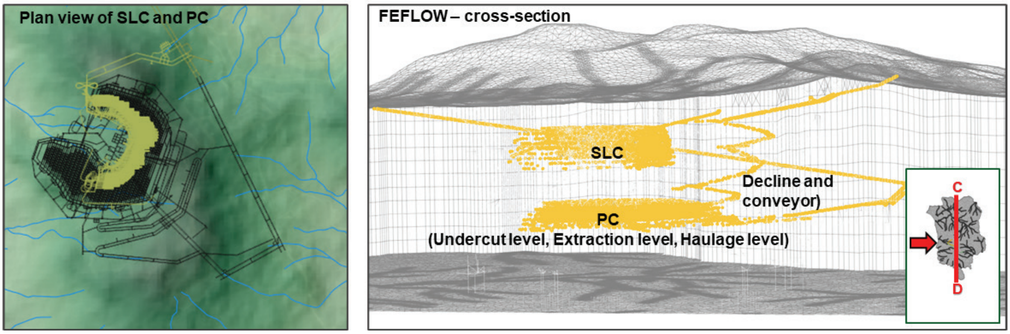

Figure 5 *Implementation of underground infrastructures in the numerical model*

of underground infrastructures is obtained by a local remeshing using the TetGen mesh generator. This powerful tool enables to evaluate alternative mine plans proposed during the development of the study.

Cave propagation: The model includes the transition of fractured bedrock caused by the release of confining stress which forms a halo around the cave zone (Figure 6). This is included in the FEFLOW model with a time-variant hydraulic conductivity that is linearly interpolated between the different cave shapes derived from a geomechanics model. Increased fracturing facilitates the drainage of groundwater towards the cave zone. The influence of the cave zone on the groundwater level distribution is simulated to occur mostly in the fresh and unweathered bedrock. Given the low hydraulic conductivity associated with the deep bedrock, the halo of fractured bedrock could easily move the groundwater further away from the cave zone in its deeper part, but probably with a minimal effect on the total groundwater inflow.

4. Model results

The higher hydraulic conductivity associated with the fractured and caved material generates an area of drawdown around the cave zone. Groundwater levels in the fresh, unweathered bedrock around the cave zone become decoupled from weathered zone groundwater levels. Groundwater level trends in the weathered zone are more subdued than in the deeper rock.

The model results show that drawdown is mostly limited to the local area of the cave zone because of the low conductivity and compartmentalized nature of the bedrock. Drawdown at the end of mining is developed around the cave, but the lateral extension is limited to less than 1 km.

Community wells located in the floodplain to the north of the project area are unlikely to be affected by any groundwater level variation because simulated drawdown in the fresh bedrock is centered over the cave zone and propagates essentially below Mount Tumpang.

Inside the zone of influence of the cave zone, the groundwater flow direction is modified towards the extraction level under the cave zone. Outside the zone of influence of the block cave, the groundwater flow continues to discharge towards the natural drainage system.

The BC's western limit of underground infrastructure is about 440 m laterally offset from the western hydraulic boundary (at 600 m depth) (Figure 7). Development of the overlying fracture zone and cave zone includes groundwater level variations in the fresh unweathered rock below the level of 5000 m.

The numerical model indicates that the hydraulic gradient, which is initially towards the west of the block cave, decreases and is almost neutralized by 2050. Simulated groundwater discharge towards the section located to the west of the project area decreases from 26 L/s in current conditions to 2.5 L/s at the end of the life of the mine. The current model has no simulated flow from the sea towards the block cave.

