Appendix H

Geotechnical and subsidence assessment

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GEOTECHNICAL AND SUBSIDENCE ASSESSMENT FOR NEW COBAR COMPLEX PROJECT (SSD-10419)

PREPARED FOR
EMM AND PEAK GOLD MINES

DOCUMENT CONTROL

Date	Version	Comments	Signed
2020JULY30	DRAFT01	Initial draft issued for review by EMM and Peak Gold Mines.	
2020SEP28	FINAL	Updates following feedback form EMM and Peak Gold Mines	

EXECUTIVE SUMMARY

Beck Engineering (BE) has conducted a geotechnical and subsidence assessment for proposed continuation of underground mining at the New Cobar Complex in Cobar, far western New South Wales. The New Cobar Complex includes New Cobar (including Jubilee), Great Cobar, Gladstone and Chesney mines. The aim of this project was to address the Secretary's Environmental Assessment Requirements (SEARs) from the Department of Planning, Industry and Environment (DPIE) for the SSD EIS received in February 2020. The project scope included:

1. Forecasting of mine subsidence and surface deformation, including impacts to surface infrastructure and environmentally sensitive sites.
2. Simulating the planned underground mining sequence and forecasting the geotechnical response in ore drives, level accesses, declines and infrastructure.
3. Forecast potential for additional instability in the open cut due to underground mining.
4. Provide general guidance on the stoping sequence and recommend changes as required.
5. Provide feedback on ground support requirements, based on the model forecasts and our experience at other mines in similar conditions.

Our assessment is based on numerical modelling using finite element (FE) methods. An overview of the assessment, including the main findings, risks and recommendations is summarised below. More extensive details are provided in Section 3 of this report.

Main findings

The main findings of our assessment include:

- Surface subsidence forecasts are very low (less than 15mm) and are considered negligible. We note that this level of deformation is within the levels of precision of a mine scale model.
- Negligible subsidence is expected for the proposed underground mining due to:
    - Small footprint of future underground mining.
    - Relatively strong rockmass conditions.
    - Small (narrow) stopes with a small footprint.
    - Low extraction ratio due to the narrow stopes and small amount of rock planned to be mined (compared to other larger stoping mines).
    - Use of backfill.
- Planned underground mining is not in proximity to the New Cobar open cut and there is no significant stress interaction and minimal subsidence in the vicinity of the open cut. Proposed underground mining does not result in instability in the open cut in the model forecasts.
- Minor to moderate levels of rockmass damage is forecast in proximity to some stopes. This increases with depth. Forecast levels of damage would generally be associated with minor dilution and stope overbreak. This is normal in most stoping mines. Moderate level of rockmass damage with potential for increased levels of stope overbreak is forecast along the Great Chesney and Great Cobar faults which bounds the hangingwall of some future stopes.
- There are stopes at New Cobar and Gladstone which are close to, or intersect the weathered/oxidised layers near surface. The rockmass in the oxidised layers is weaker and more susceptible to instability and chimneying. We note these stopes are conceptual only and were designed based on the Inferred Mineral Resource and may not be economic or become part of the Ore Reserve and executable mine design.

- Diminishing pillars are formed at Great Cobar and Gladstone mines due to the mining sequence. These diminishing pillars form as stopes are retreated to a central access. These stopes will likely have elevated levels of stope overbreak and dilution compared to nearby stopes due to the stress concentration that occurs as the pillar diminishes. However, due to the rockmass conditions, depth and small number of stopes with this sequence, this is not considered to be a significant problem for the mine.

Recommendations

- Rigorous subsidence monitoring such as regular surveying, laser scanning or InSAR is not recommended given the model forecasts and negligible amount of subsidence expected. Routine monitoring such as biannual or annual survey pick-ups of key locations as well as geotechnical inspections should be considered by Peak Gold Mines (PGM).
- Review mining of any stopes near the top of fresh rock boundary. Any stopes planned close to the oxidised layers should be risk assessed and have a stable crown pillar.
- Ongoing stope stability assessment and observation of stope performance. The mine should adjust the stope design, including stope dimensions should instability and overbreak be excessive.
- Backfill stopes in a timely manner and minimise the total mine void at each mine as far as practical.
- Review the design and dimensions of rib pillars and sill pillars in the current mine design. We note that some rib pillars in the Chesney mine design are very narrow and likely to fail during stope production.
- Based on the model forecasts for stress, strain and deformation and our experience at other mines in similar conditions, ground support requirements for the future mine will be similar to those used in previous mining to date. We do not expect damaging levels of seismicity or dynamic support to be required due to the rockmass properties, low extraction ratio and mining depth.
- The mine should adopt an observational approach and continuously evaluate the rockmass response to mining and adjust the mine plan, if required, as mining continues and as additional geotechnical information becomes available.

Limitations

In addition to the normal resolution limits associated with the current mine-scale finite element model, the main limitations of this project are:

- The current understanding of rockmass properties and the in-situ stress field.
- Resolution of the structural model. We note the structural model will evolve over time with progressive mining.
- A site inspection has not been undertaken.

Enquiries

Please direct further enquiries to the undersigned.

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1 INTRODUCTION

1.1 Overview

Peak Gold Mines Pty Ltd (PGM), a wholly owned and operated subsidiary of Aurelia Metals Limited (Aurelia), owns and operates the Peak Gold Mines operation south-east of Cobar, far western New South Wales (NSW).

The PGM operation comprises the New Cobar Complex located 3 kilometres (km) to the south-east of Cobar town centre and the Peak Complex located 10 km south-east of the town centre. Both complexes are located adjacent to Kidman Way, which connects Cobar to Hillston and Griffith to the south.

PGM has been operational since mining commenced at the Peak deposit in 1991 and all current mining operates under development approvals issued by Cobar Shire Council (CSC).

The New Cobar Complex Project State Significant Development (SSD) (the project) is an amalgamation of underground mining at New Cobar, Chesney and Jubilee deposits and development of new underground workings of Great Cobar and Gladstone deposits to create the New Cobar Complex Project.

PGM is also seeking to consolidate all existing development consents applicable to the New Cobar Complex within a single modern consent issued by the Department of Planning, Industry and Environment (DPIE). Approval will be sought for project elements accessed from, and undertaken within, the existing New Cobar Complex located within consolidated mining lease (CML) 6, mining purposes lease (MPL) 0854 and mining leases (ML) 1483 and ML 1805.

1.2 Background

PGM has been operational since mining commenced at the Peak deposit in 1991 producing gold, copper, lead, zinc and silver. Mining at the New Cobar Complex commenced with the open cut pit in 2000, then transitioned to underground mining in 2004.

The current CSC development approvals at Peak Complex and New Cobar Complex allow for the operations to continue indefinitely and process up to 800,000 tonnes per annum (tpa) of ore. Ore processing, tailings storage and concentrate handling is undertaken at the Peak Complex with ore from the New Cobar Complex trucked by public road to processing facilities at the Peak Complex. Both the processing plant and the tailings storage facility (TSF) are located at the Peak Complex, and activities at those facilities are outside the scope of this project.

PGM has identified the Gladstone and Great Cobar deposits as targets for further mining to extend the life of operations at the New Cobar Complex. The Great Cobar deposit was historically exploited by surface and shallow underground mining between 1870 and 1919, but no mining of that deposit has been undertaken since that time.

PGM has obtained conditional approval for development of an exploration decline to facilitate exploration activities within the Great Cobar deposit. The objectives of the exploration activities are to:

- further define the mineral resource through underground drilling from an exploration decline; and
- taking of a bulk sample to provide further samples for metallurgical, geotechnical and associated test work.

1.3 Objectives

The aim of this project was to address Secretary's Environmental Assessment Requirements (SEARs) from the Department of Planning, Industry and Environment (DPIE) for the SSD EIS requested by Peak Gold Mines (PGM) in December 2019 and received in February 2020 (see Figure 1.1). The project scope included:

1. Forecasting of mine subsidence and surface deformation, including impacts to surface infrastructure and environmentally sensitive sites.
2. Simulating the planned underground mining sequence and forecasting the geotechnical response in ore drives, level accesses, declines and infrastructure.
3. Forecast potential for additional instability in the open cut due to underground mining.
4. Provide general guidance on the stoping sequence and recommend changes as required.
5. Provide feedback on ground support requirements, based on the model forecasts and our experience at other mines in similar conditions.

5. Geotechnical design assessment

The Proponent is to supply a full geotechnical assessment that supports mining methods and mine design that includes, but is not limited to:

(a) Consideration of local geological structure and its influence on rock stability.

(b) An analysis of ground behaviour and ground management strategies in deep underground mining.

(c) Description of ground support system design for static and dynamic conditions that includes performance monitoring methods.

(d) Evaluation of stress management and quality control and support elements during mining operations.

6. Subsidence

To justify proposed underground mining projects, the Proponent must demonstrate the feasibility of:

(a) The proposed strategies to manage subsidence risks to surface or sub-surface features that are considered to have significant economic, social, cultural or environmental value.

Figure 1.1. Excerpt from the SEARs document related to the geotechnical and subsidence requirements for the EIS.

An aerial view of the local region is provided in Figure 1.2 and a long section of the project is shown in Figure 1.3.

This project did not include:

- Modelling of ground support.
- Detailed seismic forecasting.
- Detailed stability forecasts for individual stopes, drives or benches.
- Detailed stability forecasts for pit slopes in the Cover Sequence.
- Hydrogeological modelling.
- Forecasts of backfill behaviour.
- A site visit. This was not required for the scope of the project.

This report documents our analysis method, results, associated interpretation, conclusions and our recommendations for PGM’s consideration.

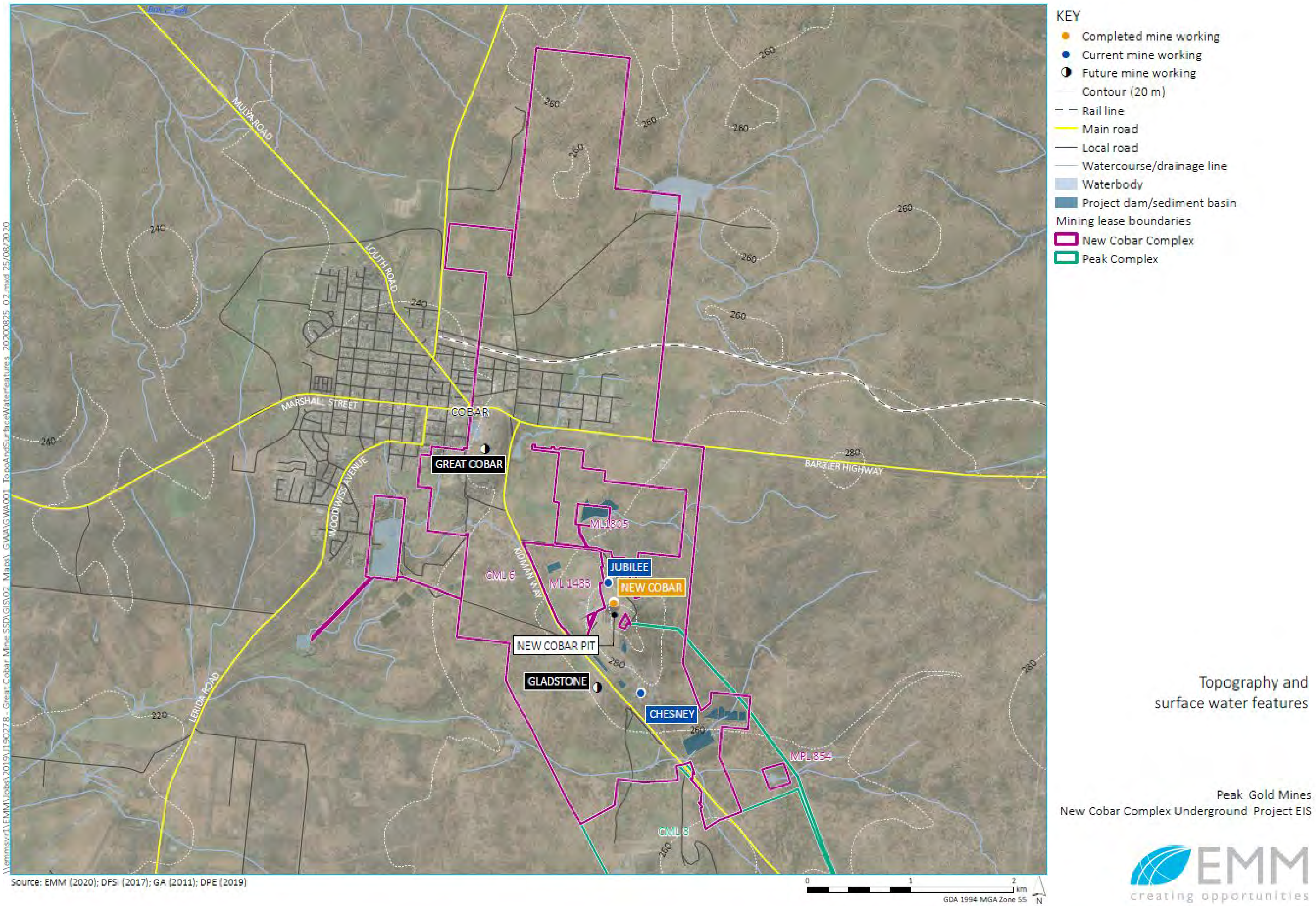


Figure 1.2. Aerial view of the New Cobar Complex, Cobar township and nearby mines.

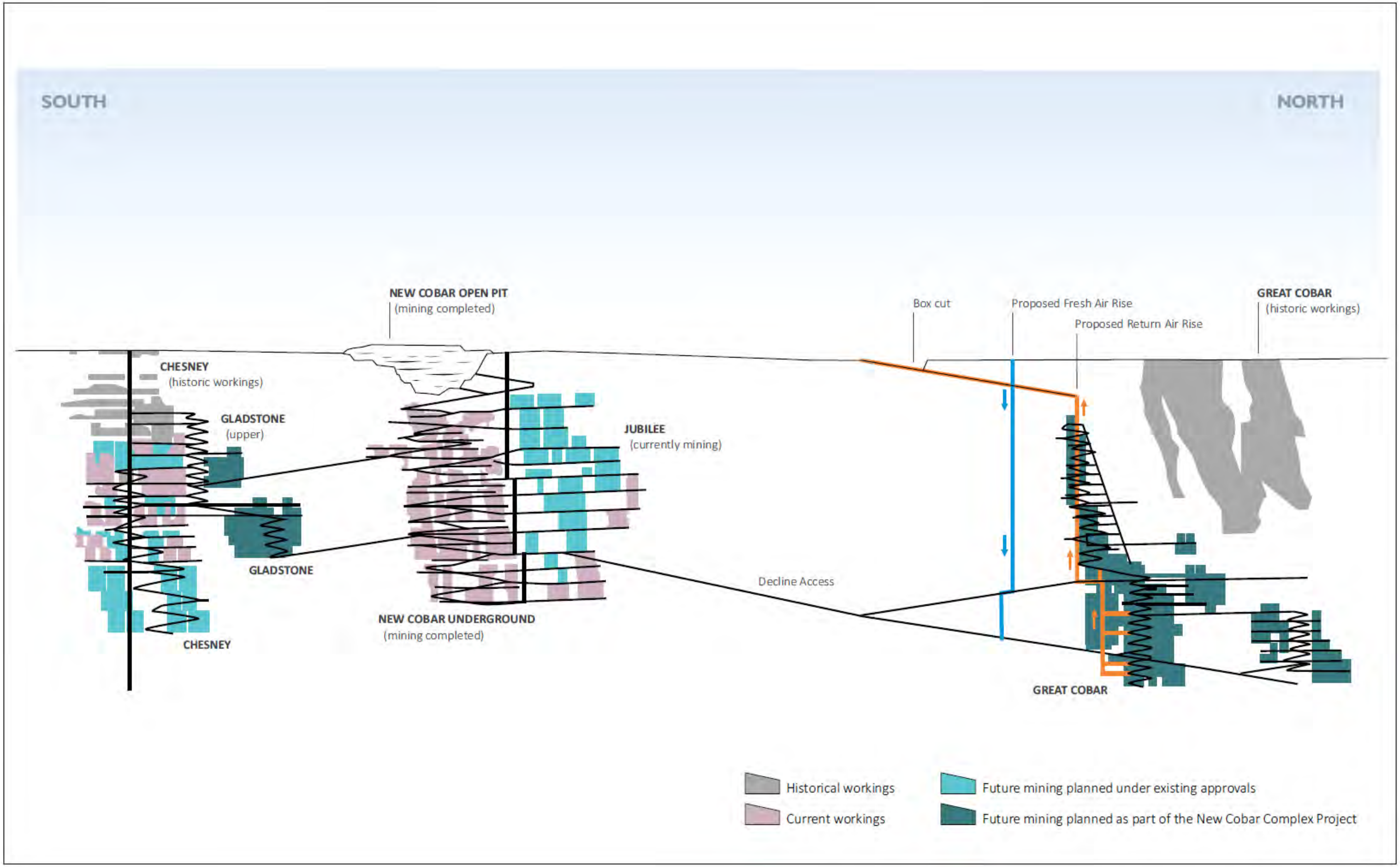


Figure 1.3. Long-section of the New Cobar mining complex showing historic mining and planned future mining

2 PROJECT WORKFLOW, BACKGROUND DATA & MODEL COMPOSITION

This section summarises the project workflow, the available background data and assumptions relevant to the project and describes how these data and assumptions have been incorporated into the workflow.

2.1 Project workflow & simulation framework

The modelling workflow for this project was:

1. Initial mining engineering and rock mechanics appreciation of the project including compilation of all relevant geometric data into a 3D CAD database using commercial software.

2. Discontinuum finite element (FE) mesh construction using commercial software and in-house scripting tools. Higher-order finite elements were used for all volume elements.

3. Assignment of the geotechnical domains, material properties, initial conditions, boundary conditions and the mining and fill sequence to the FE mesh.

4. Solution of the stress, strain and displacement fields and released energy for each step in the modelled mining sequence using the Abaqus Explicit FE solver. Abaqus Explicit is a commercial, general purpose, 3D, non-linear, continuum or discontinuum FE analysis package designed specifically for analysing problems with significant plasticity, large strain gradients, high deformation levels and large numbers of material domains. Commercial software and in-house post-processing scripts are used to process the Abaqus output and visualise the results.

5. Forecasting of future behaviour for the current LOM plan. Section 3 documents the model results, our interpretation of the results in a mining context and associated discussion.

There is limited data available to enable quantitative model calibration based on observations and measurements. Consequently, this project does not include calibration, except to the extent that that the results are generally consistent with previous geotechnical reports from New Cobar and our general experience in stoping mines under similar geotechnical conditions.

The Levkovitch-Reusch 2 (LR2) discontinuum constitutive framework was applied in Abaqus to describe the mechanical behaviour of the rockmass and structures. The Appendix contains further details of the LR2 framework. The LR2 framework includes:

1. Three-dimensional (3D) geometry, with the mine excavations sequenced in a sufficient number of separate excavation steps (called frames) to capture the necessary temporal resolution for the project scope.

2. Strain-softening dilatant constitutive model for the rockmass and structures with a generalised Hoek-Brown yield criterion. Different material properties are assigned to each geotechnical domain.

3. Discontinuum formulation using cohesive finite elements to model discrete structures. Cohesive elements are free to dislocate, dilate and degrade and can realistically capture the behaviour of thin structures which tetrahedral finite elements cannot achieve as effectively. The complete interpreted structural model at the required resolution can be included, and where appropriate, can be supplemented with a discrete fracture network (DFN) to improve the structural resolution.

4. Structures less persistent than those modelled explicitly can be represented by "smearing" the effects of structures within the continuum regions of the modelled rockmass.

5. Hydromechanical coupling, where necessary, to capture the effects of pore water pressure on the rockmass yield surface, or to estimate water flow rates.

The LR2 modelling framework aims for physical similitude, by making the fewest possible assumptions about the governing physics of the entire mine system within a single physics-based numerical model, at the required scale of the analysis. This results in a realistic but complex model, since complexity is the reality of all mines. Building a realistic mine model by including the governing physics means that realistic rockmass behaviour evolves naturally in the model, and is therefore essential for developing a detailed understanding of the likely rockmass response to mining.

2.2 Topography

The natural ground surface at New Cobar is predominantly flat, with some small hills. The supplied topographic data was used to build the natural surface topography, with extensions out to the model boundaries. Except for the open cuts and the waste dumps, there are no surface features of geotechnical significance for the underground mine.

2.3 Stress field

The in situ stress field at New Cobar Complex that was provided for the analysis is shown in Table 2.1. Review of this stress regime following the first model simulation identified some problems in the stress regime. This includes the high shear stress component and low vertical stress, which does not match gravitational effects in the rockmass due to the overburden pressure. In short, the stress regime does not satisfy equilibrium at surface or at depth. Feedback from site geotechnical engineers identified the single stress test conducted in vicinity of the New Cobar Complex was conducted in 1996 and was likely impacted by bedding of the rockmass. The measurement is regarded as having low confidence by PGM. As a result, the stress regime was adjusted slightly for a second model iteration. The vertical stress at depth was increased to approximately match gravitational effects (i.e. the overburden pressure). The dip of the principal stresses was also adjusted to mitigate the high shear stress component. The principal stress bearings were not adjusted. Overall, the adjusted stress regime is comparable to the regional stress regime for the district as shown in Figure 2.1. The adjusted in situ stress field is provided in Table 2.2. The model forecasts provided in this report are for the second model iteration.

Table 2.1: In situ stress regime provided by PGM.

	Stress Depth Relationship	Dip/ Dip Direction	Stress at 1000m
Major	$\sigma 1 = 3.8 + 0.056 \times H$	20/255	59.8
Intermediate	$\sigma 2 = 1 + 0.03 \times H$	05/165	31
Minor	$\sigma 3 = -0.75 + 0.01875 \times H$	70/75	18

Table 2.2: In situ stress field S02 used in this project.

Principal stress component	**Magnitude gradient** (MPa/km)	**Dip** (degrees)	**Dip azimuth** (degrees)
σ_1	56	0	075 ≡ 255
σ_2	35	0	165 ≡ 345
σ_3	25	90	075 ≡ 349

Cartesian stress tensor at 1,000m:

$$\begin{bmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{zx} \\ \sigma_{xy} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{yz} & \sigma_{zz} \end{bmatrix} = \begin{bmatrix} \sigma_{EE} & \sigma_{EN} & \sigma_{UE} \\ \sigma_{EN} & \sigma_{NN} & \sigma_{NU} \\ \sigma_{UE} & \sigma_{NU} & \sigma_{UU} \end{bmatrix} = \begin{bmatrix} 57.8 & 0 & 0 \\ 0 & 38.6 & 5.5 \\ 0 & 5.5 & 26.5 \end{bmatrix} \text{MPa}$$

Note: x is east on the local mine grid, y is north and z is up.

