

The planning of a cave reorientation at the Ernest Henry sublevel cave mine

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Abstract

The Ernest Henry Operation (EHO) in Queensland (Australia) is developed to a depth of just over 1 km, and current active production cave levels have reached a depth of 800 m, with a pre-feasibility study underway to assess a mine extension to around 1,375 m below surface. The EHO main cave orebody is changing shape with depth, narrowing from east to west and elongating north to south. The narrowing and elongation of the orebody is resulting in the current longitudinal mining layout to consist of a reduced number of ore drives at an extended length, impacting productivity and mining associated risks. The extended ore drives (>400 m) pose a secondary ventilation challenge, ground instability risks in maintaining access crossing a major geological structure and excessive cave loader tramming distances. The intersection of new major geological structures within the cave footprint significantly increases potential unravelling and seismic risk, particularly with the start-ups of new levels and their associated step-outs. These ground related issues are expected to be challenging with depth and therefore necessitate a change in cave orientation. Altering the mine design, to reduce these challenges, is considered an optimal way to de-risk the mine plan at depth. This paper outlines key items within the study process, some mining associated challenges and risks, a decision-making and planning process in rotating the cave layout, proposed control measures to ensure local and regional stability. Thus, the paper outlines the requirements for creating an environment where risk aversion will be the state of play in an increasingly challenging environment.

Keywords: *mine planning, caving, sublevel cave, reorientation, cave flow, seismicity, stability*

1 Introduction

Ernest Henry Operation (EHO) is located approximately 35 km northeast of Cloncurry in western Queensland, on the traditional lands of the Mitakoodi people, as shown in Figure 1. In 1998 the mine commenced commercial production as an open pit mine until 2011 when it transitioned to underground mining. It is a 6.8 Mt per annum copper-gold operation using sublevel caving to extract ore via a dedicated hoisting shaft. It is developed to a depth of just over 1 km, with an active pre-feasibility study (PFS) underway to assess an extension to the mine. The orebody is an inclined iron oxide copper-gold (IOCG) deposit, open at depth.



Figure 1 Ernest Henry Operation location

The EHO deposit is hosted within a sequence of SSE-dipping altered meta-volcanic and sedimentary rocks. The host sequence is variably foliated and locally porphyritic (Figure 2). Copper-gold mineralisation occurs mainly within a magnetite-biotite-calcite-pyrite matrix of the felsic volcanic units. The local geology consists of a Proterozoic Sequence which is overlaid by a thin Phanerozoic Sedimentary Sequence.

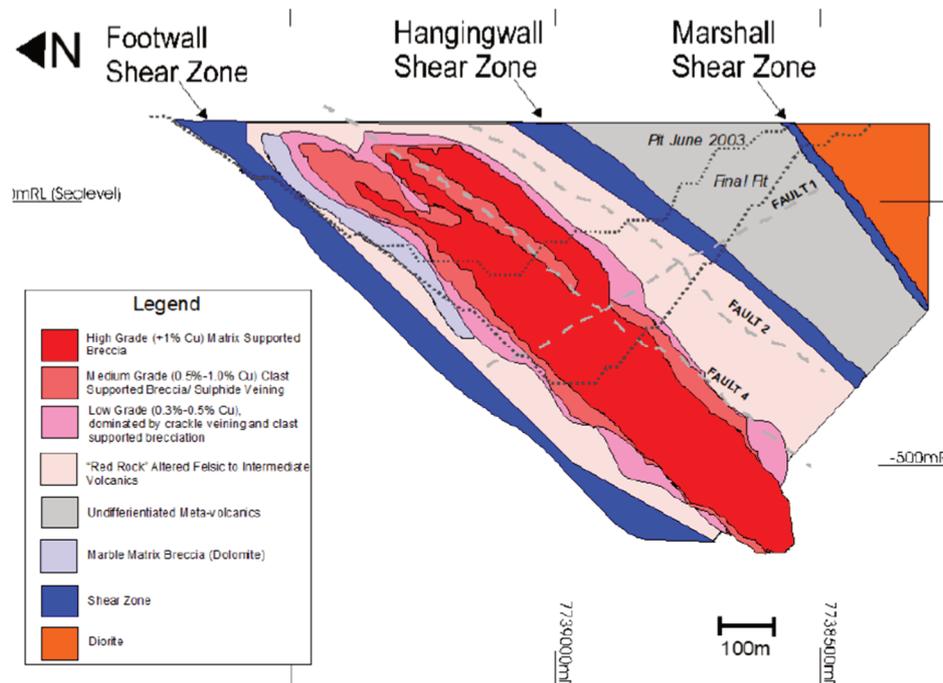


Figure 2 Ernest Henry Operation local geology (Ernest Henry Operation 2021)