The model provides results based on the assumption that the drawdown remains local to the active block cave area. The development

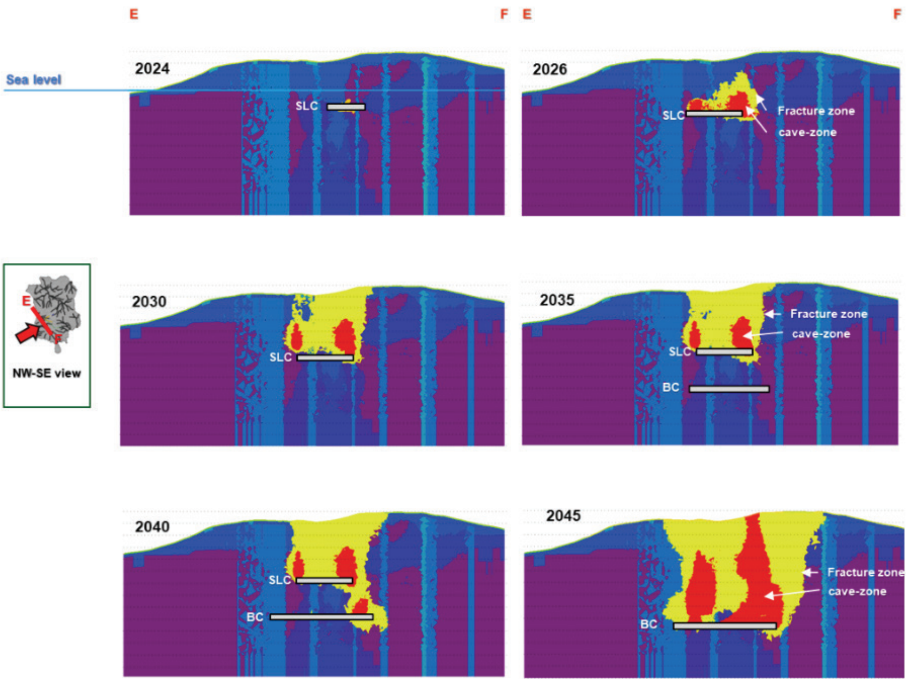

Figure 6 *Implementation of underground infrastructures in the numerical model*

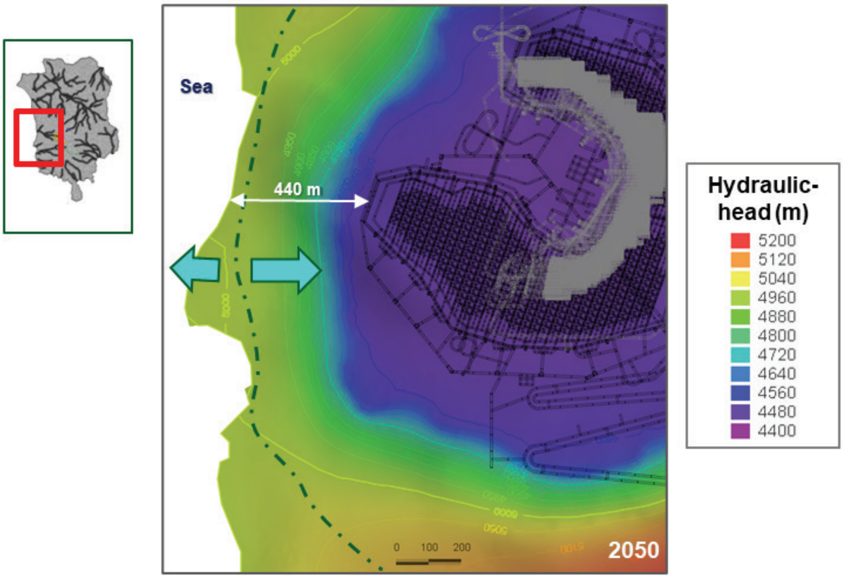

Figure 7 *Current limit of simulated drawdown*

of a fracture zone in direct contact between the underground workings and the other hydraulic boundary conditions would clearly create the potential for higher magnitude inflows. There are uncertainties associated with expected future stress release from structures in the vicinity of the fracture zone. This stress release could be transformed into preferential pathways, as such a monitoring program will need to be implemented to identify potential displacement and increases in fracture permeability. Modeling results can be used for developing an effective dewatering program for both the sub-level cave and the block cave.