Stress Province		Principal Stresses (at a depth of 1000m, for stress measurements > 500m)	
		σ1 Orientation	Magnitudes (MPa); σ1 : σ2 : σ3
1	Yilgarn	Variable, WSW-ENE (?)	**90** : 50 : 35
2	Gawler-Curnamona	WNW-ESE	**55** : 40 : 30
3	Lachlan	WNW-ESE	**55** : 35 : 30
4	Arunta	WSW-ENE	**55** : 40 : 25
5	Kimberley	SW-NE (?)	**50** : 40 : 25 (?)
6	Mt Isa Inlier	WSW-ENE	**40** : 30 : 20

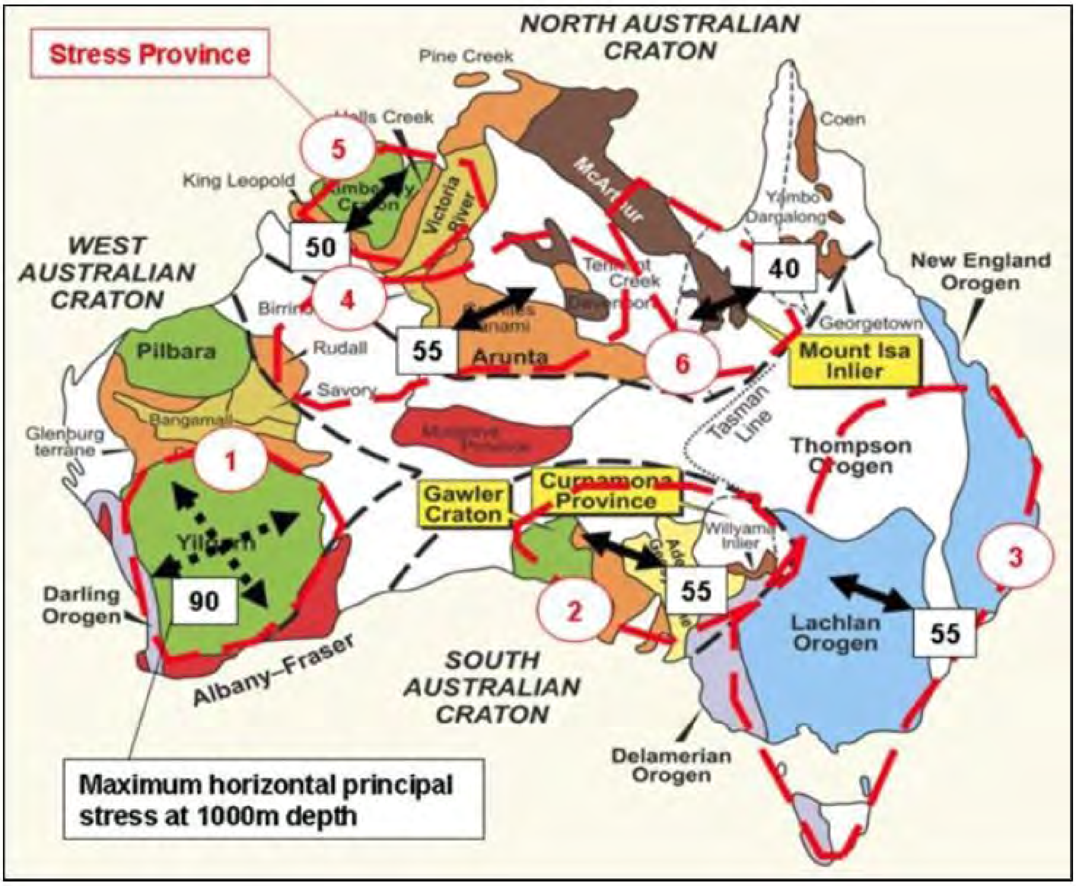


Figure 2.1: Stress provinces in the Australian continent (after Lee et al. 2010)

The initial stress field given in Table 2.2 was applied to the FE model by ramping the stresses in each element from an initial hydrostatic state to the target initial stress state over an appropriate number of computational steps. This part of the simulation procedure is called the equilibrium step and aims to generate an initial stress field in the mine precinct that is mechanically compatible with the modelled structures, geotechnical domains, material properties and topography. This procedure generates a variable in situ stress field in the mine precinct which is characteristic of the variability typically measured in mines.

2.4 Geotechnical domain assignment

The material properties have been applied according to the lithology. This domaining approach is a necessary assumption in the absence of a separate detailed geotechnical domain model, but from our general understanding of rock mass conditions at the New Cobar Complex, this assumption is probably suitable. The plan view in Figure 2.2 shows the major faults and domain assignment in the FE mesh.

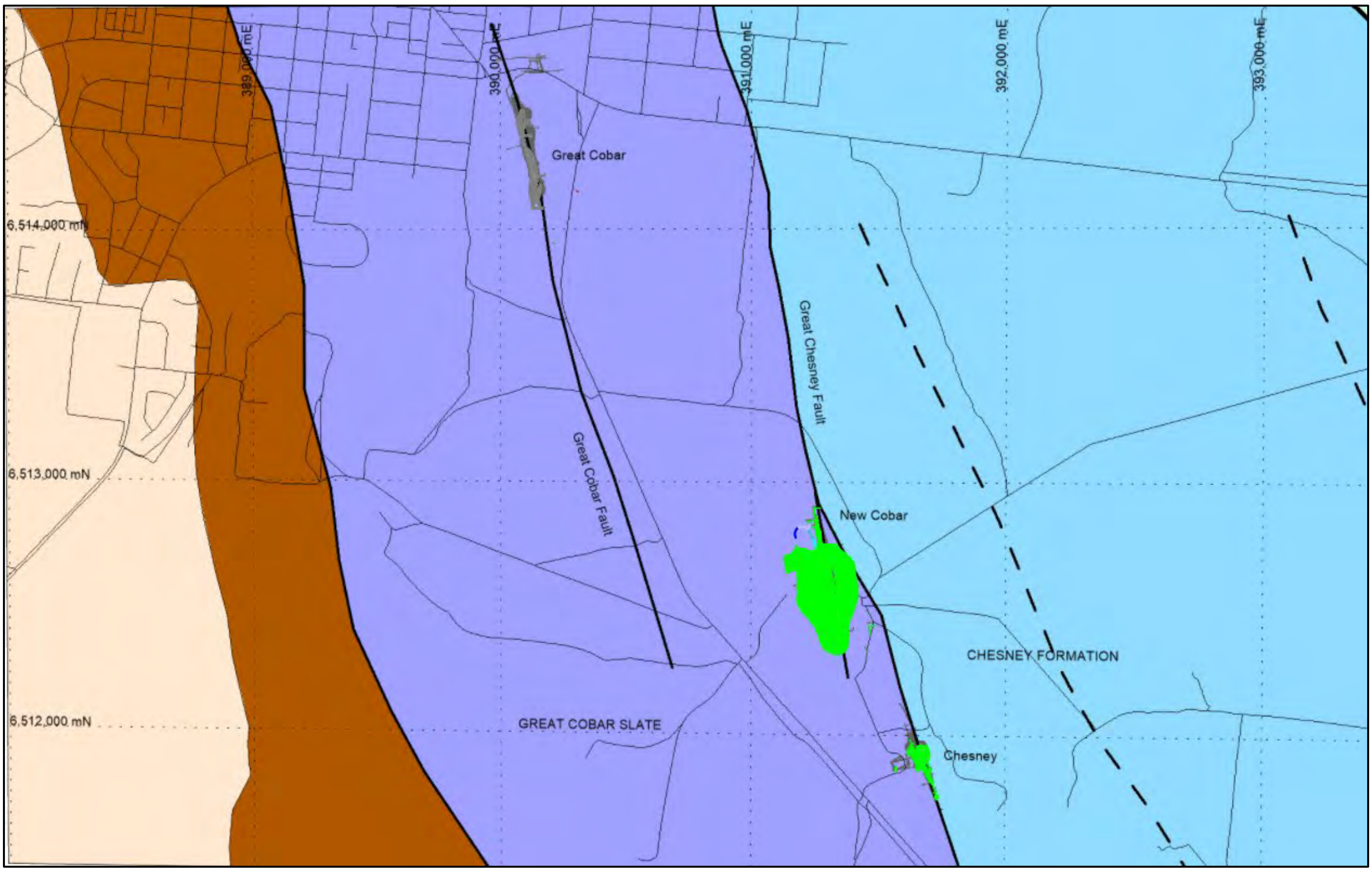


Figure 2.2: Plan view of the New Cobar Complex, major faults and geology domains.

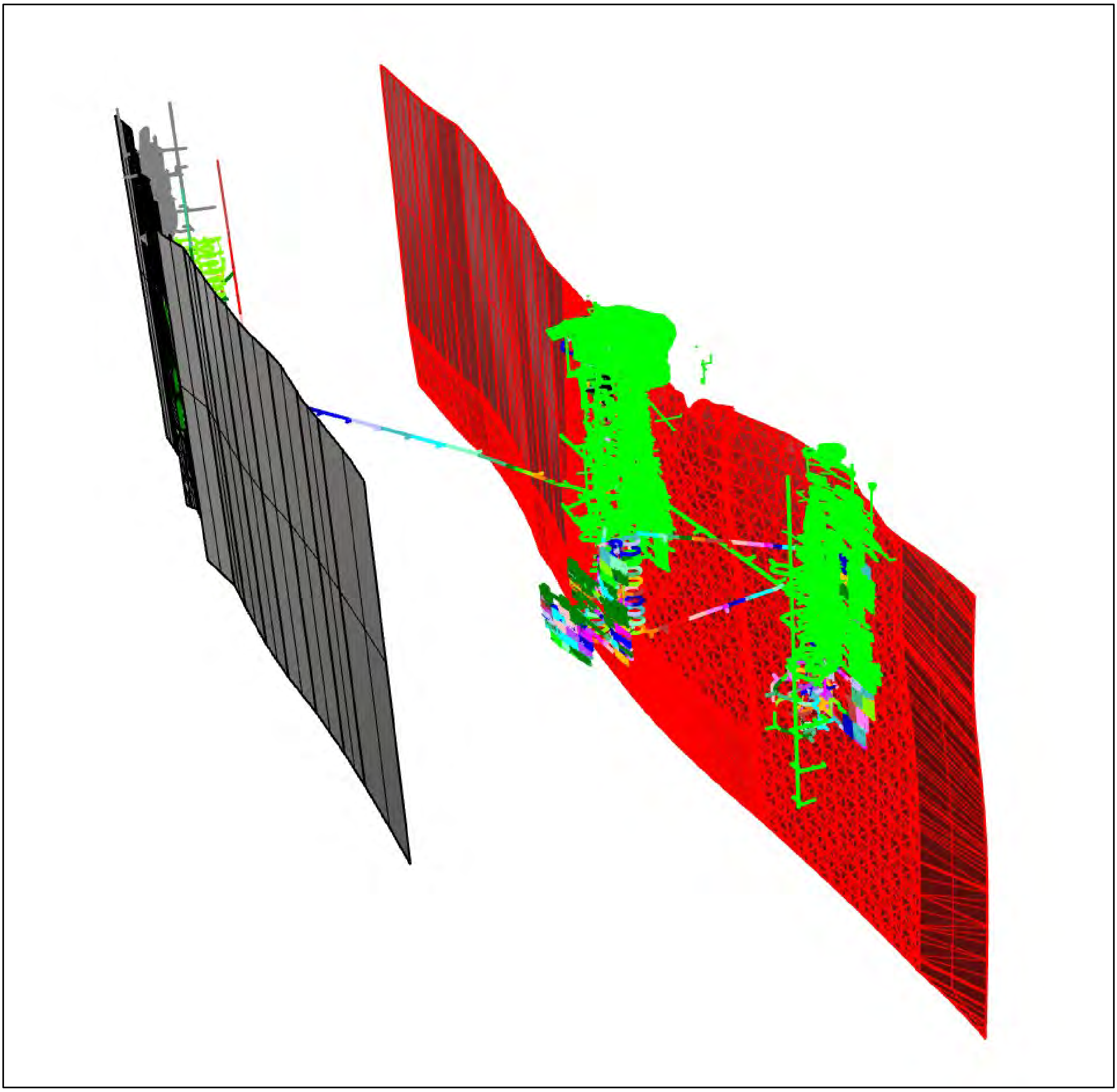


Figure 2.3. Historic and planned mining showing the two main faults. The Great Cobar fault (grey) and the Great Chesney fault (red)

2.4.1 Estimated material properties for modelling

Rockmass properties were provided by PGM and verified with site Geotechnical Engineer prior to running the model. Fault properties were not available from available testing data and generic fault properties were agreed to be used for this assessment and deemed appropriate for the mine-scale model. These properties were cohesion of 50 kPa and friction angle of 35 degrees.

The material properties used in the model were estimated using a scheme derived from calibrated case studies where observations and deformation measurements were matched to numerical modelling results (Beck et al. 2013). The material properties derived by these methods are given in Table 2.3. Derivation of material properties by a calibration process is preferred over this approach, but given that suitable data is not yet available for calibration, the estimation process is necessary at this stage of the project.

The following nomenclature is used in Table 2.3:

- UCS = uniaxial compressive strength.
- GSI = geological strength index.
- ϵ_0 = 0 = plastic strain at start of peak strength stage (see Figure 2.4).
- ϵ_1 = plastic strain at start of transitional strength stage (see Figure 2.4).
- ϵ_2 = plastic strain at start of residual strength stage (see Figure 2.4).
- E = Young's modulus for the rockmass.
- ν = Poisson's ratio for the rockmass.
- s, m, a = generalised HB yield parameters for the rockmass.
- d = rockmass dilation parameter.
- κ = $s\sigma_c{}^{1/a}$ = Generalised HB cohesion parameter for the rockmass. Units are $MPa^{1/a}$.
- Φ = $m\sigma_c{}^{1/a-1}$ = Generalised HB friction parameter for the rockmass. Units are $MPa^{1/a-1}$.

Table 2.3. Material property set M02.

NEW COBAR

Material property set M02

	Domain	Code	Density	UCS	GSI	Aniso		Stage	Plastic	E	ν	s	m	a	d
			(kg/m^3)	(MPa)		n	s		strain	(GPa)					
1	Base of complete oxidation	0	2,400	20	35	1.00	1.00	Peak	ε_0 = 0.0%	4.2	0.21	1.72E-04	0.43	0.500	0.05
								Transition	ε_1 = 3.5%	4.2	0.21	1.72E-04	0.43	0.500	0.05
								Residual	ε_2 = 6.2%	2.1	0.21	3.38E-05	0.23	0.500	0.02
2	Base of partial oxidation	0	2,600	40	40	1.00	1.00	Peak	ε_0 = 0.0%	8.4	0.22	3.37E-04	0.60	0.500	0.10
								Transition	ε_1 = 3.1%	8.4	0.22	3.37E-04	0.60	0.500	0.10
								Residual	ε_2 = 5.5%	8.4	0.22	1.61E-04	0.46	0.500	0.04
3	Base of fracture oxidation	0	2,700	60	45	1.00	1.00	Peak	ε_0 = 0.0%	12.5	0.24	6.50E-04	0.82	0.500	0.15
								Transition	ε_1 = 2.8%	12.5	0.24	6.50E-04	0.82	0.500	0.15
								Residual	ε_2 = 4.9%	12.5	0.24	4.01E-04	0.70	0.500	0.05
4	SLATE	0	2,700	74	55	1.00	1.00	Peak	ε_0 = 0.0%	15.5	0.24	1.16E-03	1.15	0.500	0.19
								Transition	ε_1 = 2.6%	15.5	0.24	1.16E-03	1.15	0.500	0.19
								Residual	ε_2 = 4.5%	15.5	0.24	6.42E-04	0.86	0.500	0.07
5	SANDSTONE	0	2,700	125	55	1.00	1.00	Peak	ε_0 = 0.0%	26.1	0.28	4.59E-03	1.92	0.500	0.31
								Transition	ε_1 = 1.9%	26.1	0.28	4.59E-03	1.92	0.500	0.31
								Residual	ε_2 = 3.3%	26.1	0.28	2.09E-03	1.45	0.500	0.11
6	ORE	0	2,800	160	60	1.00	1.00	Peak	ε_0 = 0.0%	33.4	0.30	1.29E-02	2.97	0.500	0.40
								Transition	ε_1 = 1.5%	33.4	0.30	1.29E-02	2.97	0.500	0.40
								Residual	ε_3 = 2.7%	33.4	0.30	3.64E-03	1.86	0.500	0.14

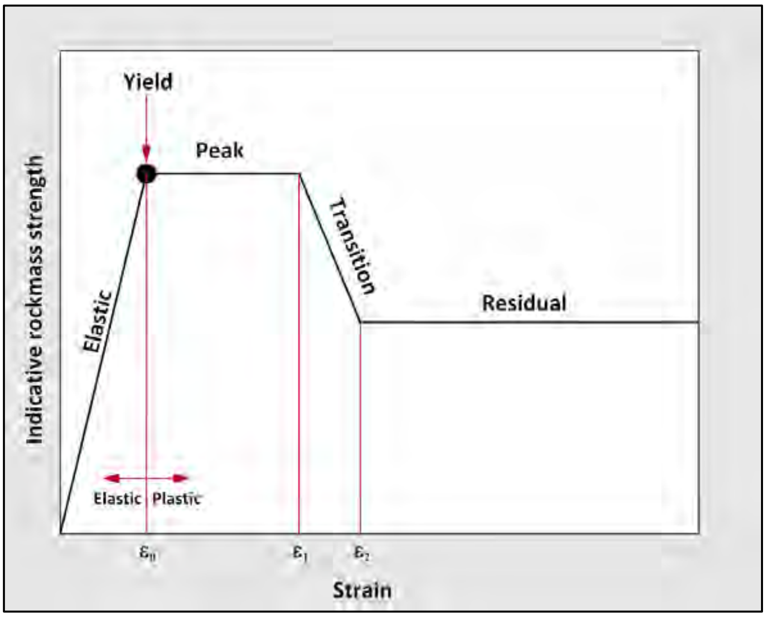


Figure 2.4. Indicative rockmass softening curve demonstrating the plastic strain transition points ϵ_1 and ϵ_2.

2.5 Hydrogeological conditions

The analysis subsidence assessment conducted has not included groundwater effects or the effects of planned drawdown of the water table.

2.6 Mining methods, geometry & sequence

The model included the complete as-built and planned LOM geometry for the New Cobar Complex, comprising of:

- Open cuts.
- All historical mining voids.
- All lateral and vertical development and all stopes.
- Geotechnical domains and major faults.

Two mine designs were provided. These include the November 2019 life of mine plan (which has a stope and development sequence) and the May 2019 life of mine design (which was not provided with a mining sequence or schedule). At the advice of PGM, the larger May 2019 mine design was used for the geotechnical and subsidence assessment conducted in this project. The November 2019 mine design was used to sequence stopes and development common to both mine designs. The additional stopes in the May 2019 design provided by PGM without a mining date were sequenced by Beck Engineering. These stopes were sequenced using the general mining sequence and mining rate in the November 2019 mine design for consistency. Care was taken to ensure the sequence would not result in any unfavourable geotechnical conditions such as undercutting, accessing through filled stopes or diminishing pillars. The mine sequence developed was provided to EMM and PGM prior to the model simulation being undertaken. The mine sequence used for this assessment is indicative, and the final mine design may vary somewhat from the one used for this assessment, based on further exploration data and market conditions. Any proposed variations to the mine sequence will remain within the limiting parameters used for this assessment. The model geometry is shown in Figure 2.7. Table 2.4 summarises the model sequence and model frames.

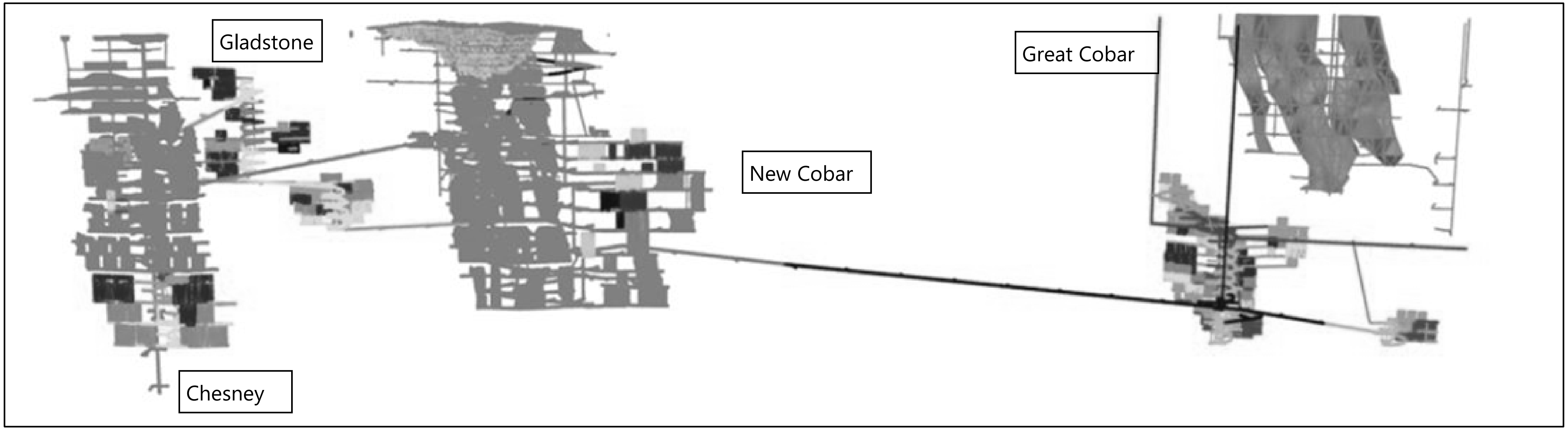


Figure 2.5: Long-section of the New Cobar Complex showing historic mining and planned future mining for the November 2019 LOM plan

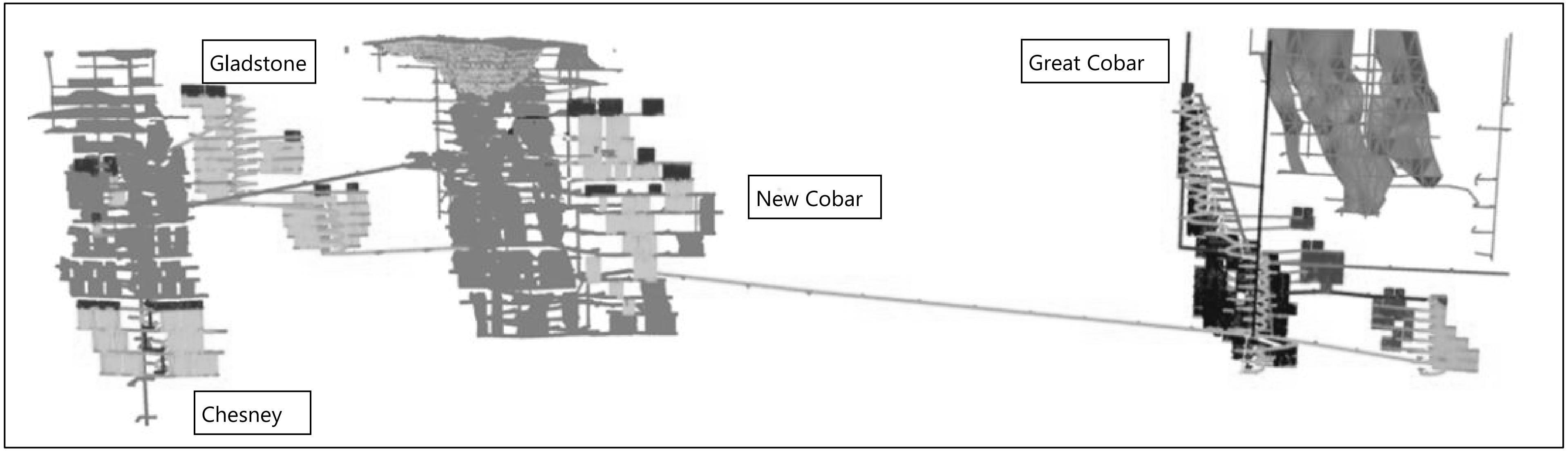


Figure 2.6: Long-section of the New Cobar Complex showing historic mining and planned future mining for the May 2019 LOM plan

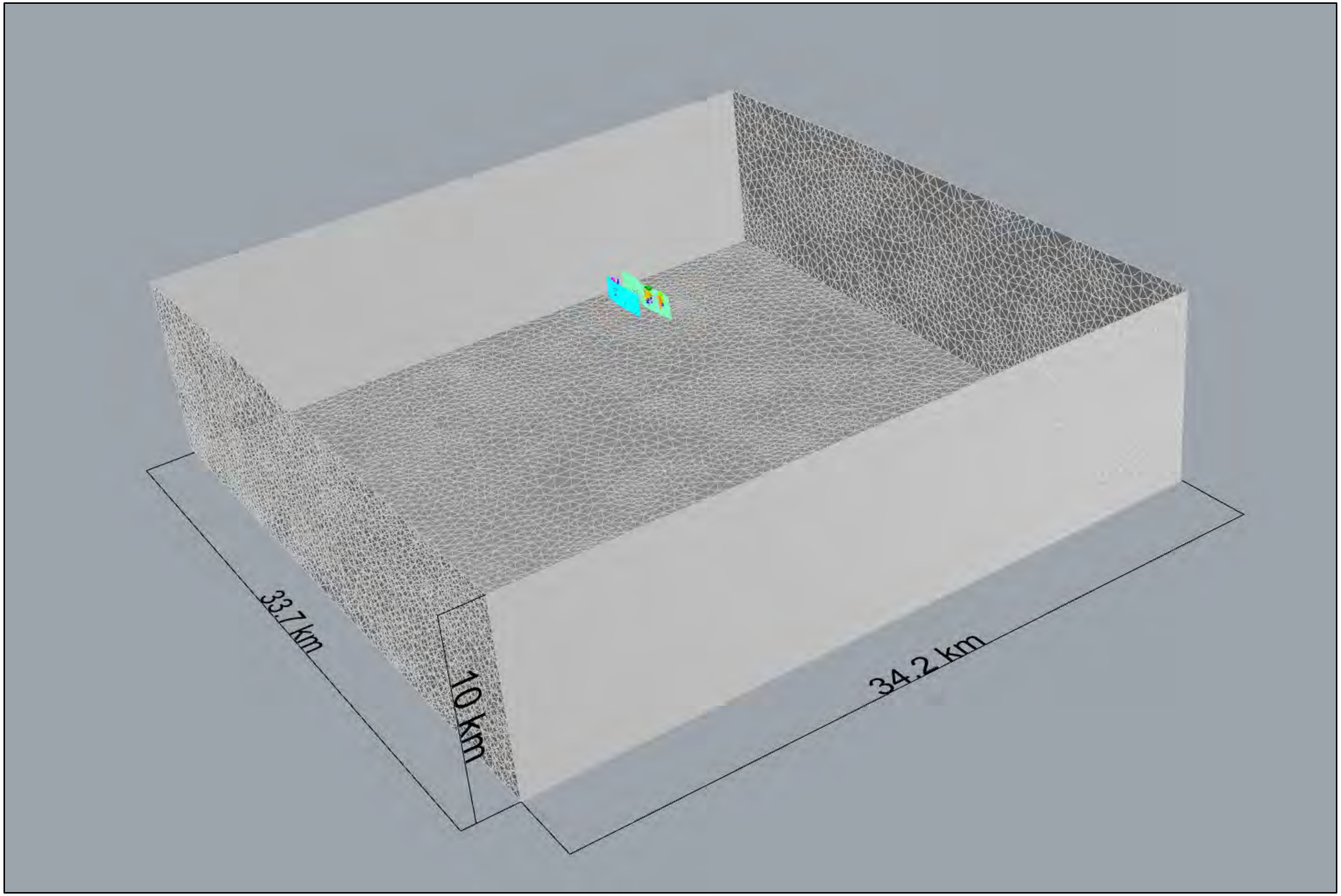


Figure 2.7. Model boundaries and dimensions

Table 2.4: Summary of model sequence Q01 with corresponding calendar dates and sequence milestones. Mining steps are called frames in the simulation workflow. F$\boldsymbol{x}$ denotes model frame $\boldsymbol{x}$.