EHO site is in the Carpentaria/Karumba Basins, close to the border of the Eastern Fold Belt; one of three broad tectonic divisions within the Mt Isa Inlier. The regional geology is associated with the North Australian Craton - an area consisting mainly of Proterozoic sedimentary and igneous rocks. Locally, the site consists of late tertiary clay dominated facies (Ernest Henry Operation 2021).

EHO's underground workings are subject to an array of seismic energy release and are separated into several seismic risk domains. One of the seismic risk domains correlates well with increased seismic activity due to development and production occurring in a step-out elevated stress abutment zone. The aim thus is to focus on this specific risk and minimise exposure to underground workforce. Historically, the largest event to occur at EHO underground mine is a 2.3 ML event that occurred on 28 September 2019 with minimal disruption.

2 Why is reorientation required

The orebody at depth is narrowing in an east–west direction and elongates in a north–south direction. This causes the previous longitudinal mining layout (with a northern footwall drive (FWD)) to become a more transverse style sublevel cave (SLC), where the length of the ore drives far exceeds the width of the SLC footprint. The longitudinal caving method has challenges in effectively managing major hazards and meeting the required production rate due to limited active ore drives. Additionally, excessively long ore drives (>400 m) pose a secondary ventilation challenge, stability risks with maintaining access and excessive cave loader tramming distances.

The intersection of new major structures to the cave footprint significantly increases the seismic hazard, particularly in the step-out areas of new levels. These issues are expected to be challenging with depth and therefore necessitate a change in cave orientation (Figure 3), below 1225 Level, between 1200, 1175 and 1150 Levels. From 1125 Level, it is assumed the entire footprint will be rotated for life-of-mine planning purposes.

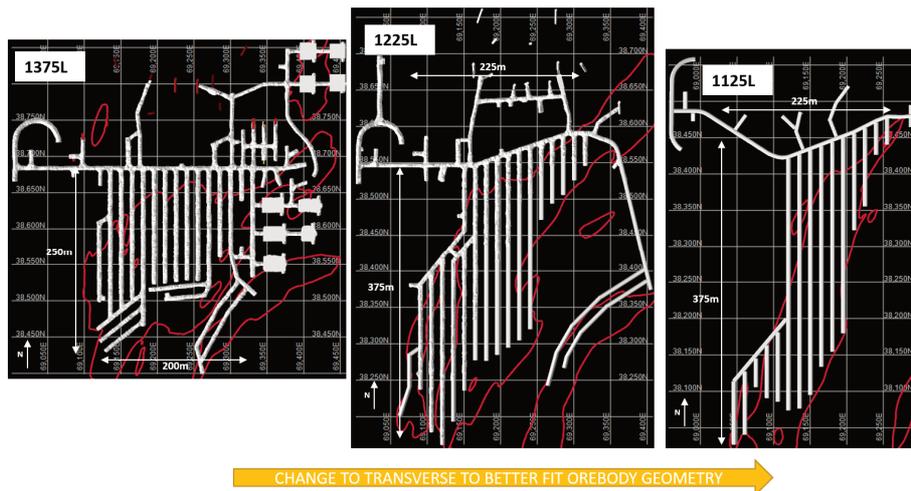


Figure 3 Changing orebody geometry from 1375 Level (left), 1225 Level (mid) and 1125 Level (right) in the base case (plan) with the 0.7 cu domain (red), 50 m grids shown (all levels to same scale)

Beck Engineering proposed a rotated hybrid layout (Figure 4) following their preliminary numerical analysis work completed in 2021 (Beck Engineering 2021), which included input from internal and external stakeholders in relation to the basis of design, modelling and analysis. A peer review was completed by an external consultant indicating no fatal flaws with the proposed cave rotation (i.e. ore drive orientation change). These proposed changes were incorporated within the preliminary planning process and formed the basis of design, flow modelling and scheduling assumptions.