Frame No.	Period		Frame No.	Period		Frame No.	Period
1	Historic mining		26	2019_Q4		51	2026_Q1
2	Historic mining		27	2020_Q1		52	2026_Q2
3	Historic mining		28	2020_Q2		53	2026_Q3
4	Historic mining		29	2020_Q3		54	2026_Q4
5	Historic mining		30	2020_Q4		55	2027_Q1
6	Historic mining		31	2021_Q1		56	2027_Q2
7	Historic mining		32	2021_Q2		57	2027_Q3
8	Historic mining		33	2021_Q3		58	2027_Q4
9	Historic mining		34	2021_Q4		59	2028_Q1
10	Historic mining		35	2022_Q1		60	2028_Q2
11	Historic mining		36	2022_Q2		61	2028_Q3
12	Historic mining		37	2022_Q3		62	2028_Q4
13	Historic mining		38	2022_Q4		63	2029_Q1
14	Historic mining		39	2023_Q1		64	2029_Q2
15	Historic mining		40	2023_Q2		65	2029_Q3
16	Historic mining		41	2023_Q3		66	2029_Q4
17	Historic mining		42	2023_Q4		67	2030_Q1
18	Historic mining		43	2024_Q1		68	2030_Q2
19	Historic mining		44	2024_Q2		69	2030_Q3
20	Historic mining		45	2024_Q3		70	2030_Q4
21	Historic mining		46	2024_Q4		71	2031_Q1
22	Historic mining		47	2025_Q1		72	2031_Q2
23	2019_Q1		48	2025_Q2		73	2031_Q3
24	2019_Q2		49	2025_Q3		74	2031_Q4
25	2019_Q3		50	2025_Q4		75	2032_Q1
						76	2032_Q2

2.7 Stope filling methodology & fill properties

In the model, stopes to be mined in frame i starting at time t_i are excavated over the period t_i to t_i + 0.1s by ramping down the Young's modulus from the rockmass value to the void value of 100 kPa. Stopes are filled at the end of the frame (at t_i + 3.0s) by setting the elastic constants of the stope void to fill properties. In practice, the mine could leave stopes open for longer than modelled and may not always achieve tight filling.

For this project, the following elastic constants were applied for fill:

- Young's modulus E_{fill} = 100 MPa.
- Poisson's ratio ν_{fill} = 0.25.

2.8 Structural resolution of model

The resolution of the available structural information allows mine-scale interpretations of the model results. This means that average strains across the rockmass between modelled structures can be simulated and interpreted, but local strains due to structures smaller than those modelled explicitly cannot develop in the model. To obtain forecasts of potential peak strains, which may be needed to assess the potential for locally high deformation levels around individual stopes for example, a model incorporating structures with persistence smaller than the scale of the stopes themselves would be needed.

With the current model, we therefore cannot forecast the stability of individual stopes, because stope stability forecasts depend largely on stope-scale structures. Likewise, we cannot forecast the stability of individual drives because such forecasts depend on drive-scale structures. The model does allow general interpretations of stope and drive stability based on, for example, forecast deformation arising from weaker rockmass conditions, adverse geometric configurations and sequences but explicit forecasts are not possible.

3 FORECASTS, INTERPRETATION & DISCUSSION

This section summarises:

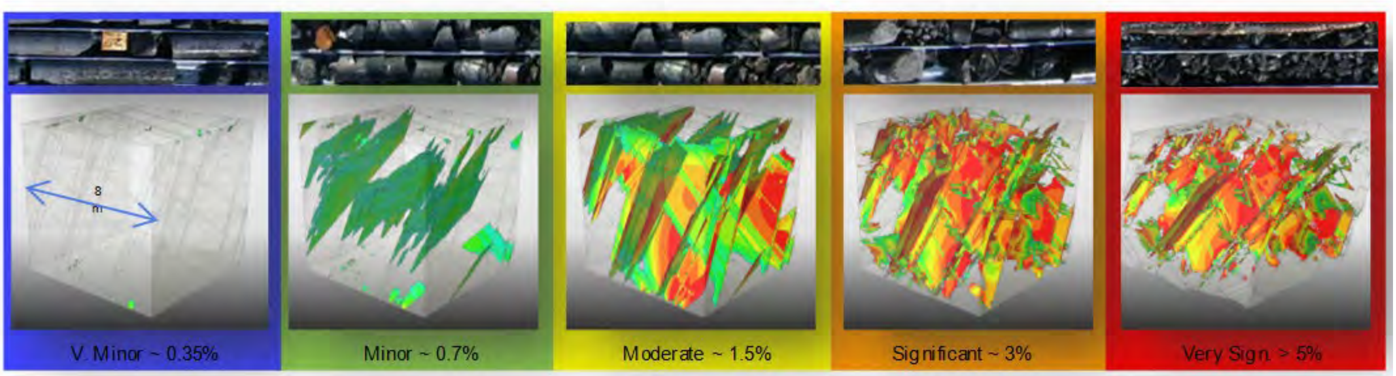
- The model results and our interpretation of the likely future behaviour of the New Cobar Complex, including subsidence forecasts.
- The results are presented according to the main mining phases associated with the underground mine.
- Stress, plastic strain (or rockmass damage) and general rockmass response for the New Cobar Complex.
- An interpretation of geotechnical challenges and vulnerabilities in the mining sequence and mine design.

The results are best reviewed and interpreted using 3D visualisation software such as VOXLER, so here we present a comparatively brief summary of the results and our interpretation of the expected behaviour, possible impacts on mining activities and possible risk mitigation measures.

Figure 3.1 shows BE's rockmass damage scale. Rockmass damage is plotted on a logarithmic scale called logP, where $\mathrm{logP} = \log_{10}(1000\epsilon_p + 1)$ and ϵ_p is the deviatoric equivalent plastic strain. This damage allows a wide range of plastic strain magnitudes to be plotted with a convenient linear colour scale. The damage scale in terms of stress and strain is shown in Figure 3.2. Damage levels in development are well defined by Sandy et al. (2010). In open stopes:

1. Minor rockmass damage indicates a low likelihood of instability.
2. Moderate rockmass damage indicates an increased likelihood of instability, particularly in hangingwalls and crowns.
3. Significant rockmass damage is characterised by relatively high frequency of instability, leading to reduced recovery and productivity and higher dilution and costs.
4. Very significant rockmass damage is characterised by severe stability problems for open stopes and usually necessitates other mining methods.

It is essential to note that these damage categories are indicative only because persistent structures strongly influence the stability of open stopes.



logP ≈ 0.65 | logP ≈ 0.90 | logP ≈ 1.2 | logP ≈ 1.5 | logP > 1.7

Figure 3.1. Rockmass damage scale.

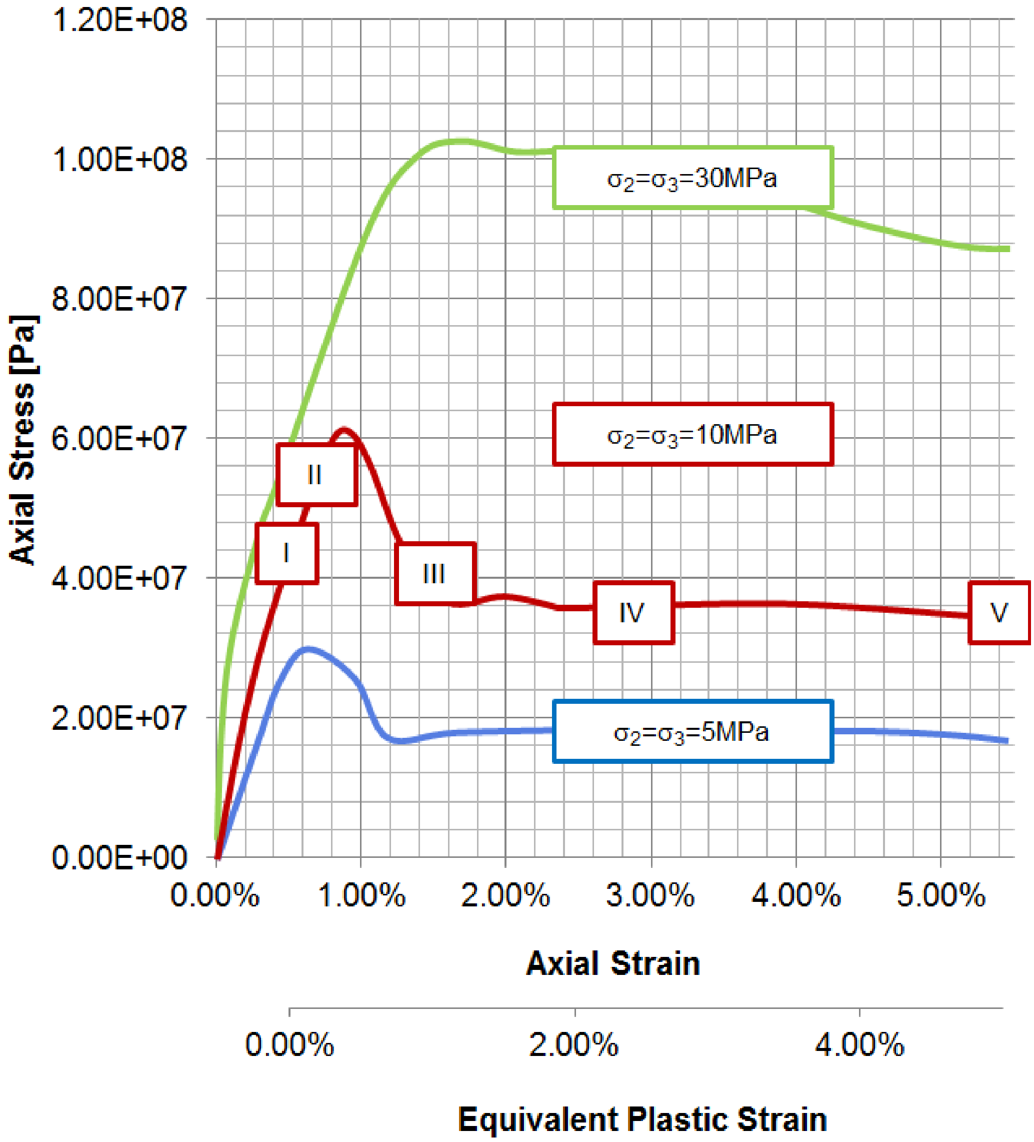


Figure 3.2. Stress vs strain chart showing corresponding rockmass damage levels

3.1 General description of forecast rockmass behaviour

Assessment of model forecasts for subsidence, stability and mine deformation are provided in this section of the report.

3.1.1 Subsidence

Model forecasts for surface subsidence are minimal. Forecasts for vertical and total displacement are less than 10-15mm and are considered negligible. Subsidence less than 50mm is considered negligible. We note that this level of deformation is less than the levels of precision of a mine scale model.

The forecast levels of surface deformation are expected due to:

- Small footprint of future underground mining.
- Depth of underground mining is generally 200m or more below surface. There are a small number of stopes between depths of 100m and 200m.
- Relatively strong rockmass conditions.
- Small (narrow) stopes with a small footprint.
- Low extraction ratio (compared to other larger stoping mines).
- Use of backfill.

The location of the mines relative to the surface landforms is provided in Figure 3.3. Subsidence forecasts at the end of planned mining are provided in Figure 3.4 and Figure 3.5. High resolution subsidence plots are provided in Figure 3.6 to Figure 3.8. This includes forecast displacements of the pit walls in the New Cobar open cut. Forecast displacement of up to 50-60mm is forecast in isolated sections of pit crests. These sections of the pit crest have likely broken off during blasting and no longer exist. No significant displacement indicating multi-bench or wall scale instability is forecast. Forecasts for small scale (i.e. bench scale) instability are beyond the resolution of the mine scale model and the geotechnical detail available for this assessment.

Cross sections showing total displacement, including surface deformation and closure in proximity to future stopes during mining for each underground mine are provided in Figure 3.9 to Figure 3.13. The majority of future displacement due to planned underground mining is horizontal closure as stopes are mined. The forecast displacements are low and normal for stoping in moderate to strong rock at the planned mining depths at the New Cobar Complex.

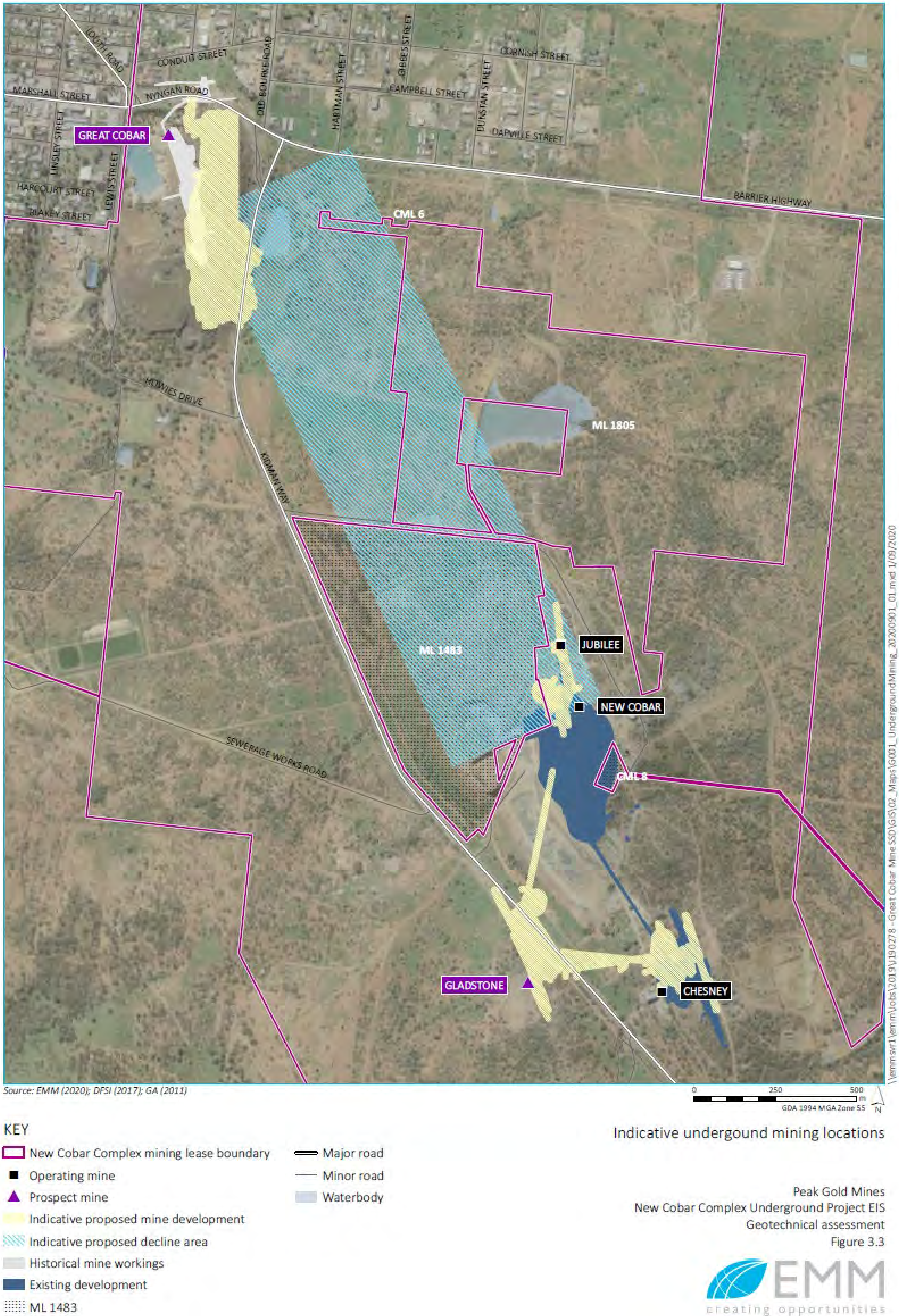


Figure 3.3: Aerial view showing the indicative New Cobar Complex geometry

Figure 3.4. Plan view showing forecast vertical displacement at the end of mine life

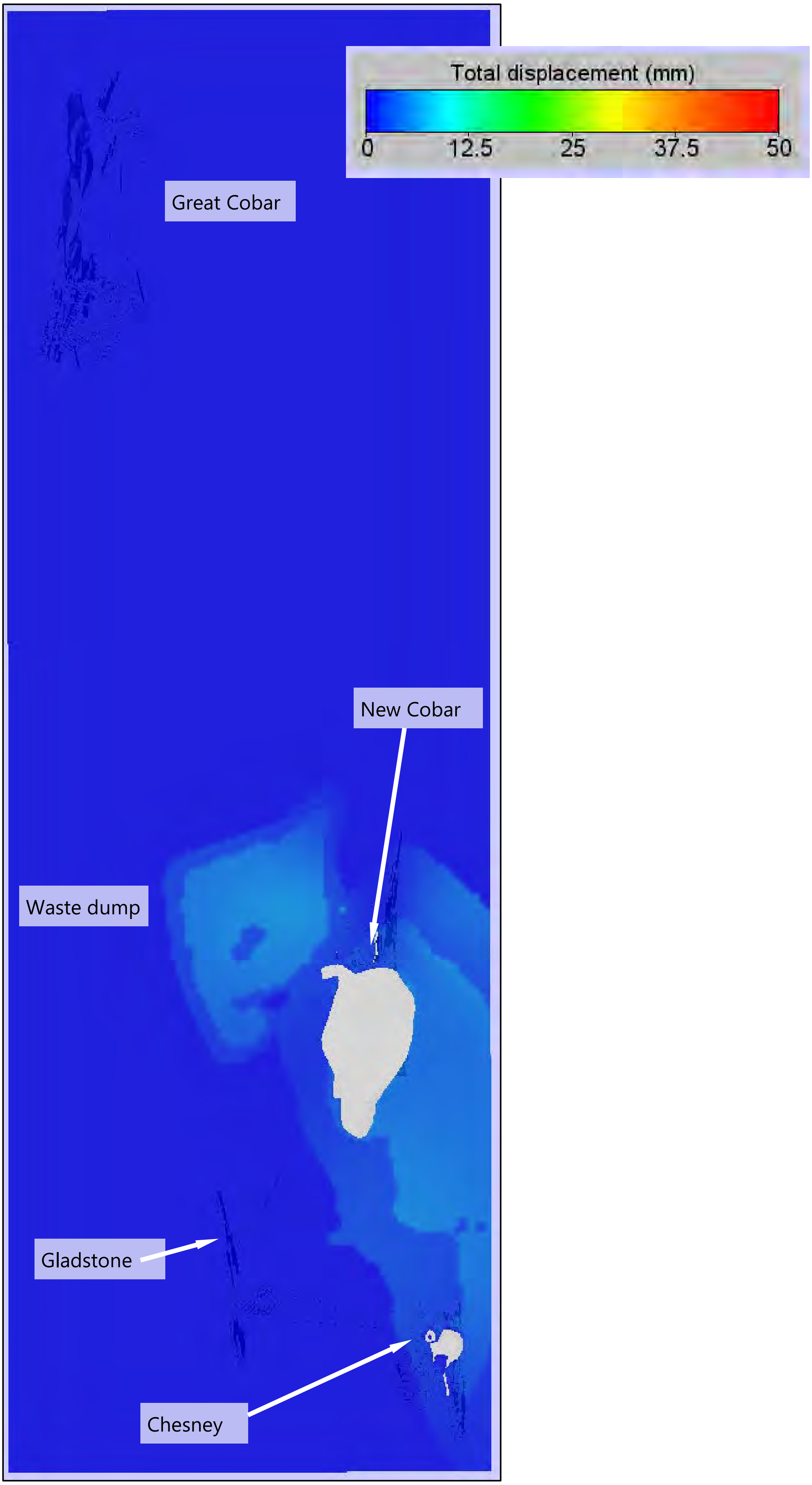


Figure 3.5. Plan view showing forecast total displacement (horizontal and vertical) at the end of mine life

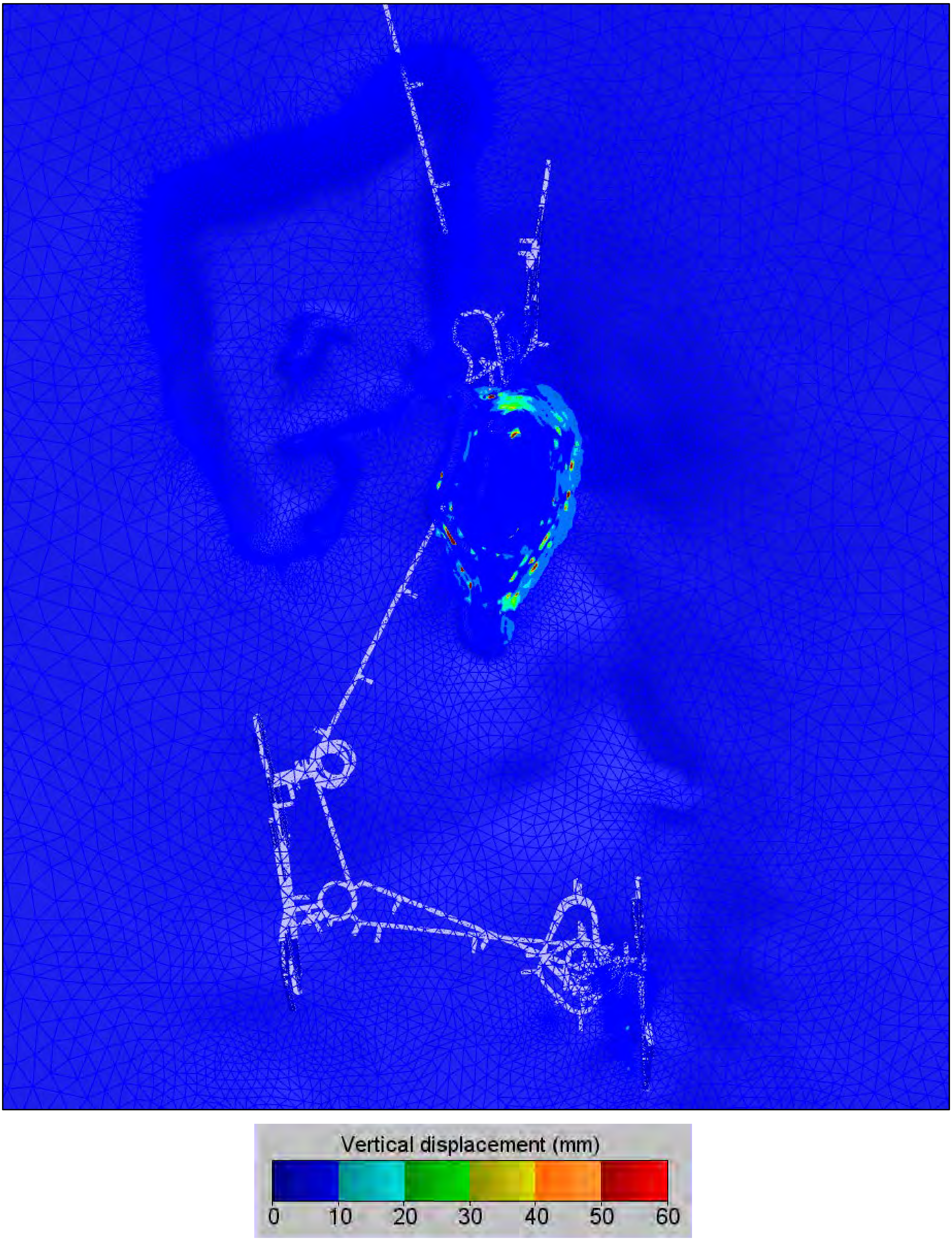


Figure 3.6. Plan view showing vertical displacement on surface (high resolution) above New Cobar, Chesney and Gladstone.