The case for reorientation of the cave footprint appears to be robust to manage geotechnical risk; however, the question of how exactly to complete the reorientation over the three levels is currently the subject of detailed scenario analyses. It is assumed within the ongoing PFS study that the cave footprint will be re-oriented at depth with footwall drive and capital development located in the west/northwest rather than the north.

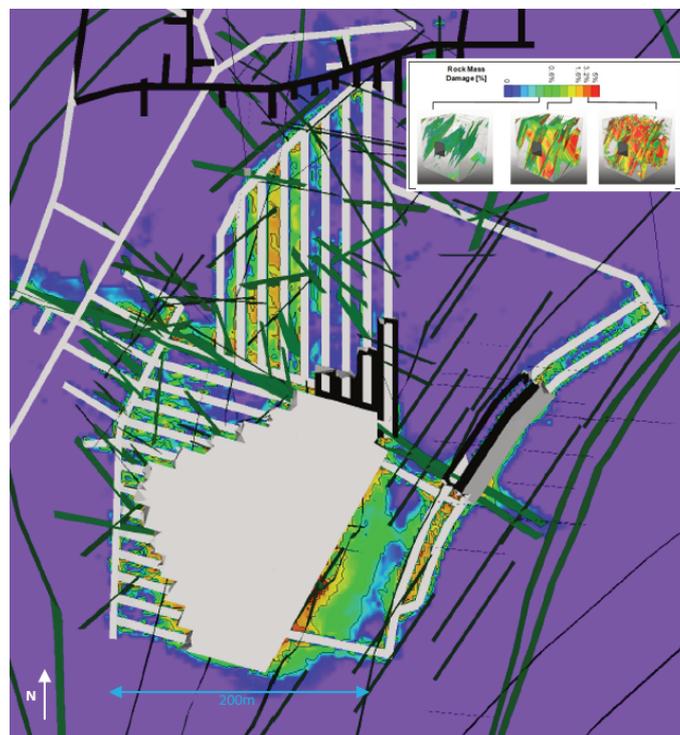


Figure 4 Numerical modelling of the hybrid design showing rock mass damage towards the end of mining and at the cave abutment areas on the 1175 Level (plan) (Beck Engineering 2021)

3 Considerations

3.1 Geological, hydrogeological and geotechnical challenges at depth

The Angry Boy Fault (Fault AB) is a planar-undulating brittle structure of varying thickness dipping approximately $45\text{--}025^\circ$, which has been modelled with moderate-high confidence for a minimum span of 500 m from east to west. The fault typically displays a 1–2 m anastomosing damage zone characterised by fault gouge, clay and angular remobilised clasts in development intersections, likely enhanced by sulphide breakdown within the orebody. Drill intersections often show wide damage zones of rubble and clay infill but can be locally narrow and/or discrete. The late nature of this structure (late-syn- to early post-mineralisation) leads to the potential for offsetting of the orebody, although indications are that an offset would be minor (<30 m vertically, <10 m laterally) (Stephens 2021). Fault AB first intersects the level footprint on 1250 at the southwest of the footprint, moving steadily north through the 1225 Level and 1200 Level due to its northerly dip. It is currently confirmed to be present at least on the 1125 Level.

A major fault zone was intersected during mining on 1300 Level known as the South-West Shear Zone (SWSZ), dipping approximately east at 75° consisting of slightly more jointed, reduced mineralisation and altered rock mass (Figure 5). The SWSZ is comprised largely of altered breccia with schist as a lesser rock-type. Brittle medium scale structures intersecting the SWSZ have exhibited seismic energy release during cave extraction requiring some rehabilitation during 1300 Level production.

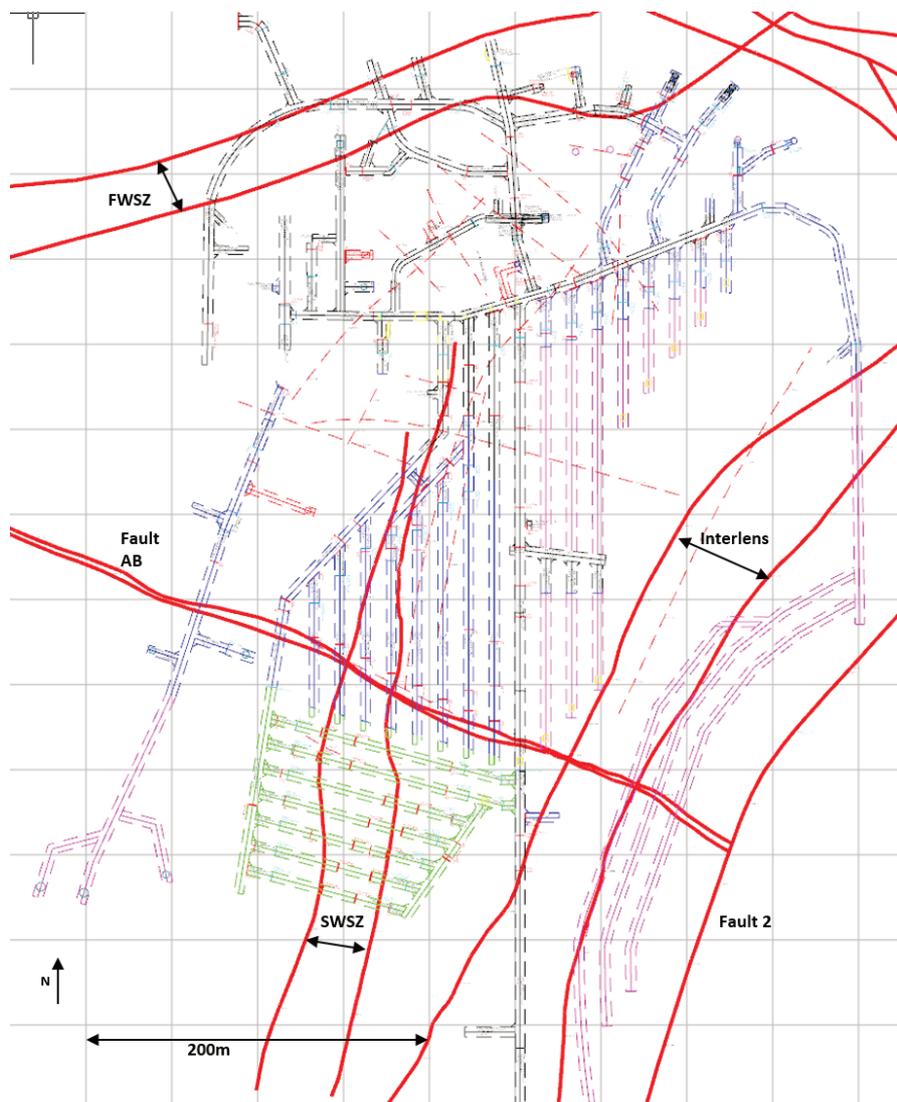


Figure 5 Overview of all current major and intermediate structures on the 1200 Level

In addition, the EHO underground mine is situated within a fractured Proterozoic aquifer that receives most of its groundwater recharge from the overlying Gilbert River Formation (GRF). Direct rainfall runoff recharges the GRF and the fractured Proterozoic which is hampered by low conductive shale layers in the cover sequence (Ernest Henry Operation 2021). Hydrogeological influences are anticipated to have an impact to the mining operation at depth as the watertable is being drawn down in conjunction with mining. High water inflows, varying from 50 to more than 300 L/min, were recorded along the Fault AB zone at various depths. It is shown that the fault structures are highly conductive and any change to the aquifer system results in an increase in the water level (e.g. de-watering changes). Thus, the basis of the mine design for the vertical development was to avoid the Fault AB to better manage inrush risks (Copper Resource Engineering 2021). De-watering tasks were also built into the mine schedule.

Rock mass classification within the orebody and surrounds vary from 61–65 RMR in the footwall lithology, to 64–70 RMR in the orebody (FV). Uniaxial compressive strengths (UCS) of the domains vary within the footwall lithology 134 MPa and orebody (FV) 114 MPa on average (Ernest Henry Operation 2021). With the high strength rock and changes in stress due to mining method, it is anticipated that seismicity and seismic induced damage to the surrounding rock mass of certain excavations will be a key risk for consideration during mine design and ground support design.