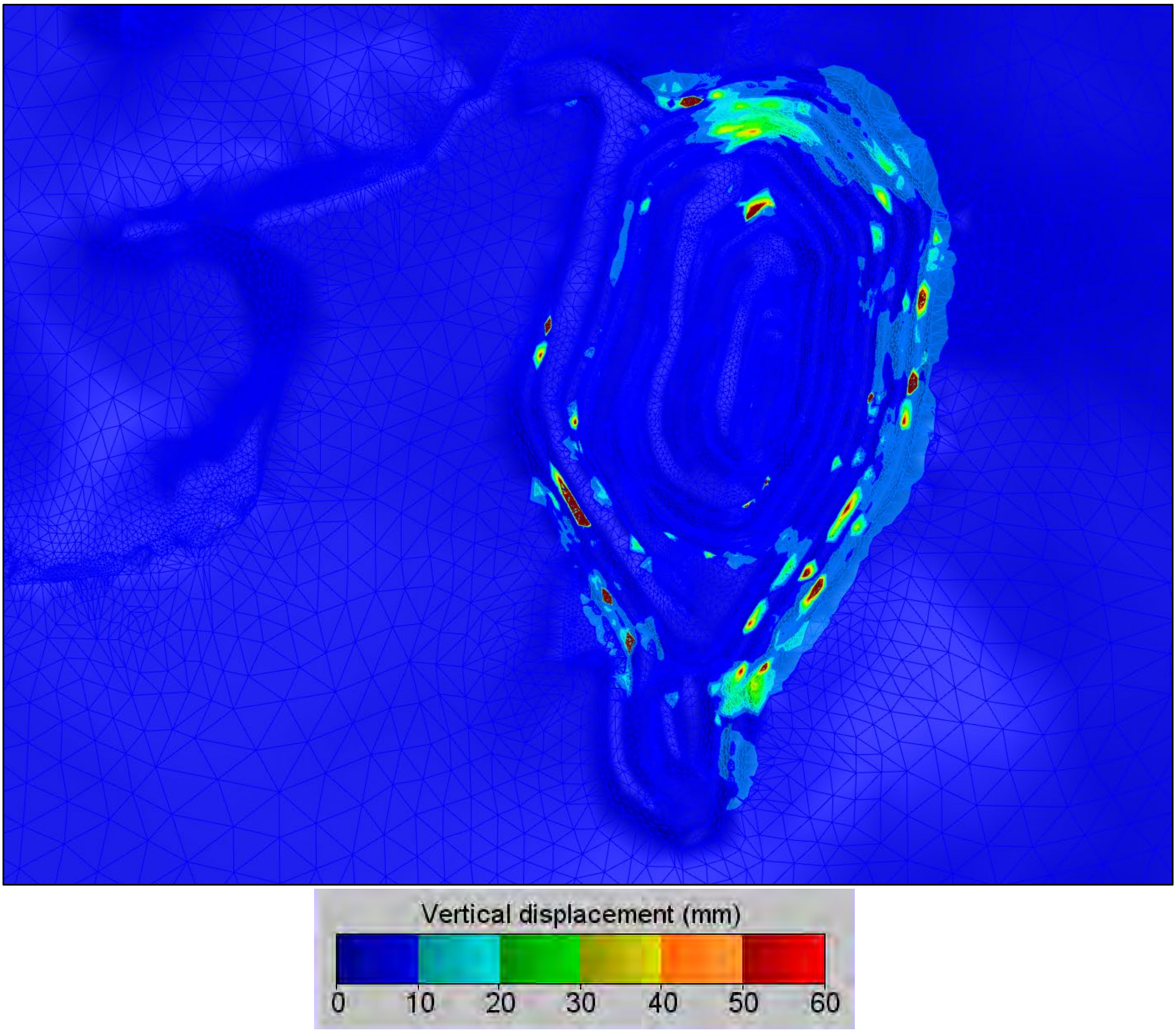


Figure 3.7. Plan view showing vertical displacement (high resolution) in the New Cobar open cut.

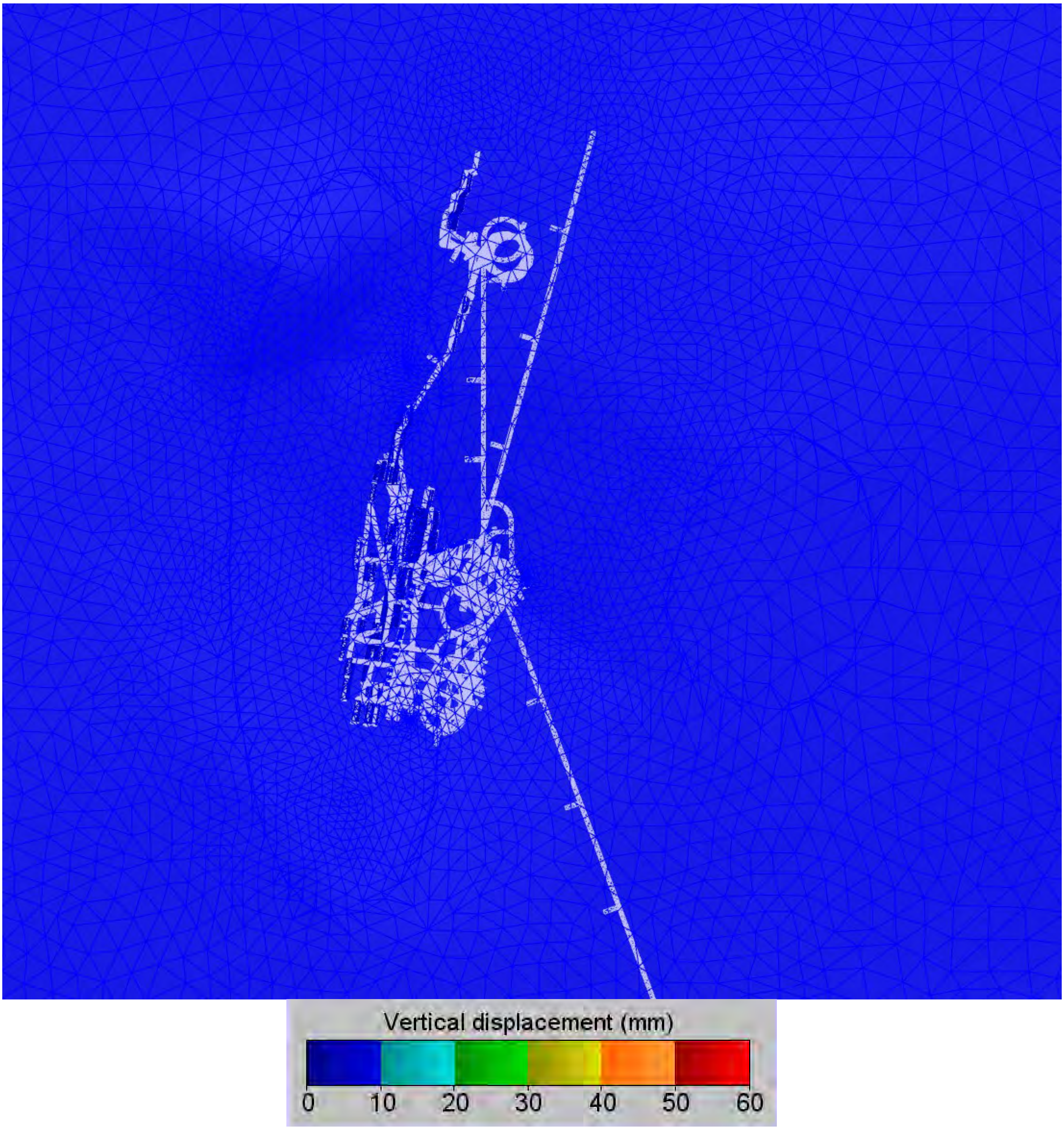


Figure 3.8. Plan view showing vertical displacement on surface (high resolution) above Great Cobar. No displacement is above 10mm.

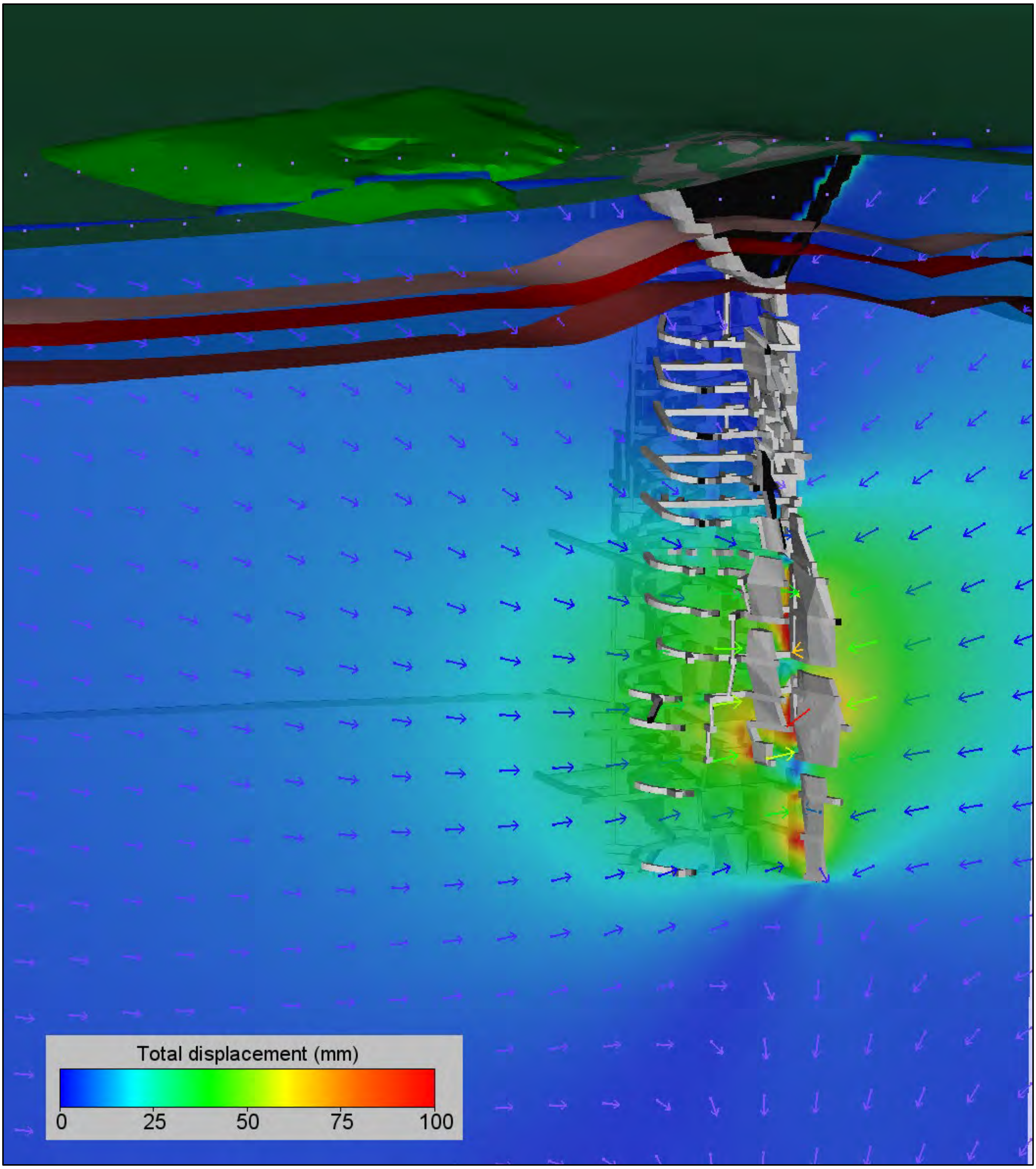


Figure 3.9. Cross section through the New Cobar mine showing total displacement from future proposed mining (facing North)

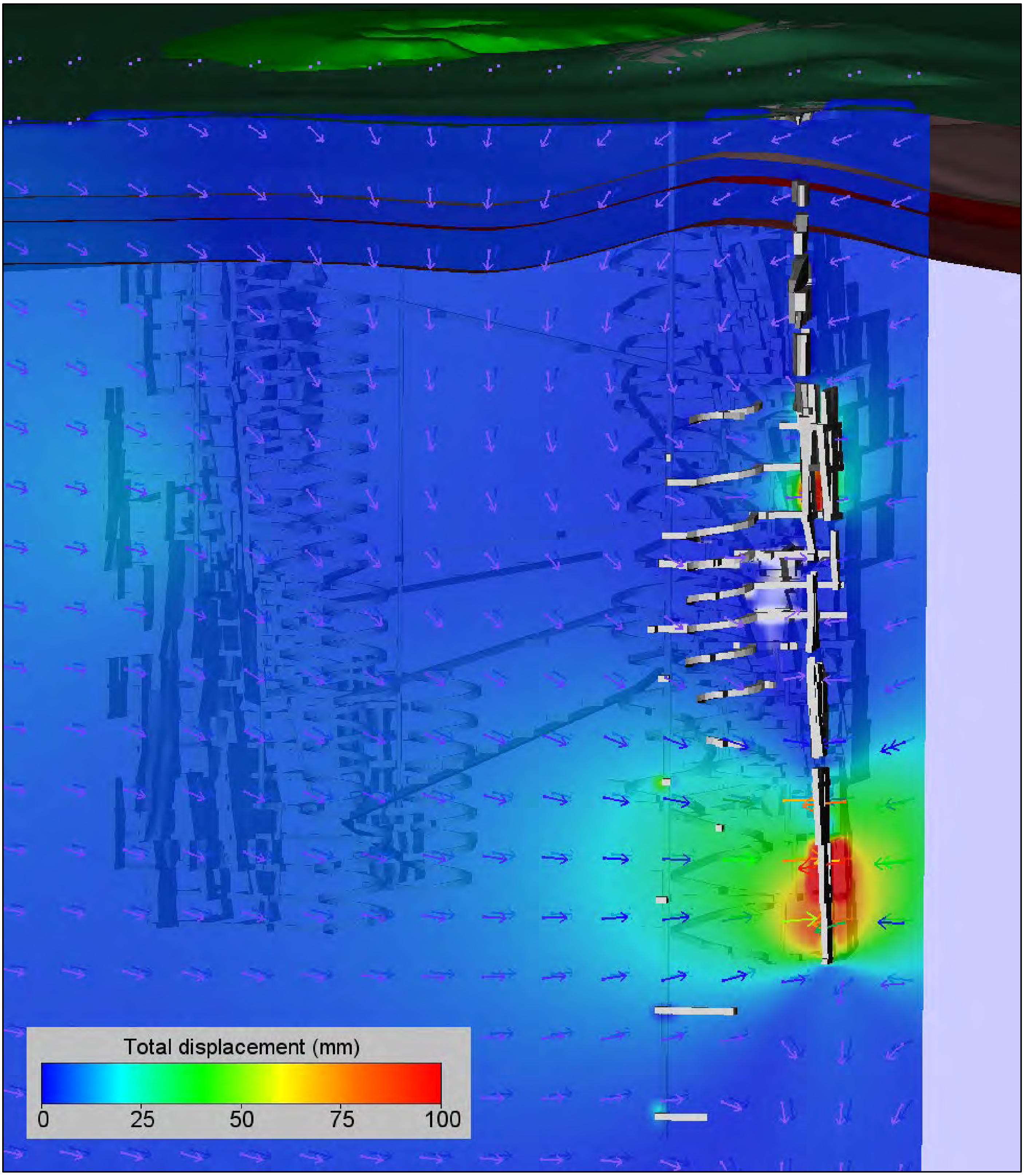


Figure 3.10. Cross section through the Chesney mine showing total displacement from future proposed mining (facing North)

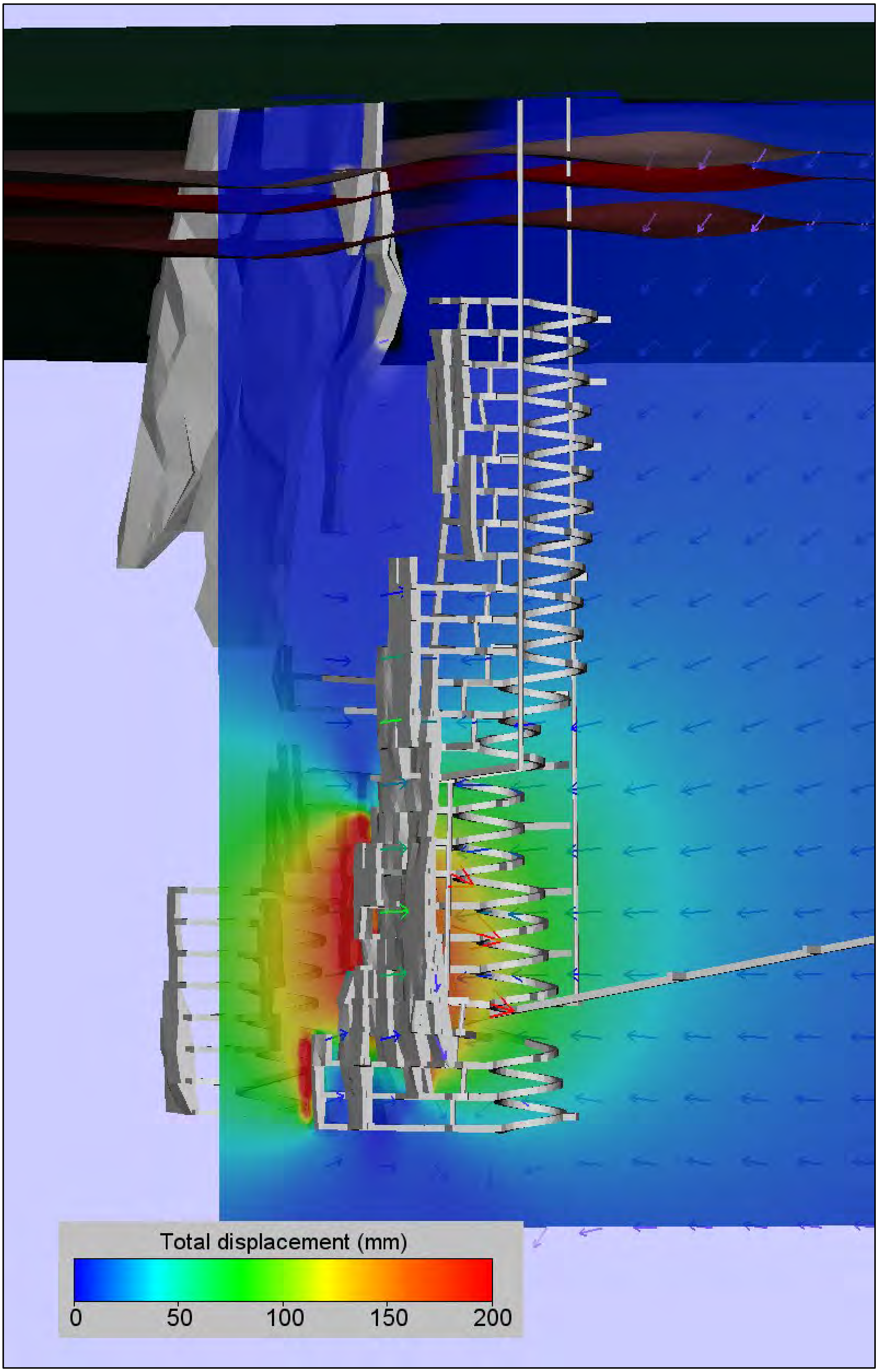


Figure 3.11. Cross section through the Great Cobar mine showing total displacement from future proposed mining (facing North)

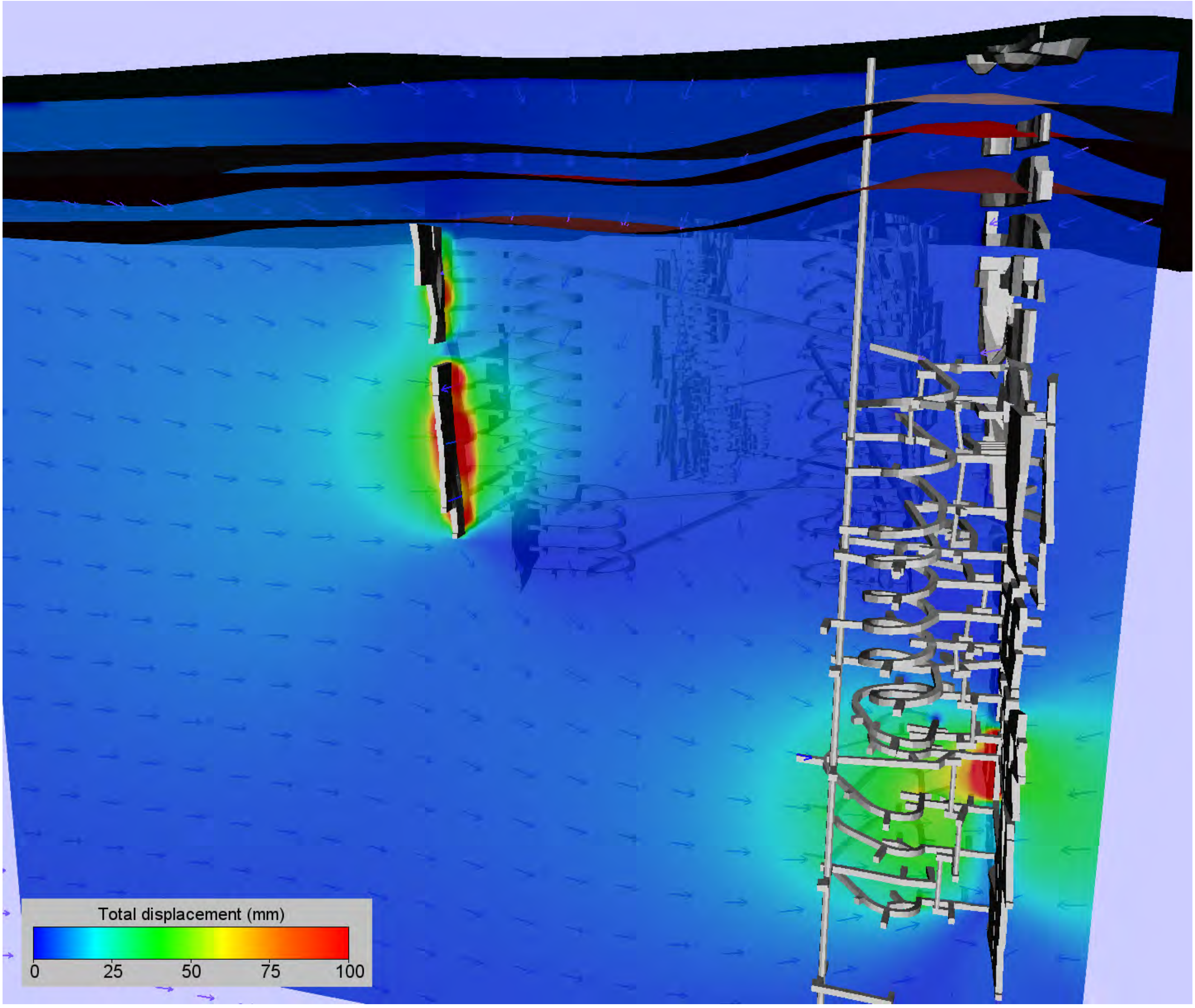


Figure 3.12. Cross section through the Gladstone mine showing total displacement from future proposed mining (facing North)