3.2 Increasing stress and seismicity

The pre-mining stresses at 1300 Level, 1100 Level and 0875 Level are approximately 46 MPa, 56 MPa and 67 MPa with stress/strength (σ_1/σ_c) ratios of 0.36, 0.43 and 0.52 respectively (intact rock strength of 129 MPa). σ_1/σ_c ratios of just greater than 0.4 are considered intermediate mining-induced stress conditions. Where the maximum induced principal stress/UCS ratio (σ_{1max}/σ_c) is greater than 1.15, which is considered high mining-induced stress (Kaiser et al. 2000), the rock mass response will be non-linear. The stress conditions at EHO, coupled with a generally massive rock mass (RMR >75), is likely to result in some brittle failure around the excavation and displacement on intersecting structures (e.g. excess shear stress resulting in seismic energy release) (Shiels 2021).

In situ stresses will continue to increase with the working depth. With the changing orebody geometry, the stress at the abutments in the south and west will be much higher than have been experienced previously. To remedy this, a transverse layout south of the AB shear (Figure 5) is proposed (hybrid layout). Ore drives south of AB will be oriented approximately east–west (transverse), and ore drives north of AB north–south (longitudinal), as per the previous layout. This avoids having intersecting ore drives oriented parallel to the Fault AB, improving working conditions (Copper Resource Engineering 2021). Though this preferred ‘shear outwards’ sequence would require southwards advance into the highest stress areas, it eliminates the even worse scenario of ‘shrinking’ towards the cave. The northern front, shadowed by previous levels, is also decoupled from the south, which would aid production ramp-up.

3.2.1 Fault AB seismicity

When considering an appropriate elevation and method to rotate the cave, the influence of the AB shear is considered. The AB shear appears to be a logical position to begin cave rotation according to Copper Resource Engineering (2021). Transitioning to a transverse orientation of the ore drives at the AB shear level intersection means that:

- Stress concentrations around the Fault AB are reduced and better managed (i.e. Fault AB is within a step-out on 1225 Level and subject to the highest loading).
- The number of transverse drives undercutting longitudinal drives is minimised, and where the change in orientation occurs the AB shear may perform poorly as a bridge.

3.3 Draw strategy

The planned mining sequence commences with the slot on the east and retreats west, with access positioned in the north-west and west. A chevron (concave) cave front has been adopted for level sequencing, which confines the rock mass ahead of the front, whilst providing schedule flexibility. A steeper chevron front (30–45°) is required to ensure the SWSZ is also approached at a more favourable angle, shown in Figure 6. Retreating west to east was considered; but did not progress due to the position of the Interlens zone and increased seismic risk, along with potential for groundwater intersections (Copper Resource Engineering 2021). Sterilisation risks were also a major factor to consider; the resource boundary is gradational to the east and northeast, whereas to the west and in the footwall is a sharper contact. Figure 6 shows the two options of cave front layout, with longitudinal ‘base case’ layout (a) and hybrid chevron caving front (b). Fault AB is pictured with red arrows (HINGE) showing where the stress disturbance is modelled to occur. White arrows point to higher stress concentrations associated with stress change south of Fault AB.