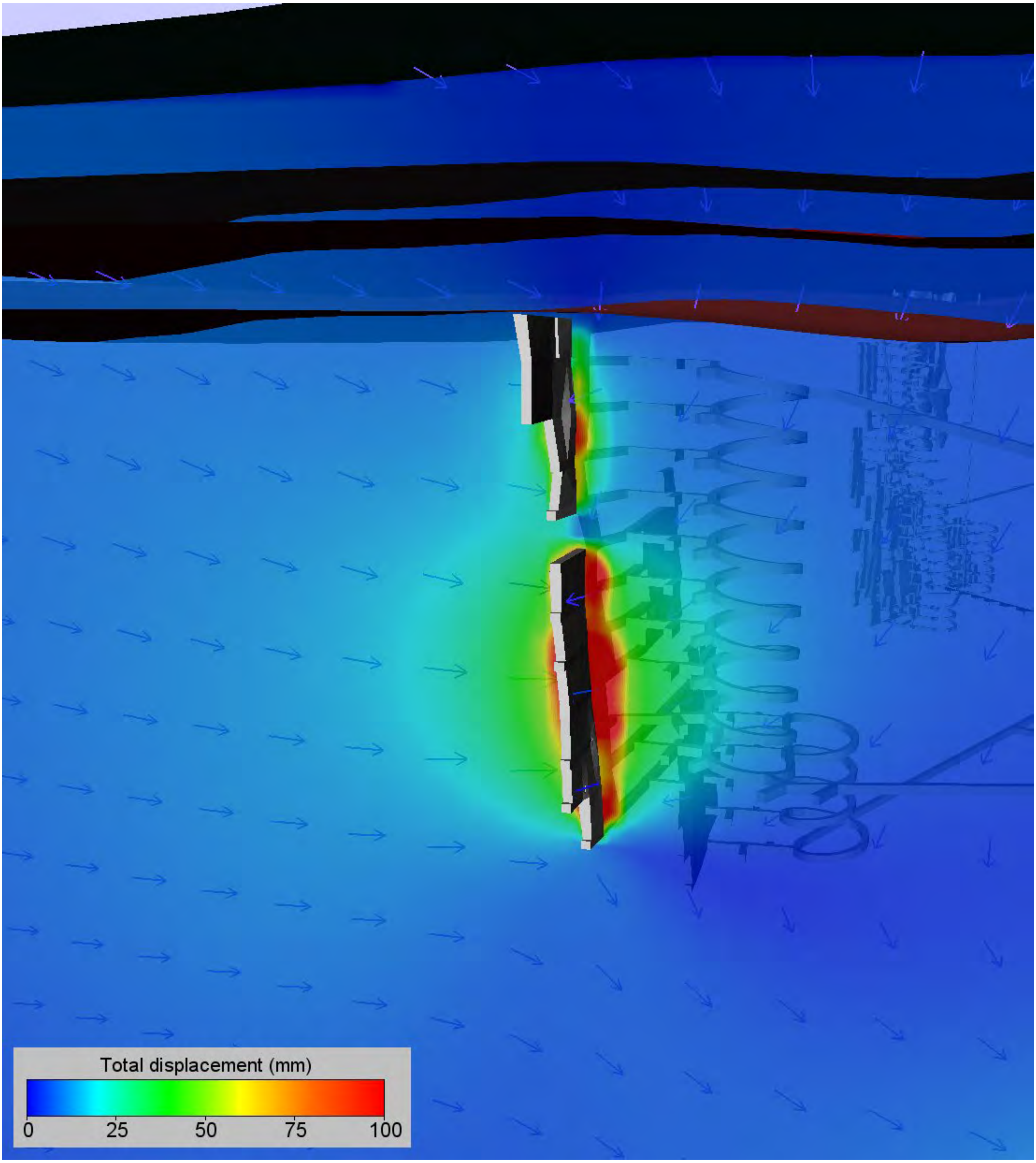


Figure 3.13. Cross section through the Gladstone mine showing total displacement from future proposed mining (facing North)

3.1.2 Stability and deformation

Forecasts for stress, deformation and mine stability are provided in this section of the report.

New Cobar

The model forecasts for New Cobar include:

- Stress concentration up to 60 MPa in pillars and stress abutments near proposed stoping (see Figure 3.14 and Figure 3.15).
- Minor to moderate levels of rockmass damage is forecast in proximity to stopes. Moderate level of rockmass damage with potential for increased levels of stope overbreak is forecast along the Great Chesney fault which bounds the hangingwall of some planned stopes. Rockmass damage forecasts in long term access drives and the declines is low. Diagrams illustrating the rockmass damage forecasts are provided in Figure 3.16 to Figure 3.19.
- The upper most level of planned stopes at New Cobar intersect the oxidised rockmass layers as shown in Figure 3.20. The oxidised (or weathered) rockmass layers are weaker than the fresh rock domains and stopes are more susceptible to overbreak or failure, including chimney failure. We note the model does not forecast high levels of rockmass damage above these stopes. However, unravelling, chimney type failure of small spans and time-dependant instability are difficult to forecast in a mine scale model.
- Planned underground mining is not in proximity to the New Cobar open cut and there is no significant stress interaction and minimal subsidence in the vicinity of the open cut. Proposed underground mining does not result in instability in the open cut in the model forecasts.

It is generally advised not to mine stopes in or close to weak cover layers such as the oxidised zone at New Cobar due to the potential for stope chimneying. We note that stopes at other mines have chimneyed along faults and through the weak cover units to surface. Although the likelihood is low, these stopes have the potential to chimney to surface. The mine should undertake a detailed geotechnical assessment during the stope design stage, prior to mining these stopes. We also recommend:

- o Crown pillar stability assessment.
- o Confirmation of the top of fresh rock boundary.
- o Backfilling of the stopes. We note these stopes in the current design are up-hole stopes, which makes tight filling from underground difficult. Downhole drilling from surface for backfilling with cemented hydraulic fill may be considered.

Great Cobar

The model forecasts for Great Cobar include:

- Stress concentration up to 60 MPa in pillars and in the abutments (see Figure 3.21).
- Similar to forecasts for New Cobar, minor to moderate levels of rockmass damage are forecast in proximity to stopes. Moderate level of rockmass damage with potential for increased levels of stope overbreak is forecast along the Great Cobar fault which bounds the hangingwall of some planned stopes. Rockmass damage forecasts in long term access drives and the declines is low. Diagrams illustrating the rockmass damage forecasts are provided in Figure 3.22 to Figure 3.24.
- No significant rockmass damage is forecast in the level accesses or decline.
- The bottom-up mining sequence has a central access for some stoping levels. We note that stopes that form diminishing pillars are subject to stress concentration and higher potential for stope instability and overbreak. Examples at Great Cobar are shown in Figure 3.25 and Figure 3.26. An example of a stope in a close-out pillar at a mine in similar conditions is provided in Figure 3.27 to Figure 3.29.

- Stopes in the close out pillars should be considered “higher” risk tonnes in terms of recovery and dilution. We note:
  - Disciplined mining with careful geotechnical controls and monitoring should be adopted to maximise recovery.
  - The schedule should be adjusted to reflect more difficult mining conditions, reduced productivity for the final stope on each level (i.e. the diminishing pillar).
  - The mine should consider adjusting the stope strike length so the final stope is smaller and less susceptible to overbreak and dilution.

Overcut drives in bottom-up sequences are susceptible to damage and undercutting from stope instability. This impacts re-accessing the overcut drive for the next stope above in the mining sequence. This is a problem in some bottom-up stoping mines where stope instability is frequent. The mine will need to manage hangingwall overbreak through means such as appropriate stope sizing using geotechnical assessment of local ground conditions, timely filling of nearby stopes, ground support and careful drill and blast.

Gladstone

The model forecasts for the Gladstone mine include:

- Stress concentration in the abutments up to ~50 MPa (Figure 3.30). Low stress occurs in stope hangingwalls and footwalls due to progressive mining and stress shadowing.
- Minor to moderate levels of rockmass damage is forecast in proximity to stopes. The potential for overbreak will be governed by stope scale structures which are not yet identified, however there is potential for minor to moderate levels of overbreak.
- No significant rockmass damage is forecast in the level accesses or decline.
- Stopes on the upper most level are in close proximity to the zone of oxidation (see Figure 3.32). These stopes have a crown pillar thickness of approximately 4 to 5m. The stope width is approximately 5m wide. A minimum crown pillar thickness to height ratio of 2:1 is generally recommended. The mine should confirm top of fresh rock boundary and crown pillar thickness required for stability when more detailed geotechnical information is available.
- Historic mining at Chesney and New Cobar demonstrates that stopes in the weathered layers have been mined successfully without significant overbreak or chimneying to surface. However, historic underground stoping in the oxidised zone was most likely undertaken using cut and fill methods and not open stoping as planned.
- The two stopes closest to the top of fresh rock are short up hole stopes. As these stopes are up-hole stopes, backfilling of the stopes is not possible with rockfill. We note that the potential for long term instability of these stopes is low, however we recommend backfilling of these stopes be considered by either:
  - Developing an overcut drive and rock filling the stopes, including pushing up as much rockfill into the stopes as possible to minimise the unfilled void in the stope.
  - Backfill with cemented hydraulic fill or some other form of cemented fill via up-holes drilled from the access underground.
  - Backfill with cemented hydraulic fill or some other form of cemented fill via down-holes from the surface.
- We also recommend:
  - Crown pillar stability assessment during the detailed stone design phase.
  - Confirmation of the top of fresh rock boundary prior to mining the stopes.
  - The mine should undertake a thorough risk assessment prior to mining of these stopes and consider not mining these stopes at all or reducing the height of the stopes to allow for a larger crown pillar to be left in place.

Chesney

The model forecasts for the Chesney mine include:

- Stress concentration in pillars sufficiently high to cause failure of the rib pillars between the planned future stopes (see Figure 3.34 and Figure 3.35).
- Moderate levels of stress and minor levels of rockmass damage in the sill pillars between the historic stopes and planned stopes as shown in Figure 3.35 and Figure 3.36. A comparison between rib pillar dimensions in old and future stoping blocks is shown in Figure 3.37. It is recommended the rib pillar dimensions be reviewed once more detailed geotechnical information becomes available. This assessment should be conducted as part of the stope design assessment.
- Moderate level of rockmass damage with potential for increased levels of stope overbreak is forecast along the Great Chesney fault which bounds the hangingwall of the planned stopes (see Figure 3.35).
- Rockmass damage forecasts in long term access drives and the declines is low.
- The planned bottom up sequence with rockfill causes a diminishing pillar sill pillar. The sill pillar is forecast to remain stable, however the concentration of stress may result in minor seismicity as the pillar is loaded. We do not expect the levels of seismicity to be damaging given the relatively benign history of mining and limited rocknoise reporting in the information provided in previous geotechnical assessments.

3.1.3 Ground support recommendations

Feedback on ground support is a requirement of the SEARs. We note there is a long history of underground mining at some of the underground operations at the New Cobar Complex and well established ground support practices. General ground support recommendations for mines operating in the conditions of the New Cobar Complex would include:

- Resin bolts with fibrecrete or weld mesh for long term accesses.
- Friction bolts (or resin bolts) with fibrecrete or weld mesh for short term accesses.
- Cablebolting of all intersections, wide spans and stope brows, including temporary brows.
- Some stope hangingwalls may require cablebolting pending local ground conditions. Stope crowns below sill pillars may also warrant cablebolting to reinforce the sill pillar and prevent potential unravelling of the sill pillar as this could result in significant dilution from rockfill in the previously mined stopes above.
- Dynamic ground support would generally not be required as damaging levels of seismicity would not be expected at the mining depths of the New Cobar Complex.

The site Ground Control Management Plan (GCMP) includes ground condition monitoring and a QA/QC programme. This programme includes the following considerations:

- Geotechnical mapping and inspections to confirm ground conditions match expect conditions and those used in the basis of the ground support design.
- Observation of ground support installation, and QA/QC such as pull testing of bolts, shotcrete thickness and strength testing and grouting practises for cablebolt installation.
- Damage mapping and monitoring of ground support performance.
- Monitoring of support corrosion and rehabilitation where required.

All areas of the existing mine that planned to be accessed for the proposed mine expansion should be inspected by site Geotechnical Engineers to identify potential ground control hazards. All areas requiring additional support or rehabilitation would then form part of the mine plan for continued underground mining.

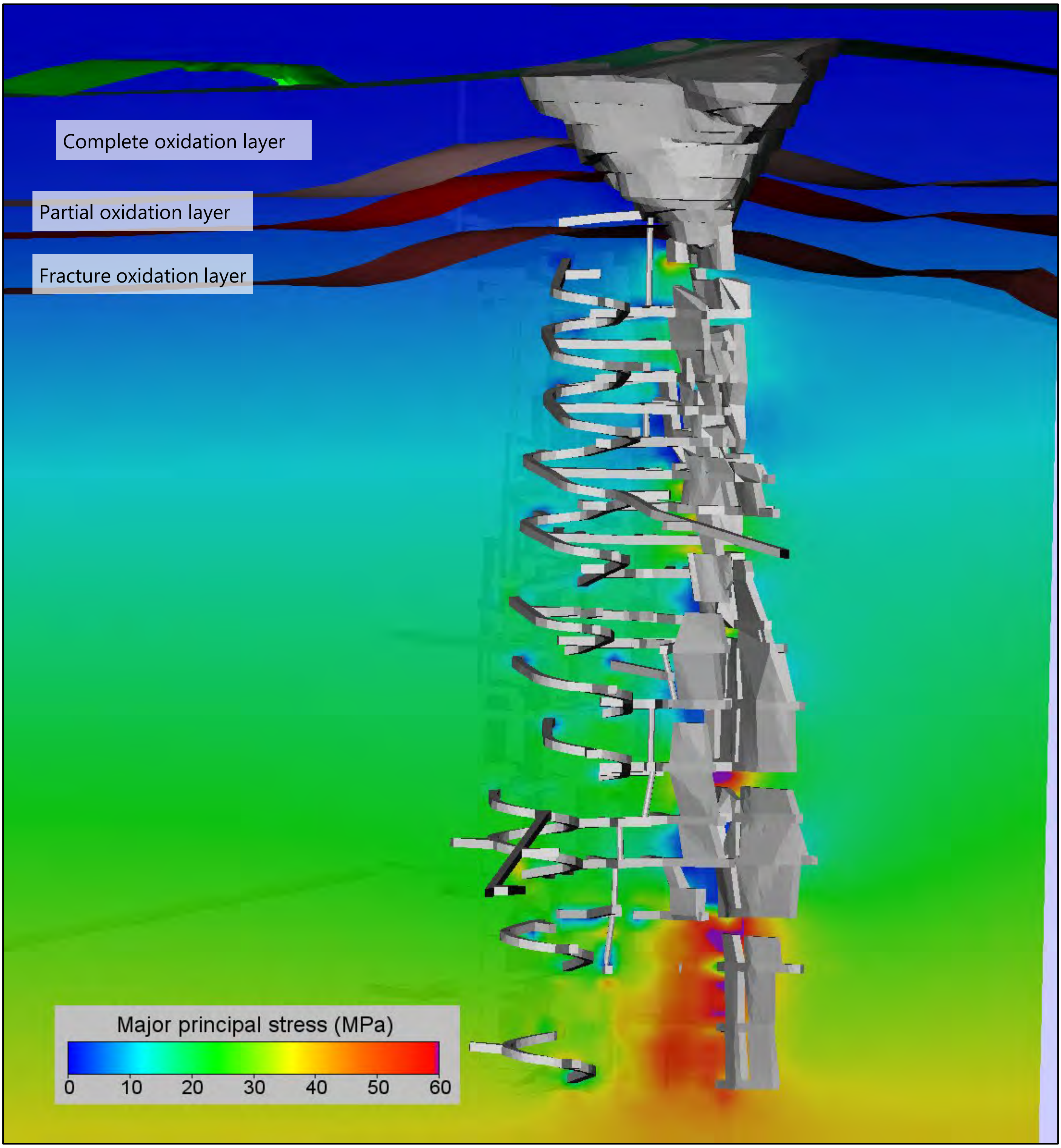


Figure 3.14. Cross section through the New Cobar mine showing major principal stress at the end of mining (facing North)

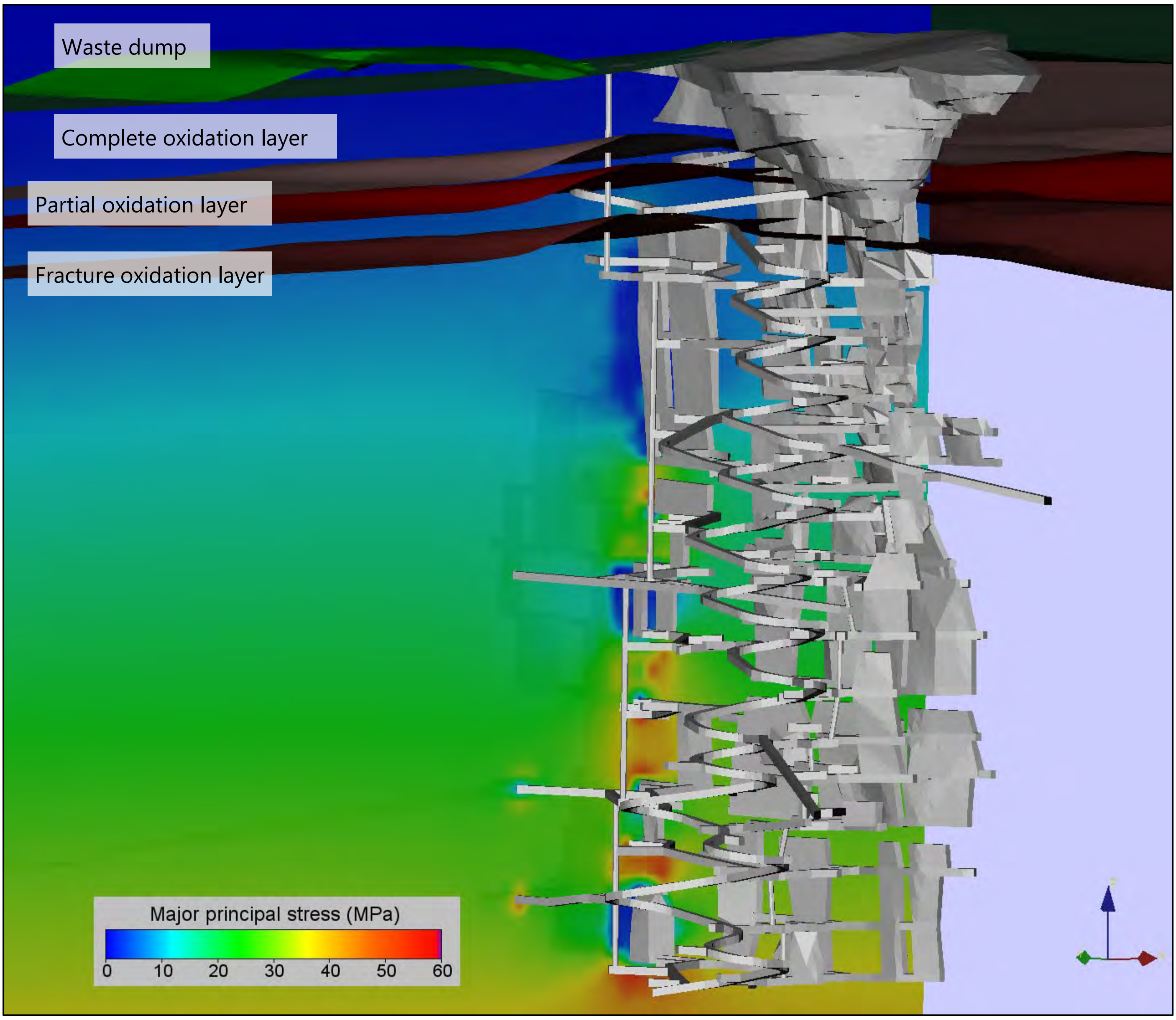


Figure 3.15. Cross section through the New Cobar mine showing major principal stress at the end of mining (facing North East)

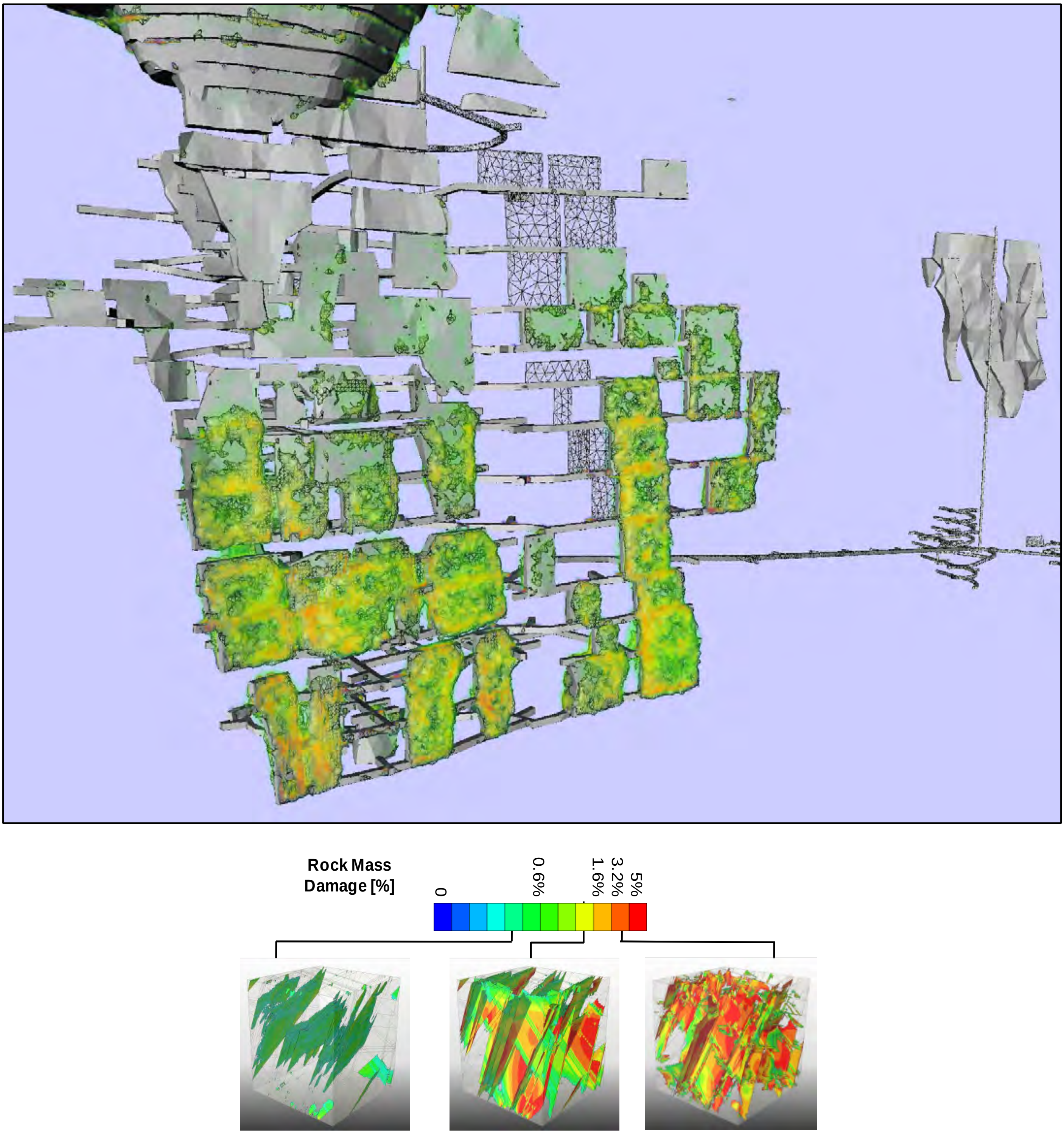


Figure 3.16. Forecast rockmass damage at the New Cobar mine in 2021, approximately half-way through future stoping. Future unmined stopes shown as wireframes (facing North West)