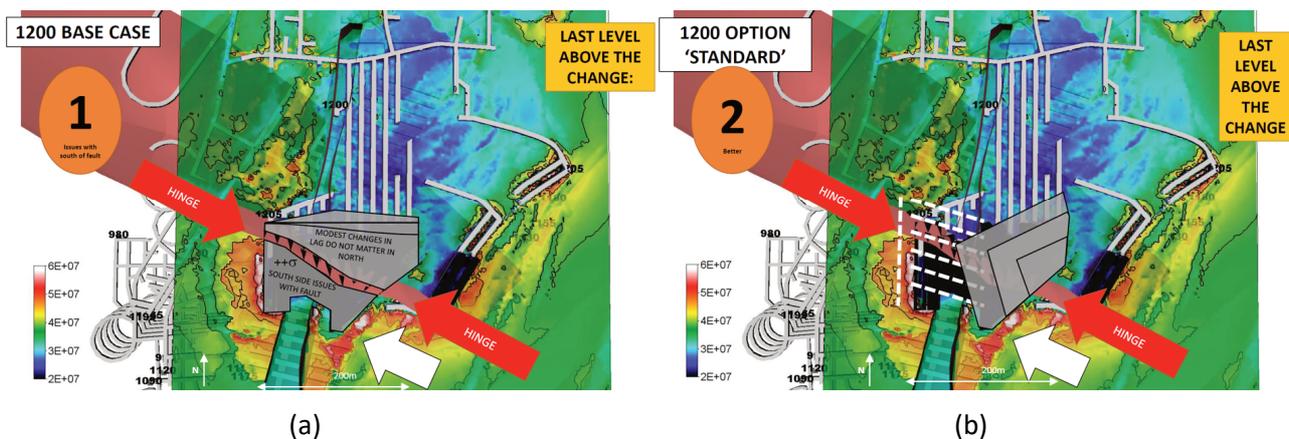


Figure 6 Longitudinal layout mining south to north towards AB (a) and hybrid layout with a chevron front mining east to west along AB (b) (1200 Level plan) (Beck Engineering 2021)

3.4 Operational considerations

The continuation of longitudinal caving results in reducing the number of crosscuts, posing potential risk to production rates. Additional ore drives can be opened by adopting a transverse layout. Additionally, increased longitudinal tramming distances will have a detrimental impact on loader productivity. A transverse layout allows for up to 17 active ore drives per level and a total of 28 ore drives on 1125 Level (Copper Resource Engineering 2021). This layout facilitates shorter tramming distances to the western FWD, faster level ramp-up and close out, and increased operating areas.

Shorter drives will also be less difficult to ventilate compared to longer drives.

4 Ongoing numerical analysis

4.1 Reorientation scenarios

Three scenarios have been proposed for the reorientation, with various risks and opportunities inherent to each option. Flow modelling, scheduling and modelling of various cave front sequences has been completed on all three models, and stability modelling results, coupled with flow modelling and impacts of subsidence on surface infrastructure, is currently ongoing to ensure the optimal scenario is taken into production.

4.1.1 Scenarios 1 and 2

These two scenarios (Figures 7 and 8) are considered the most likely options. Development drives intersect Fault AB perpendicularly, it provides a decoupled cave front, and maintains a chevron front along Fault AB whilst having more flexibility in the longitudinal/northern section.

Whether 1175 Level is hybrid or full transverse, the Fault AB intersection will be in the 1200 Level stress shadow, therefore posing less of an intersection risk for the cave front compared to when it is in the diminishing pillar. It would still be recommended to retreat west along the AB, preferable with a chevron cave front as mentioned previously.

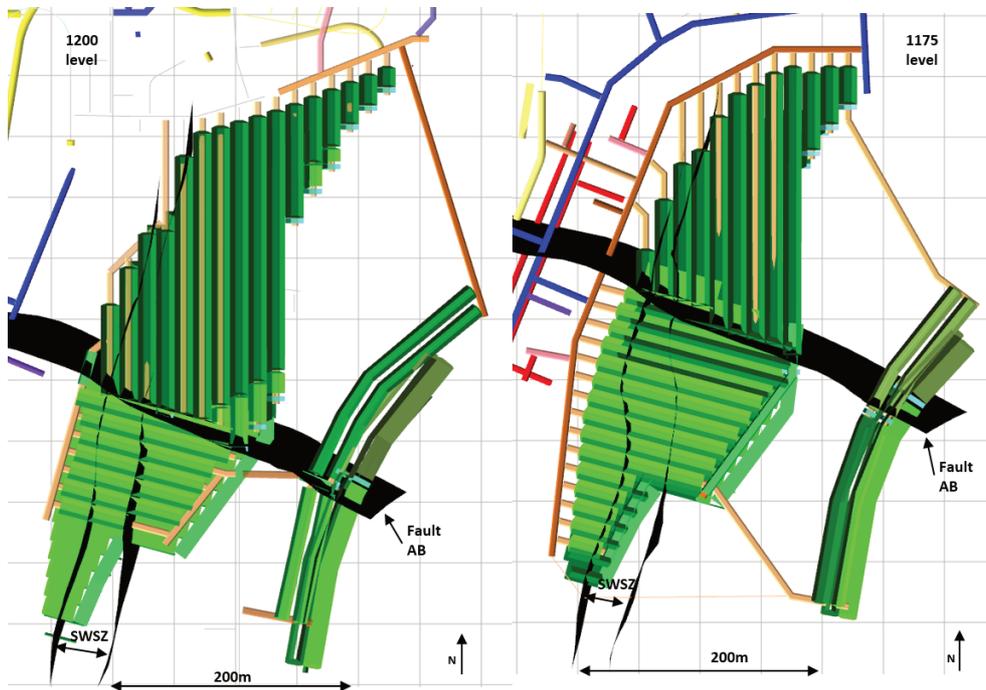


Figure 7 Scenario 1 involves a hybrid cave footprint on 1200 Level, continuing hybrid to 1175, with full transverse not until 1150 Level. South East Lens production is shown to the bottom right