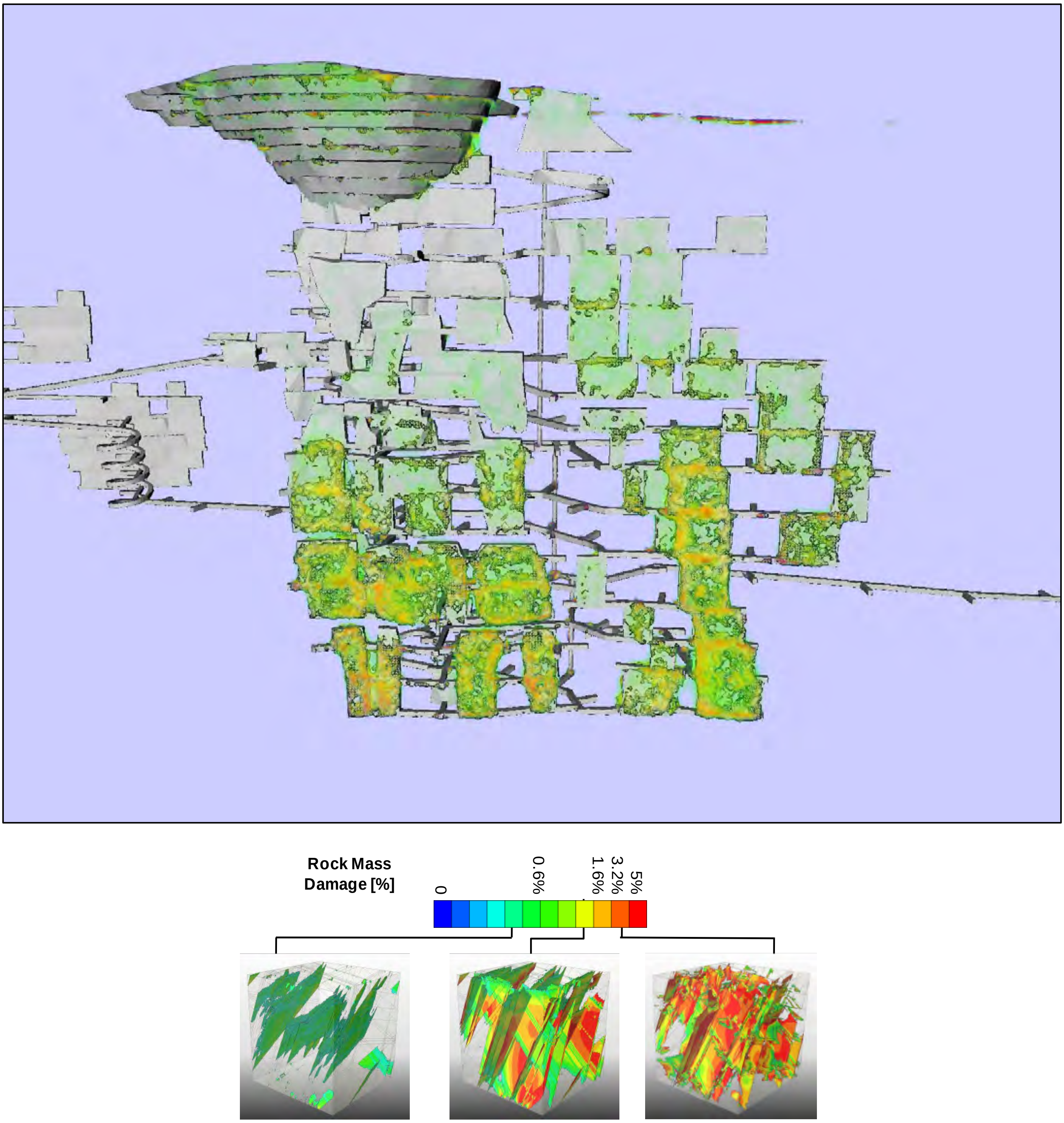


Figure 3.17. Forecast rockmass damage at the New Cobar mine at the end of mining (facing West)

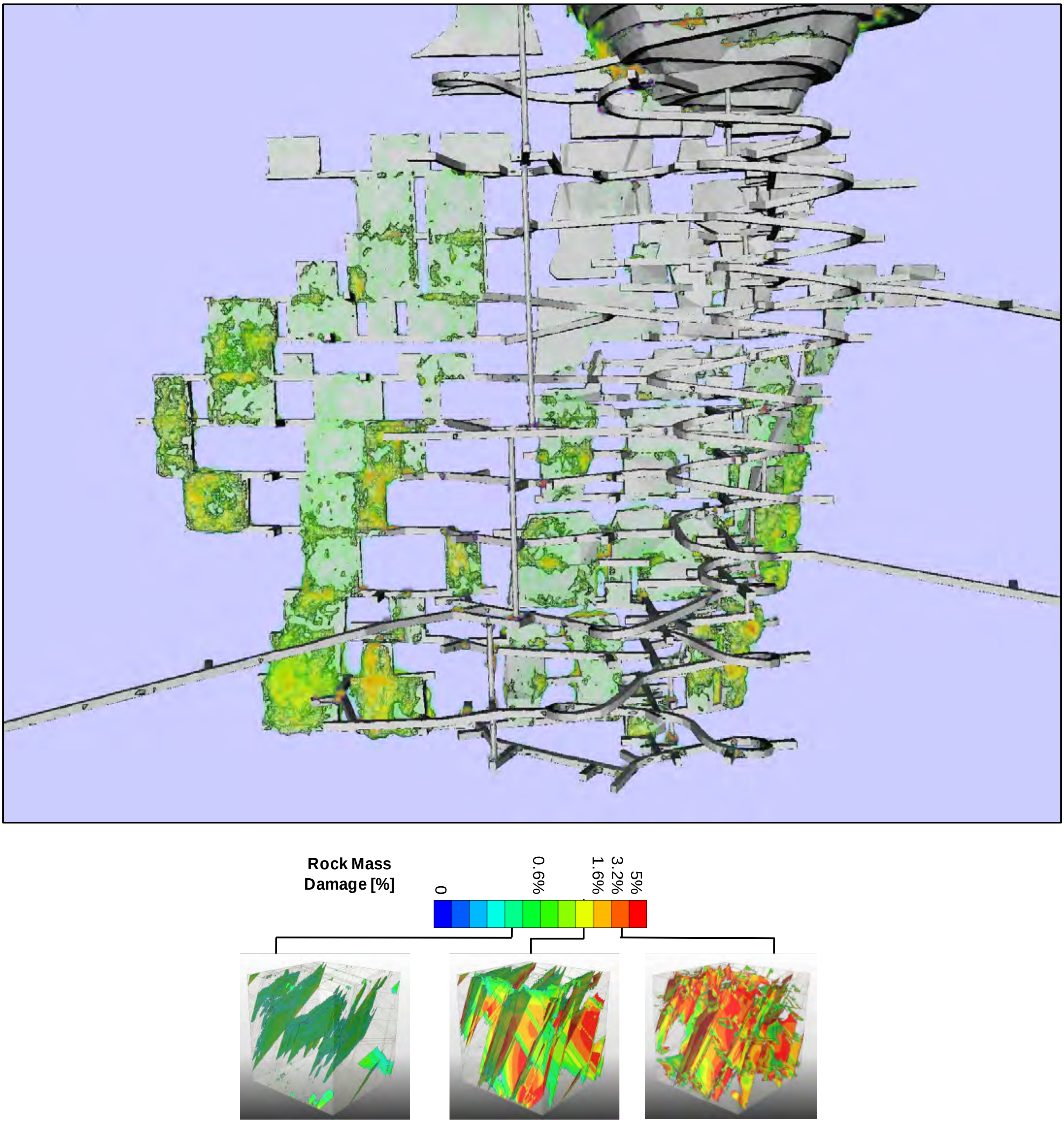


Figure 3.18. Forecast rockmass damage at the New Cobar mine at the end of mining (facing East)

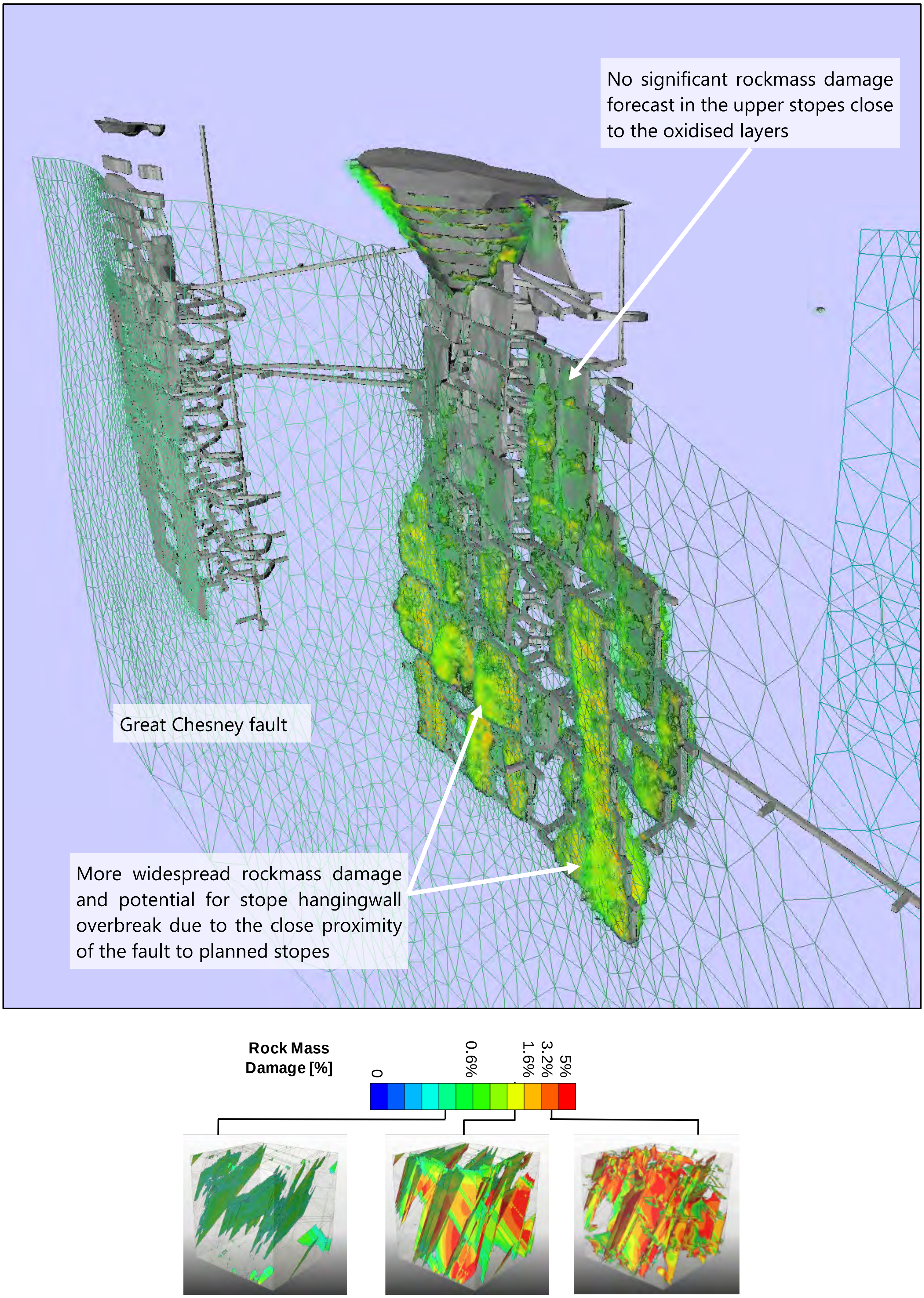


Figure 3.19. Forecast rockmass damage at the New Cobar mine at the end of mining showing the Great Chesney fault (facing South West)

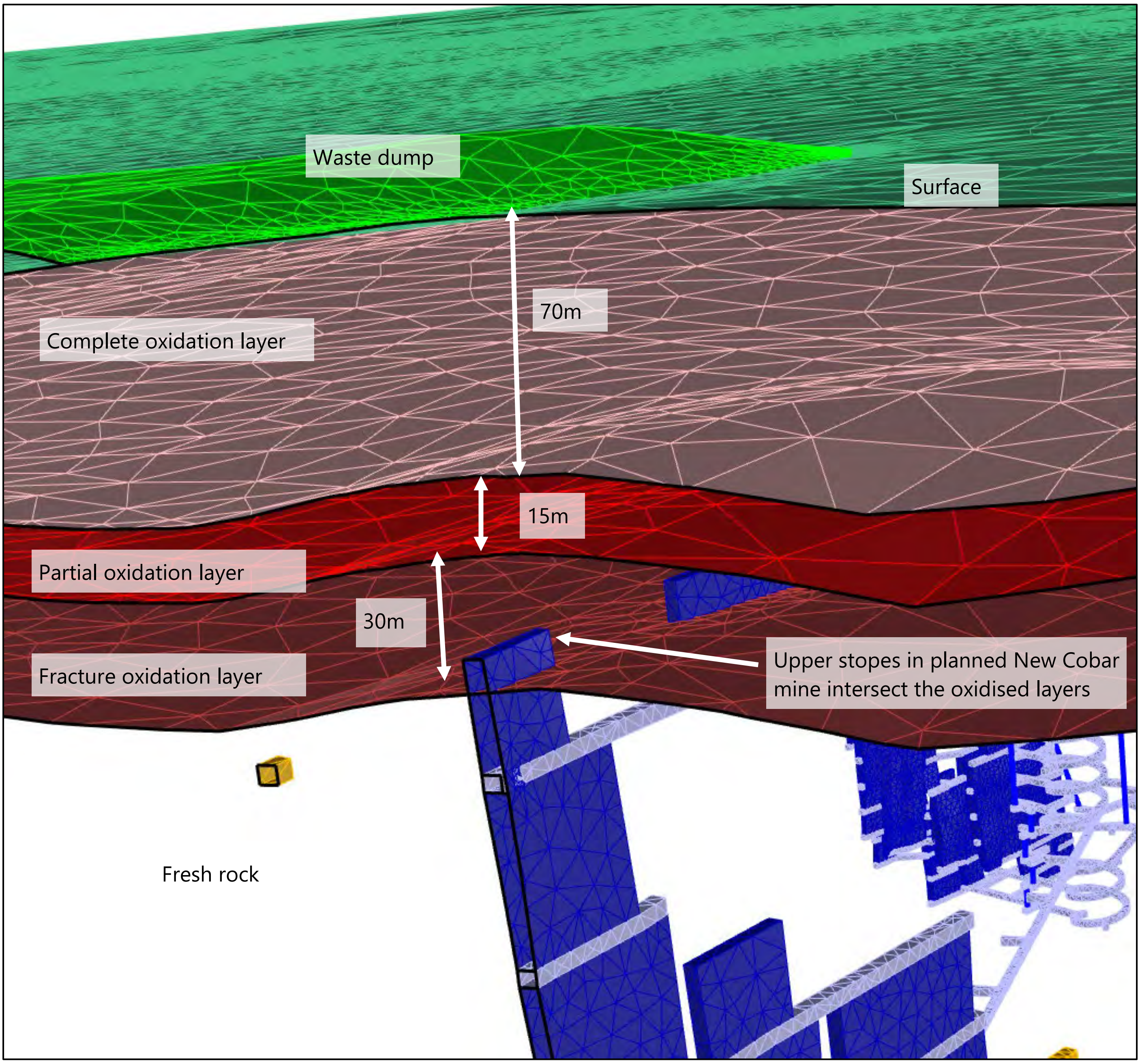


Figure 3.20. Cross section through the New Cobar mine showing planned stopes intersecting the oxidized layers (facing North West)

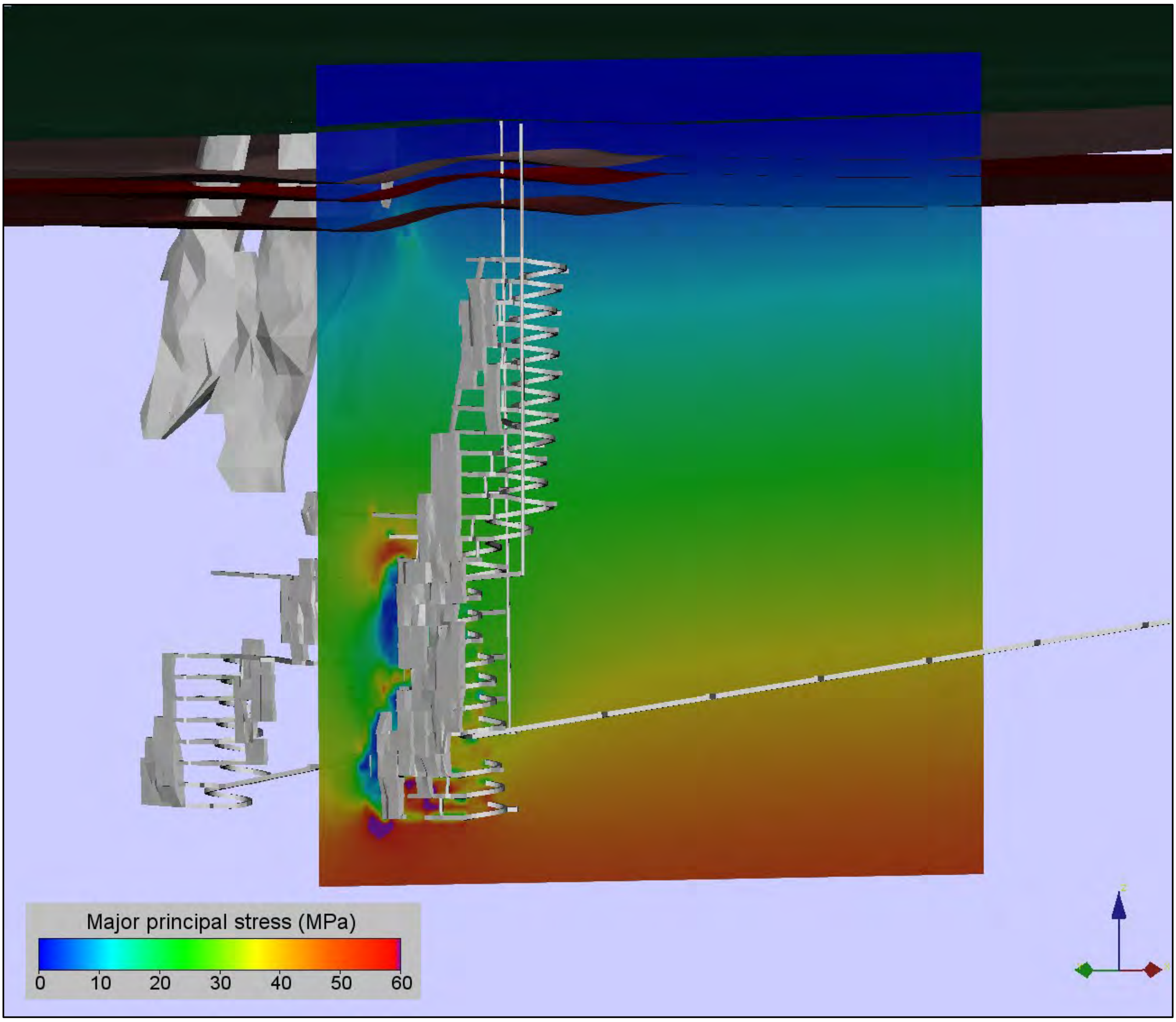


Figure 3.21. Cross section through the Great Cobar mine showing major principal stress at the end of mining (facing West)

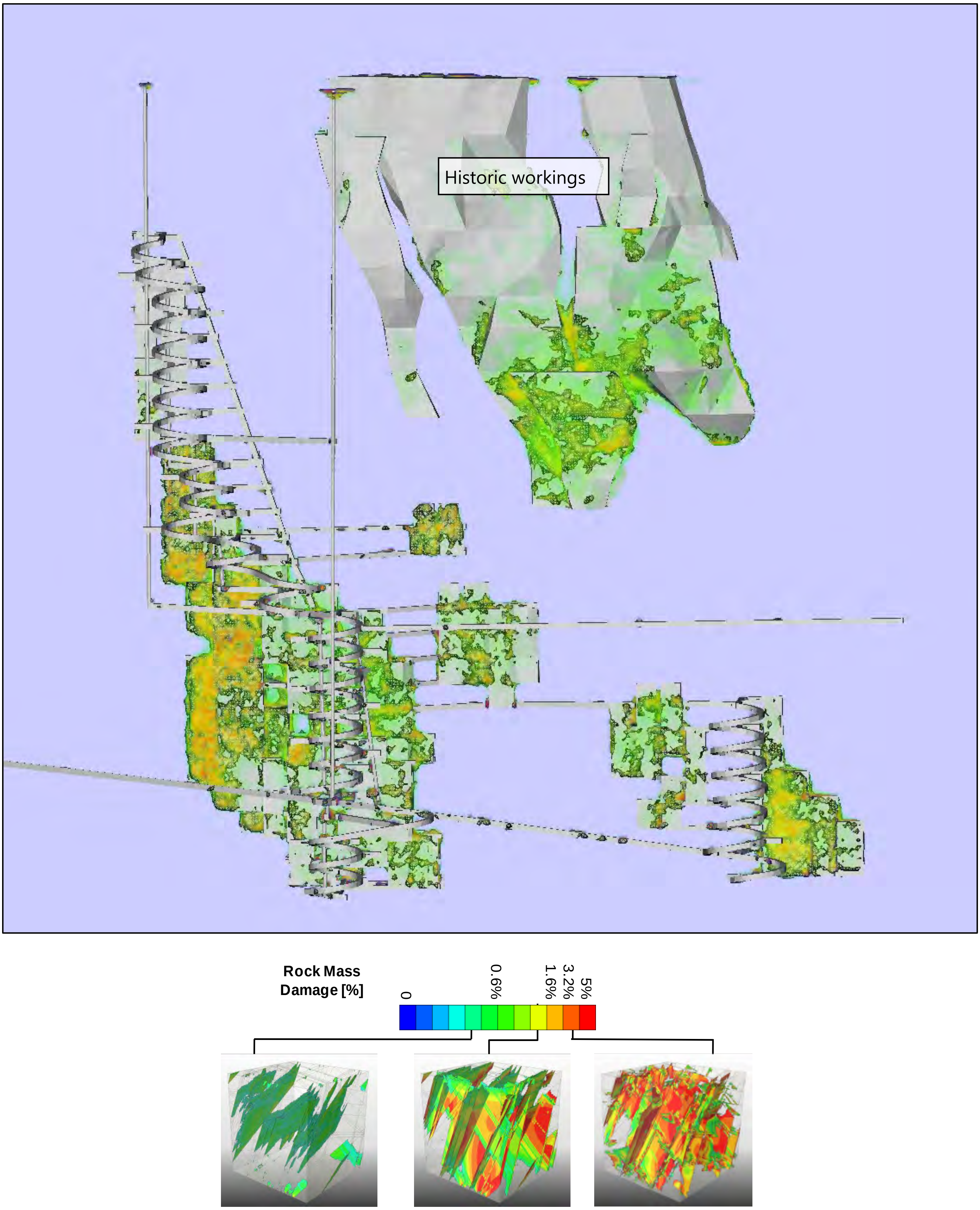


Figure 3.22. Forecast rockmass damage at the Great Cobar mine at the end of mining (facing West)

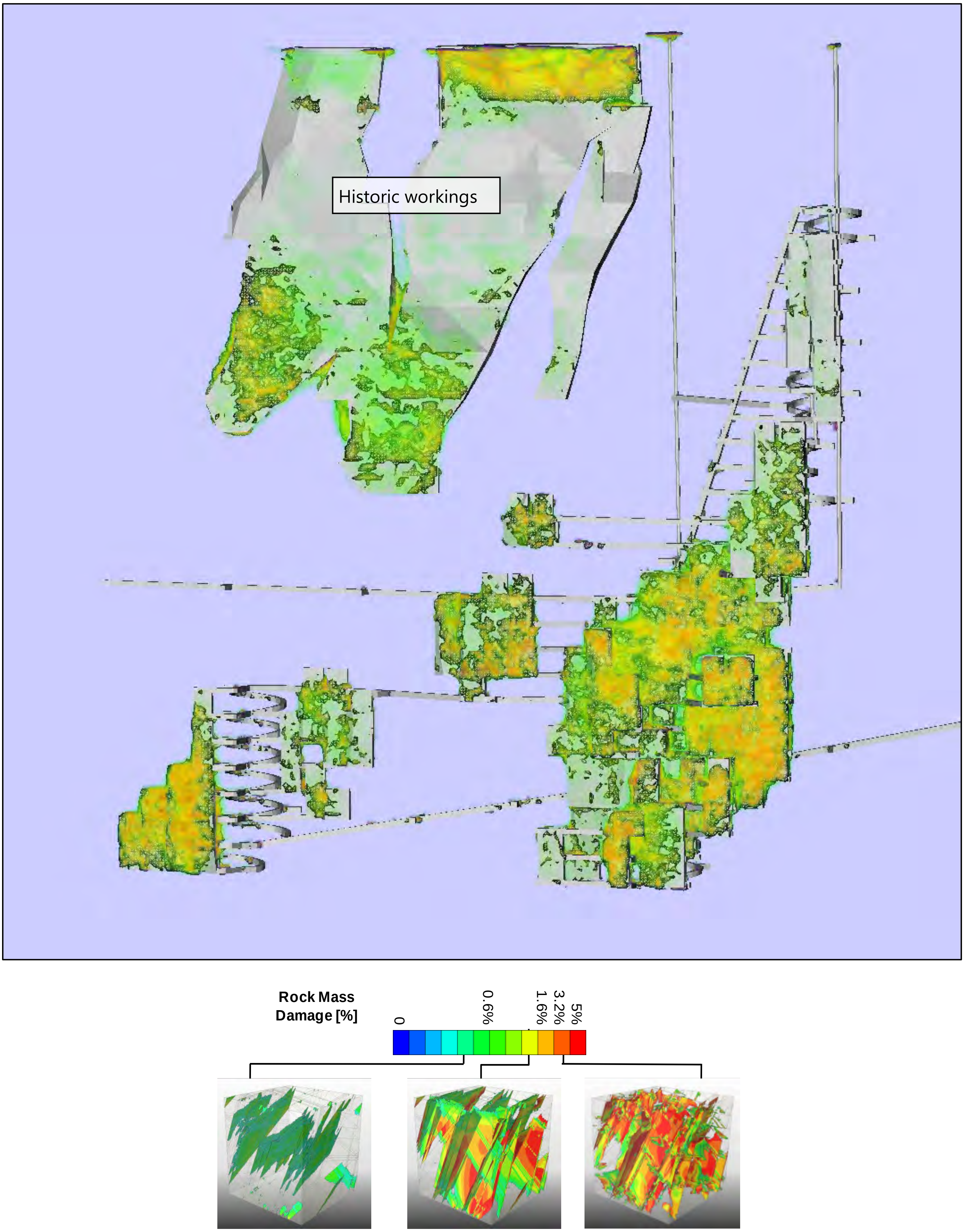


Figure 3.23. Forecast rockmass damage at the Great Cobar mine at the end of mining (facing East)

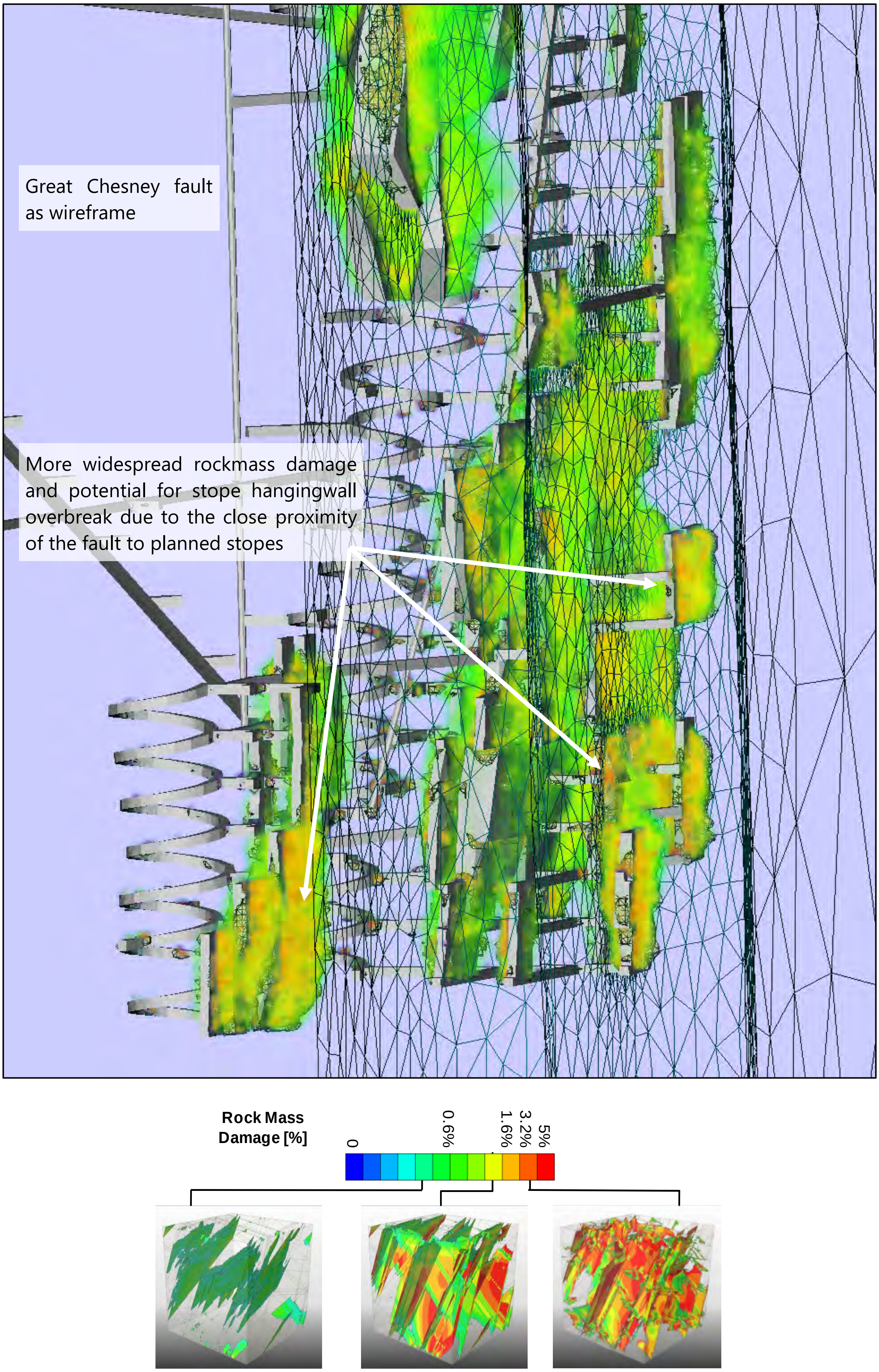


Figure 3.24. Forecast rockmass damage at the Great Cobar mine at the end of mining showing increased stope overbreak in stopes in close proximity to the Great Chesney fault (facing South)

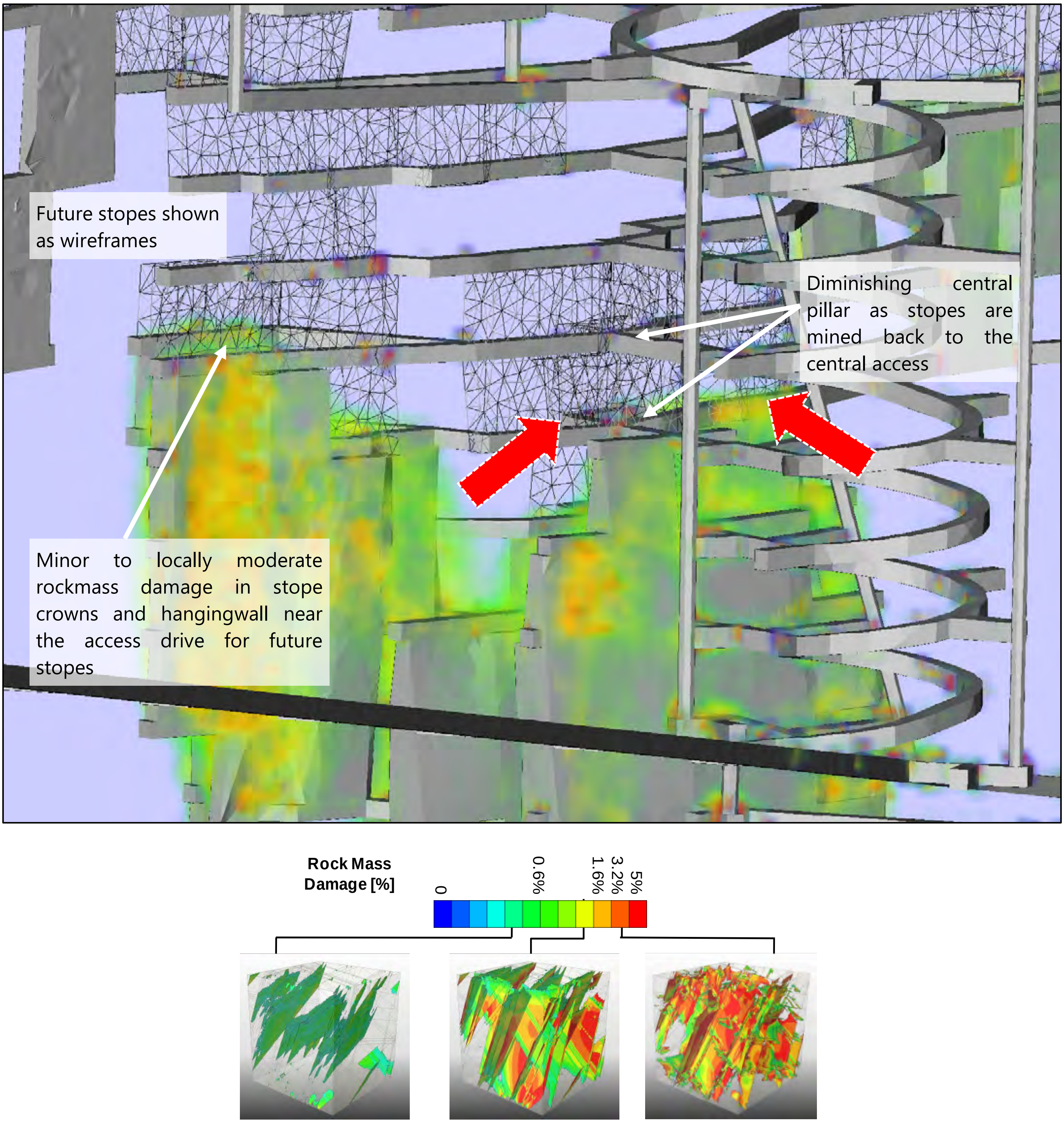


Figure 3.25. Forecast rockmass damage at the Great Cobar mine in late 2027 (facing West)

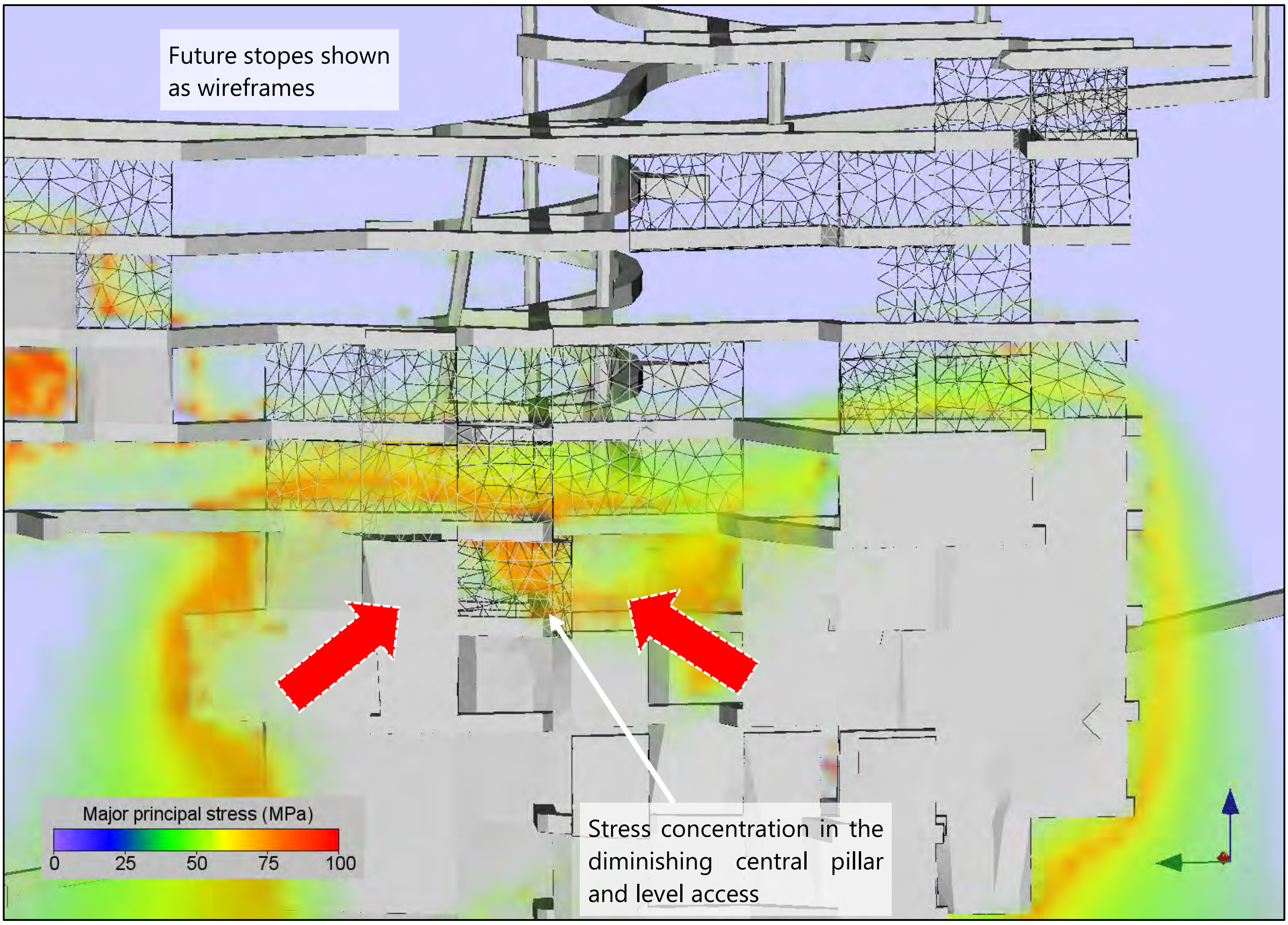


Figure 3.26. Forecast major principal stress at the Great Cobar mine in late 2027 (facing East)

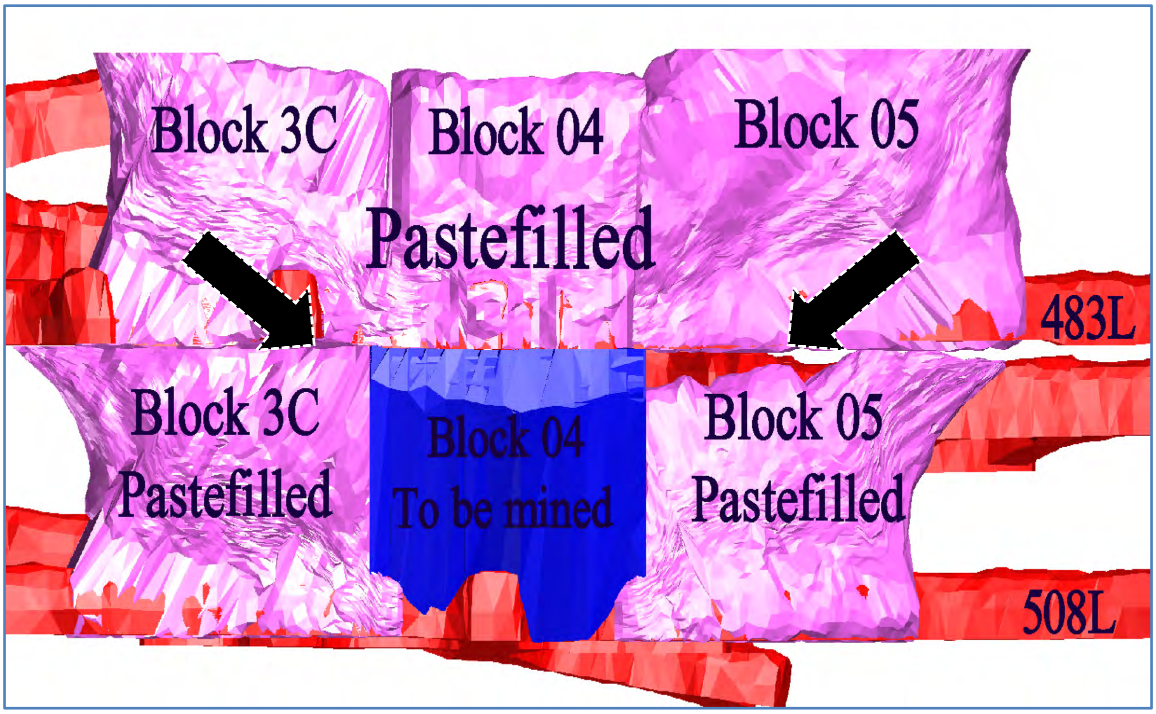


Figure 3.27. Example scenario showing a diminishing central pillar in a top-down longitudinal sequence at another mine in similar geotechnical conditions and mining depth as Great Cobar

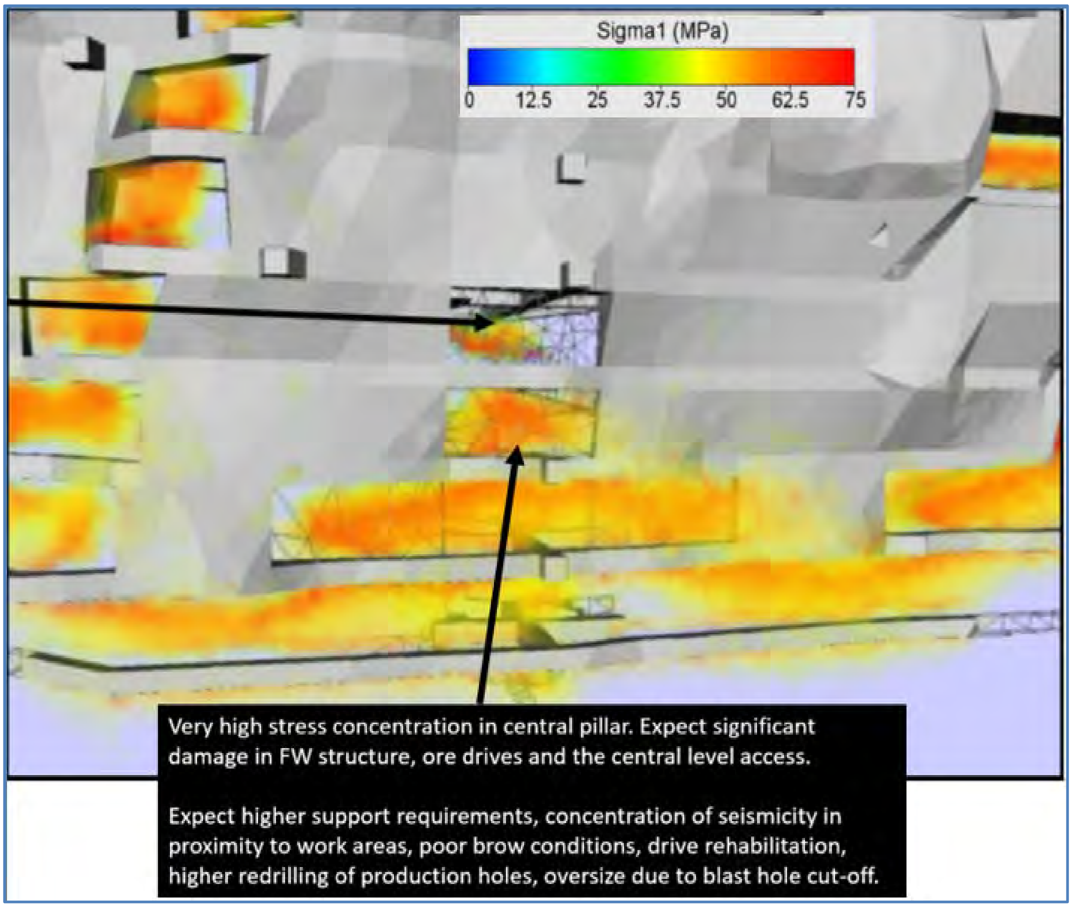


Figure 3.28. Example scenario showing forecast stress concentration in the diminishing pillar shown in Figure 3.27 at another mine with a diminishing central pillar sequence (Beck Engineering 2019)

Figure 3.29. Example scenario showing a drawpoint photo of the stope shown in Figure 3.27 and Figure 3.28 in 2020 showing major stope overbreak and dilution due to collapse of the stope hangingwall at another mine with a diminishing central pillar

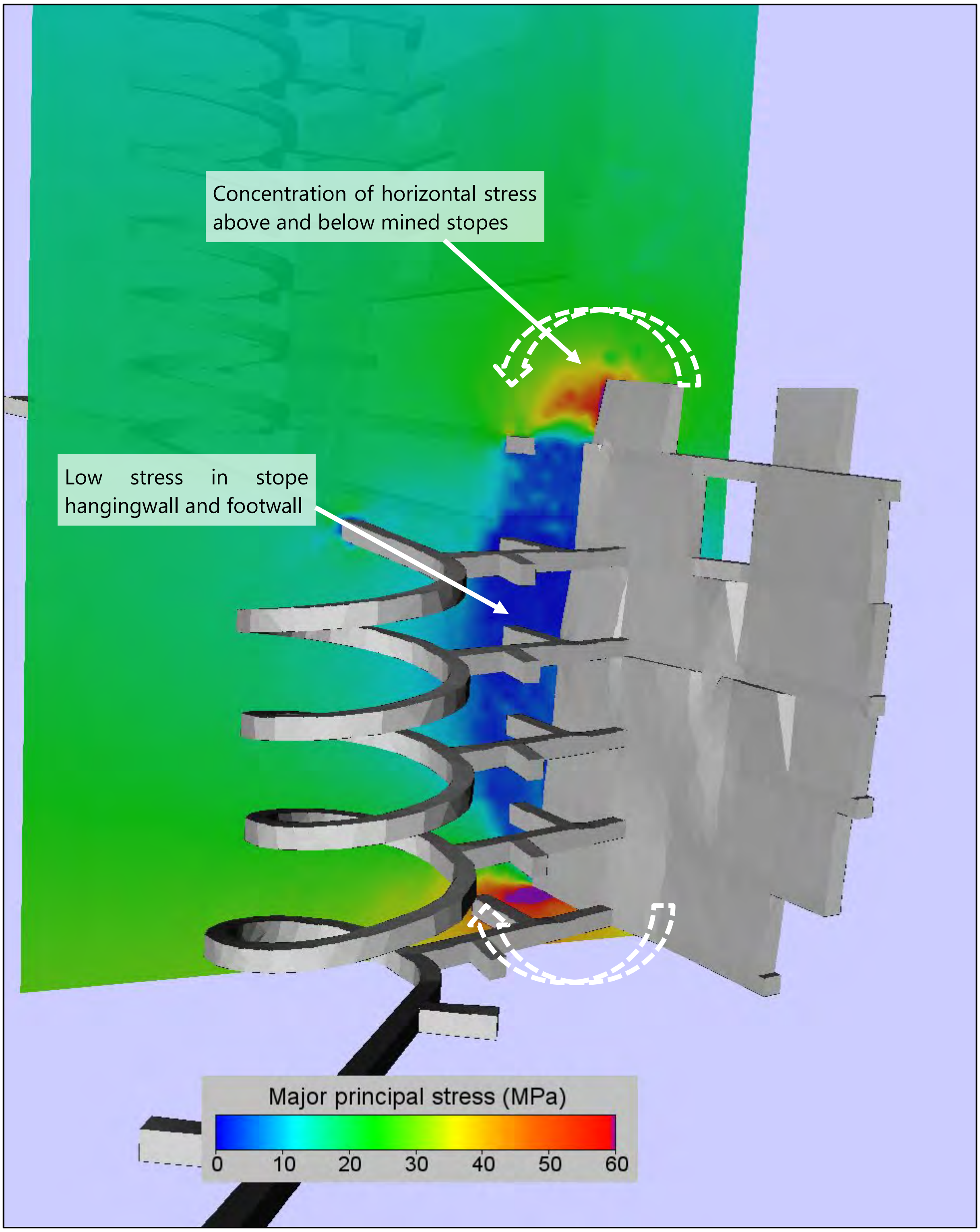


Figure 3.30. Cross section of major principal stress at the Gladstone mine at the end of mining (facing South West)