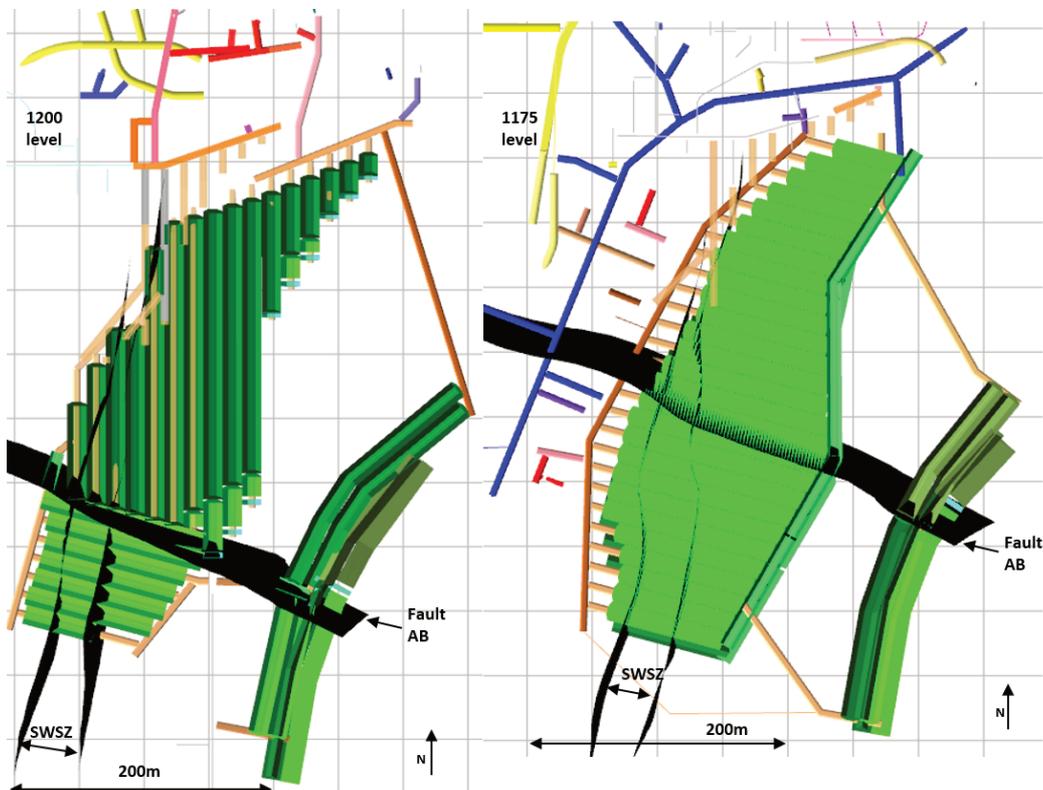


Figure 8 Scenario 2 involves a hybrid cave footprint on 1200 Level, continuing to full transverse layout on 1175 and 1150 Level. South East Lens production is shown to the bottom right

4.1.2 Scenario 3

This scenario (Figure 9) would involve retreating from east to west, rotated around the central oredrive (13). Transverse ore drives would run parallel to Fault AB, which is considered manageable, albeit not ideal. A chevron cave front leading along Fault AB would also potentially be easier to control operationally with transverse ore drives.

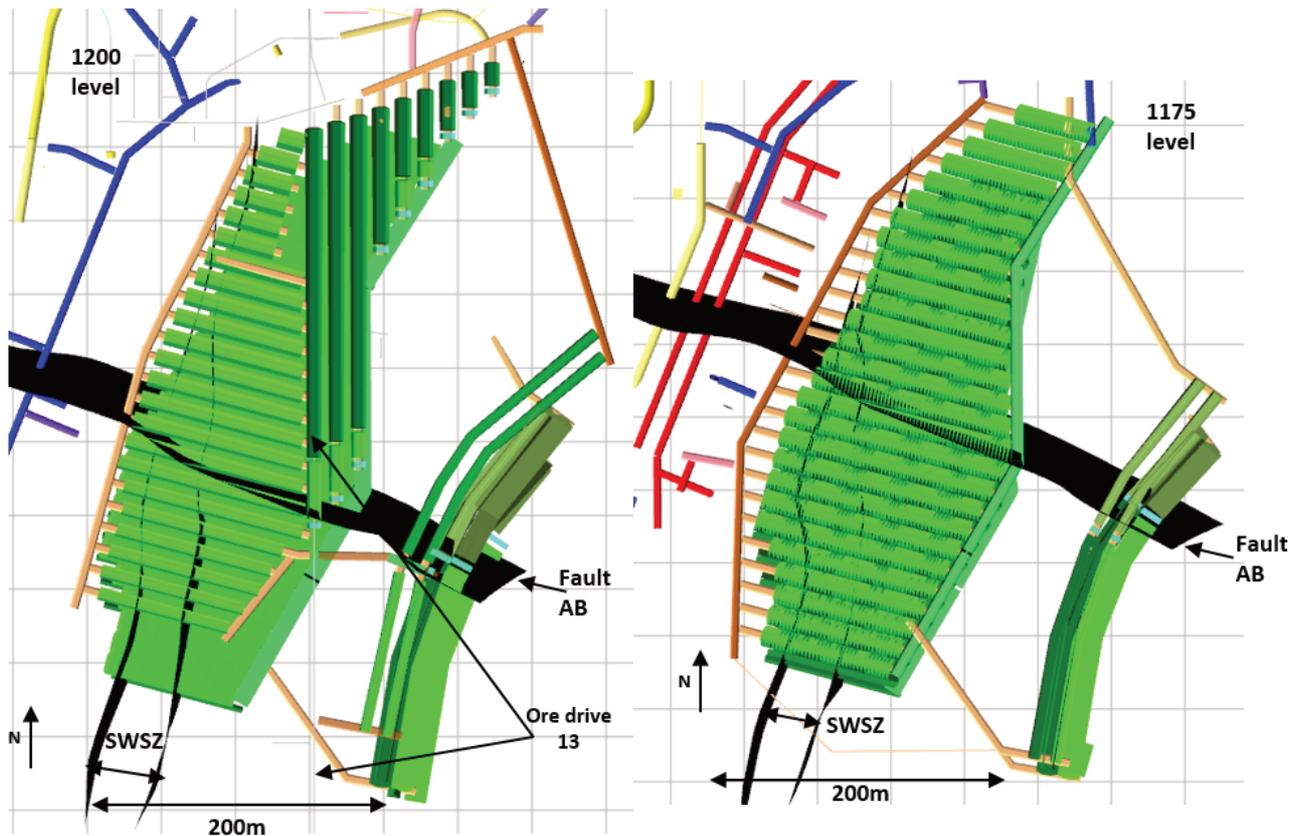


Figure 9 1200 and 1175 footprint layouts for Scenario 3 involve rotation around central oredrive 13 on 1200 Level, with complete transverse layout on 1175 and 1150 Level

Following completion of the numerical modelling work on the three scenarios, peer review of the work by a third party will be conducted to ensure the risks of reorientation are well understood. Following this process, a decision will be made with clear risk ranking of the three scenarios to select the best option to proceed with.

5 Conclusion

Altering the mine design for the EHO SLC not only reduces geotechnical challenges, but it also considers an optimal way to de-risk the mine plan at depth. This paper has provided key factors within the study process, namely geological and geotechnical characteristics, increasing mine seismicity with depth, cave draw strategy and operational considerations to guide the selection of the mining strategy study. This resulted from the identification of mining associated challenges and risks, a decision-making and planning process in rotating the cave layout as well as proposed control measures to ensure local and regional stability. Key to this planning process is ensuring a safe extraction and minimising exposure to all underground personnel. Therefore, the requirements for creating an environment where risk aversion will be the state of play in an increasingly challenging environment.

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