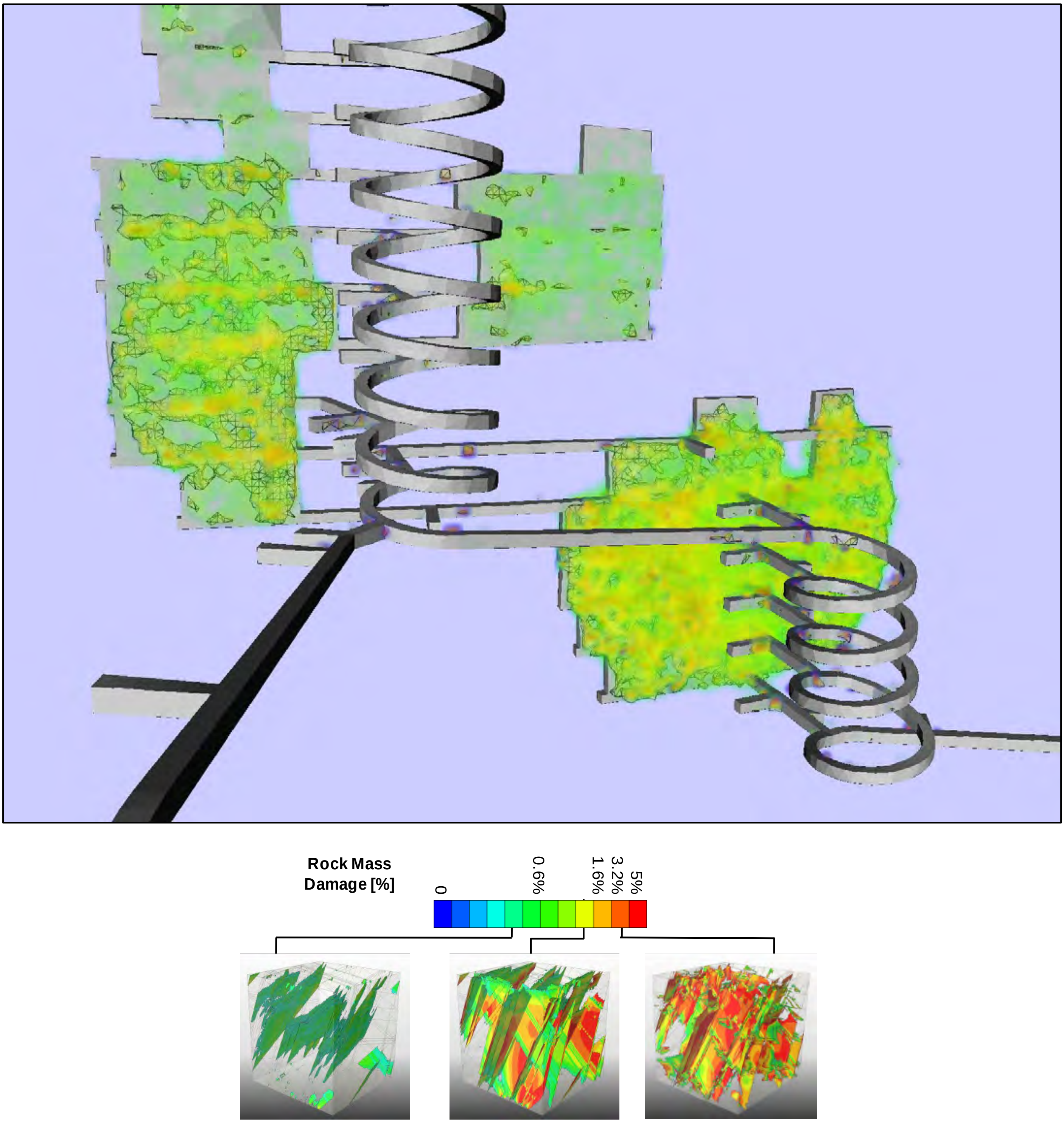


Figure 3.31. Forecast rockmass damage at the Gladstone mine at the end of mining (facing West)

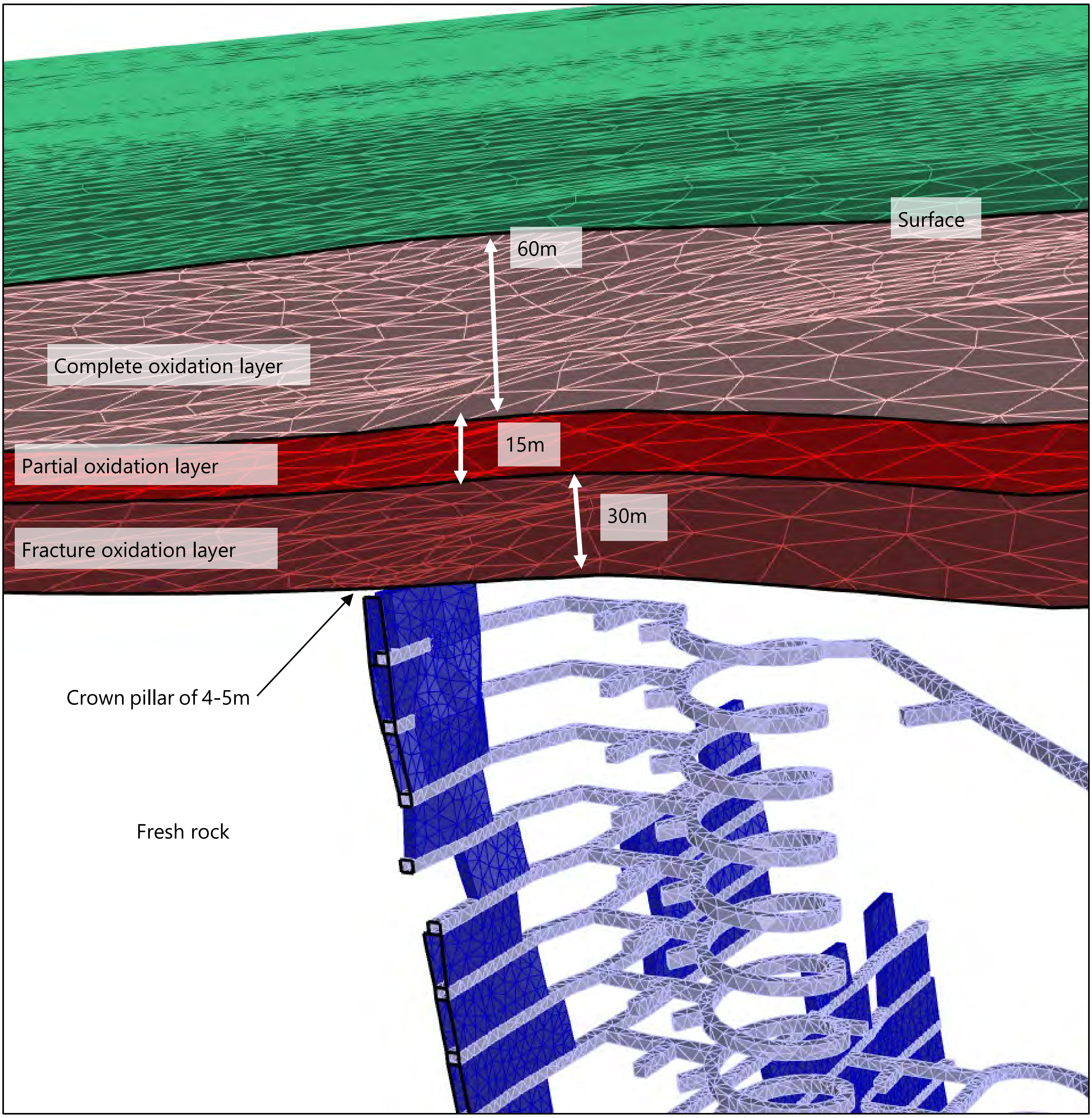


Figure 3.32. Cross section through the Gladstone mine showing planned stopes in proximity the oxidized layers (facing North West)

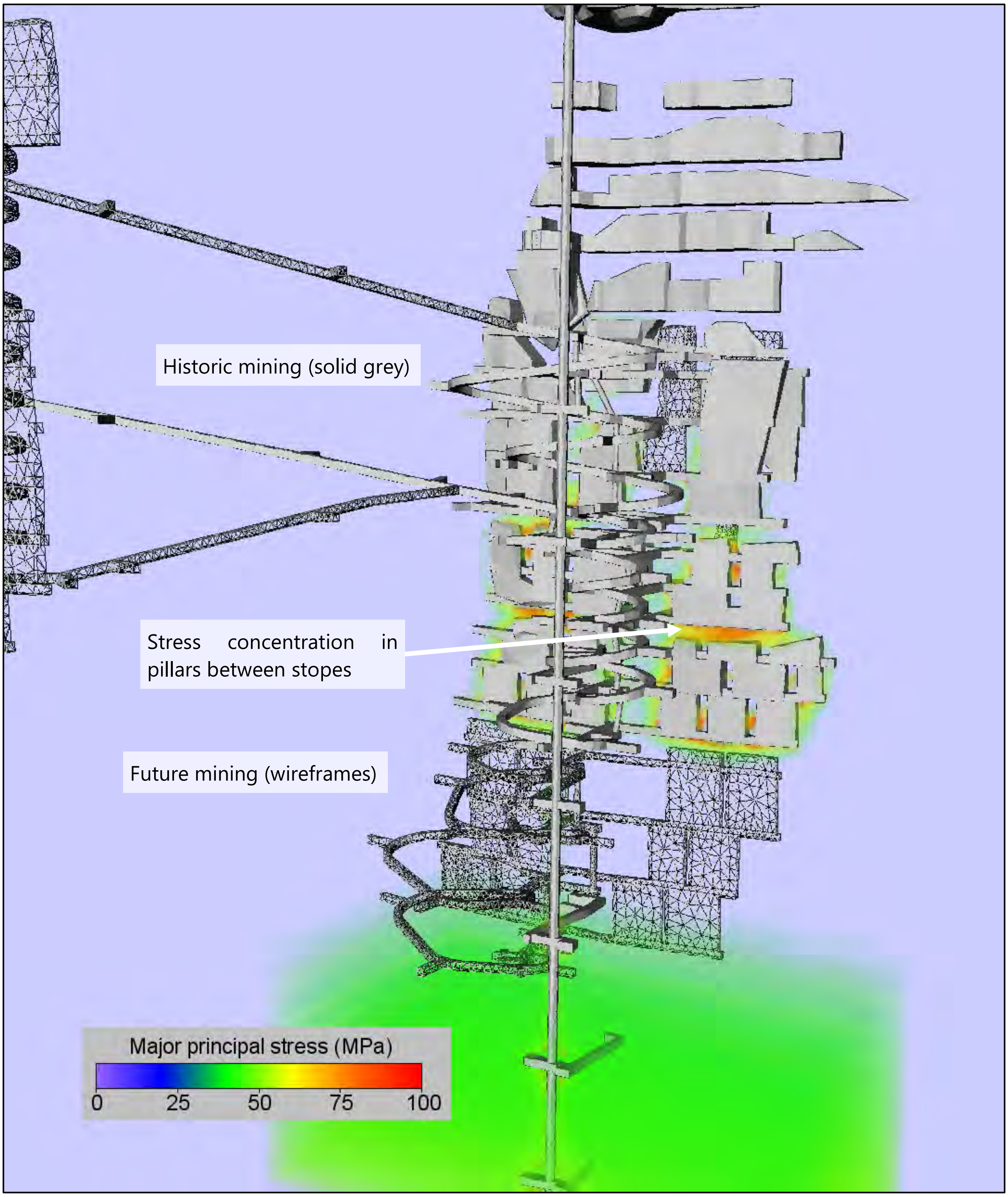


Figure 3.33. Volume rendering of major principal stress at the Chesney mine at present (stress below 40 MPa not shown). Facing North East

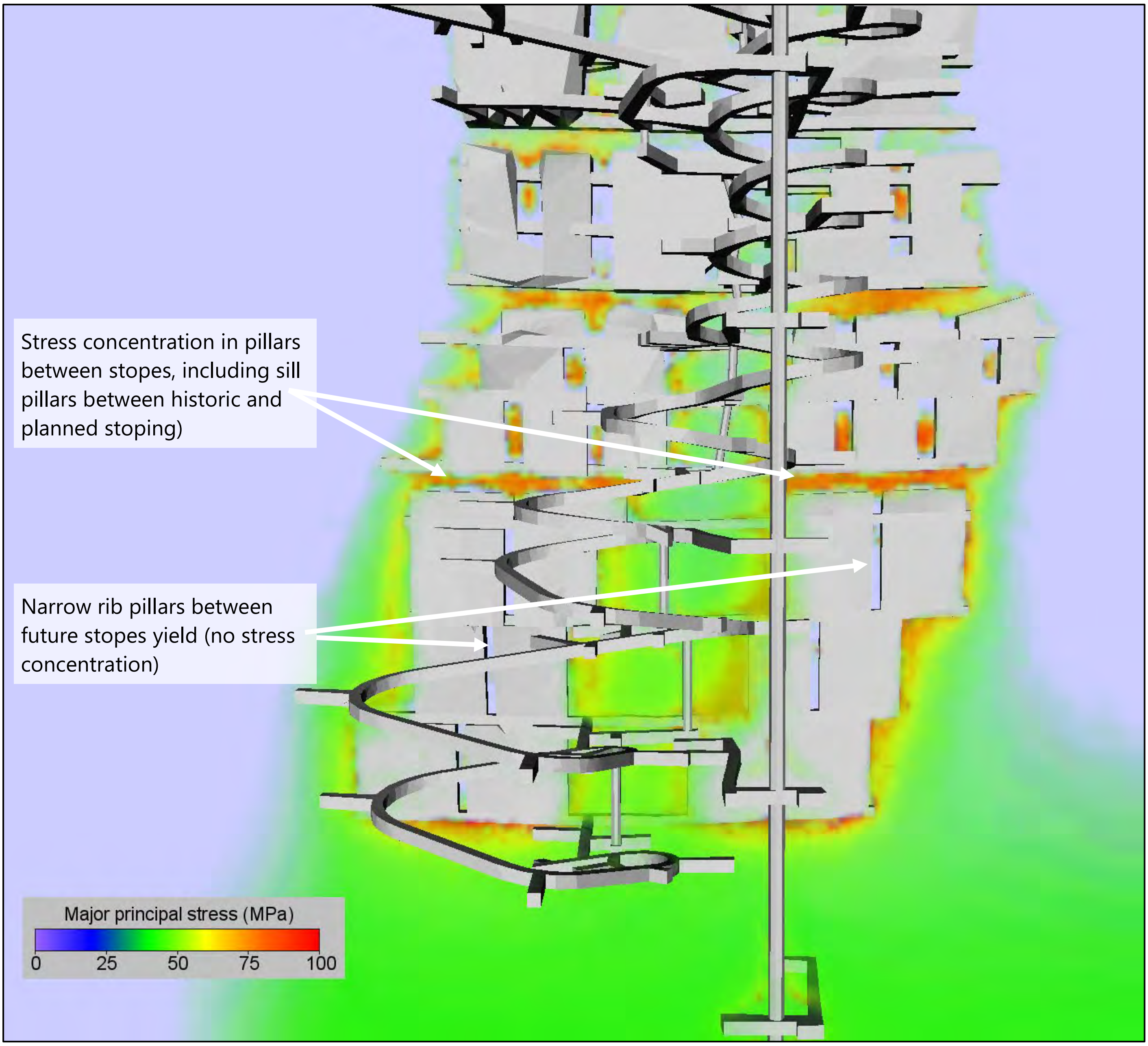


Figure 3.34. Volume rendering of major principal stress at the Chesney mine at the end of mining (stress below 40 MPa not shown). Facing East

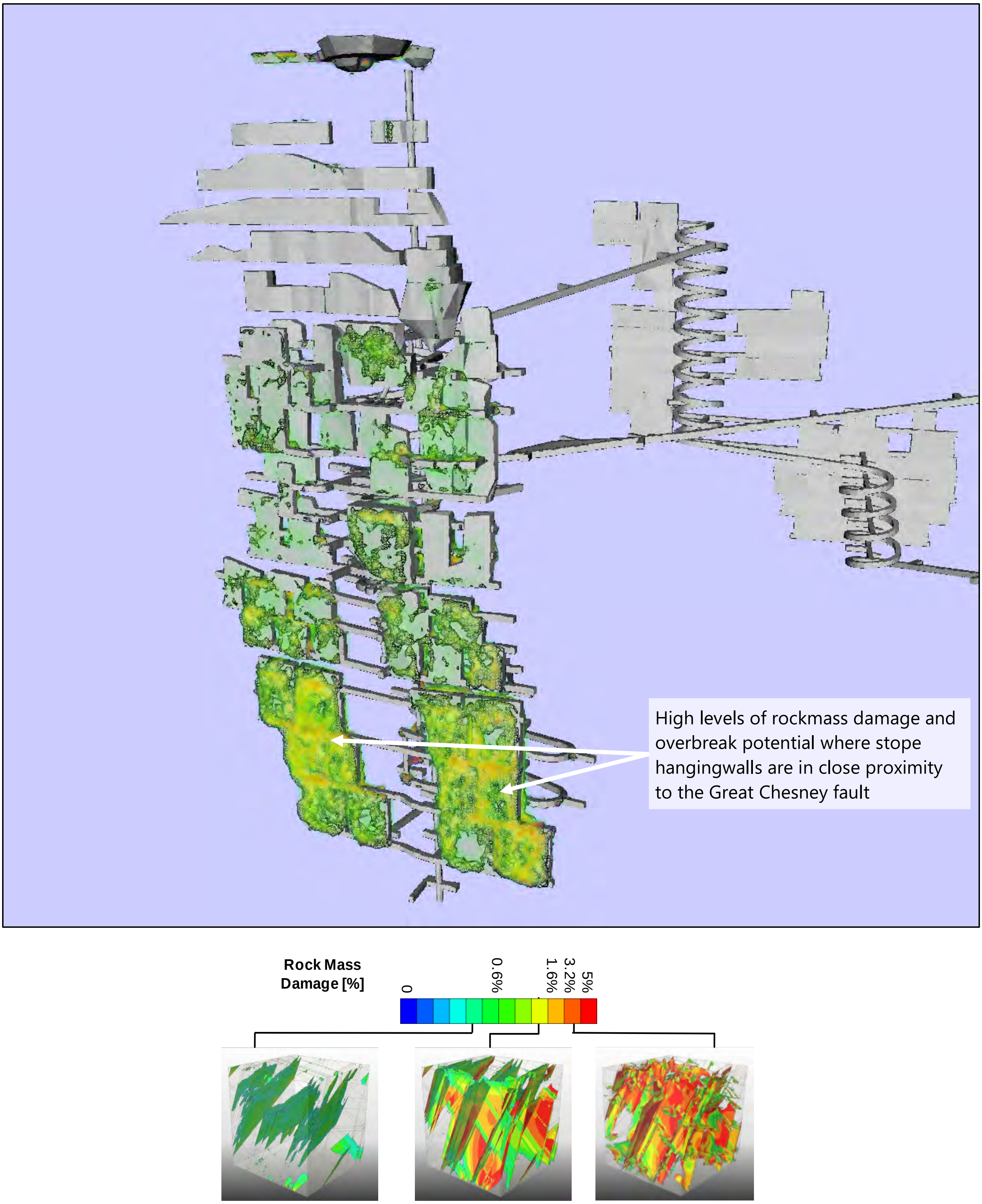


Figure 3.35. Forecast rockmass damage at the Chesney mine at the end of mining (facing South West)

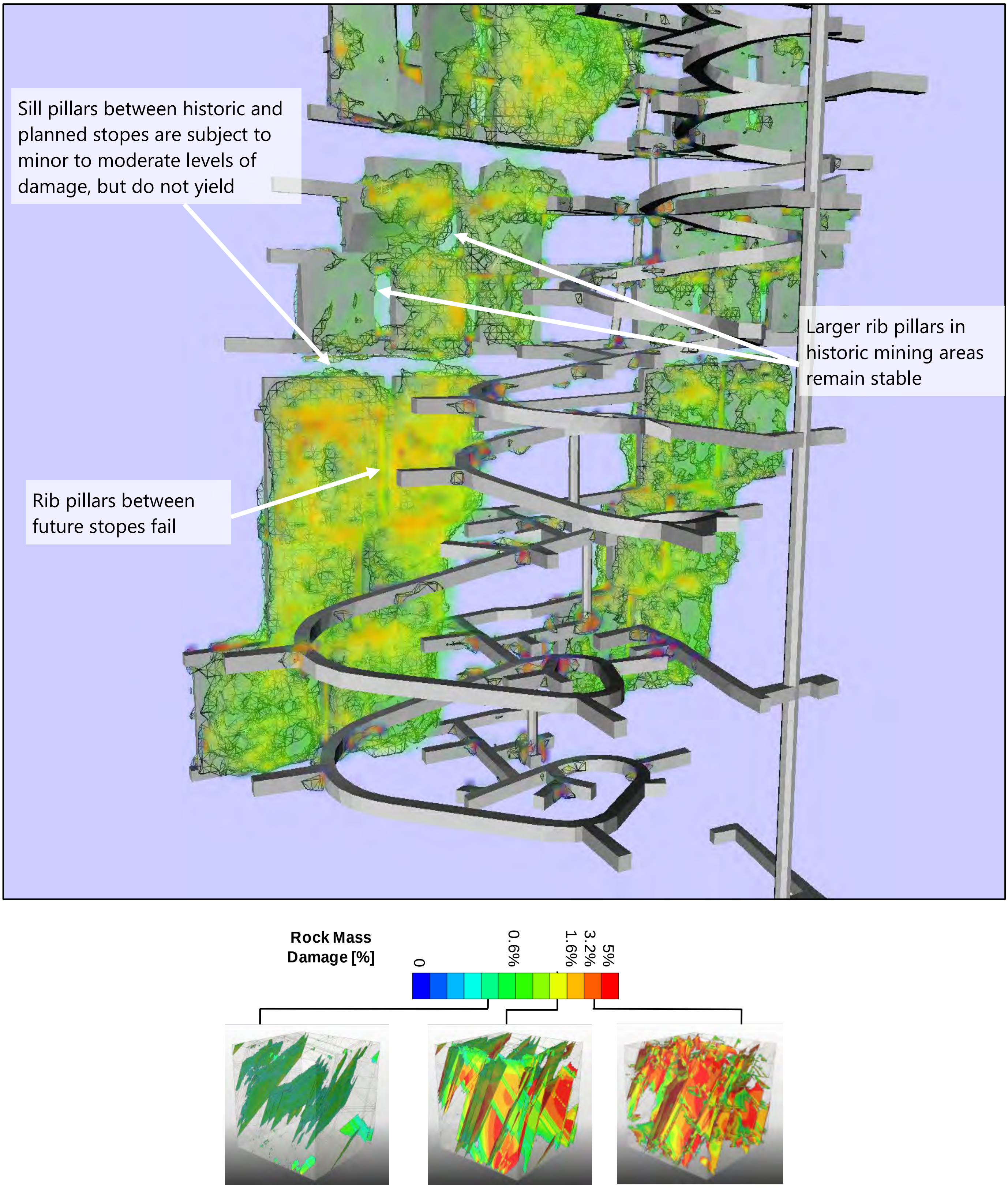


Figure 3.36. Forecast rockmass damage at the Chesney mine at the end of mining (facing East)

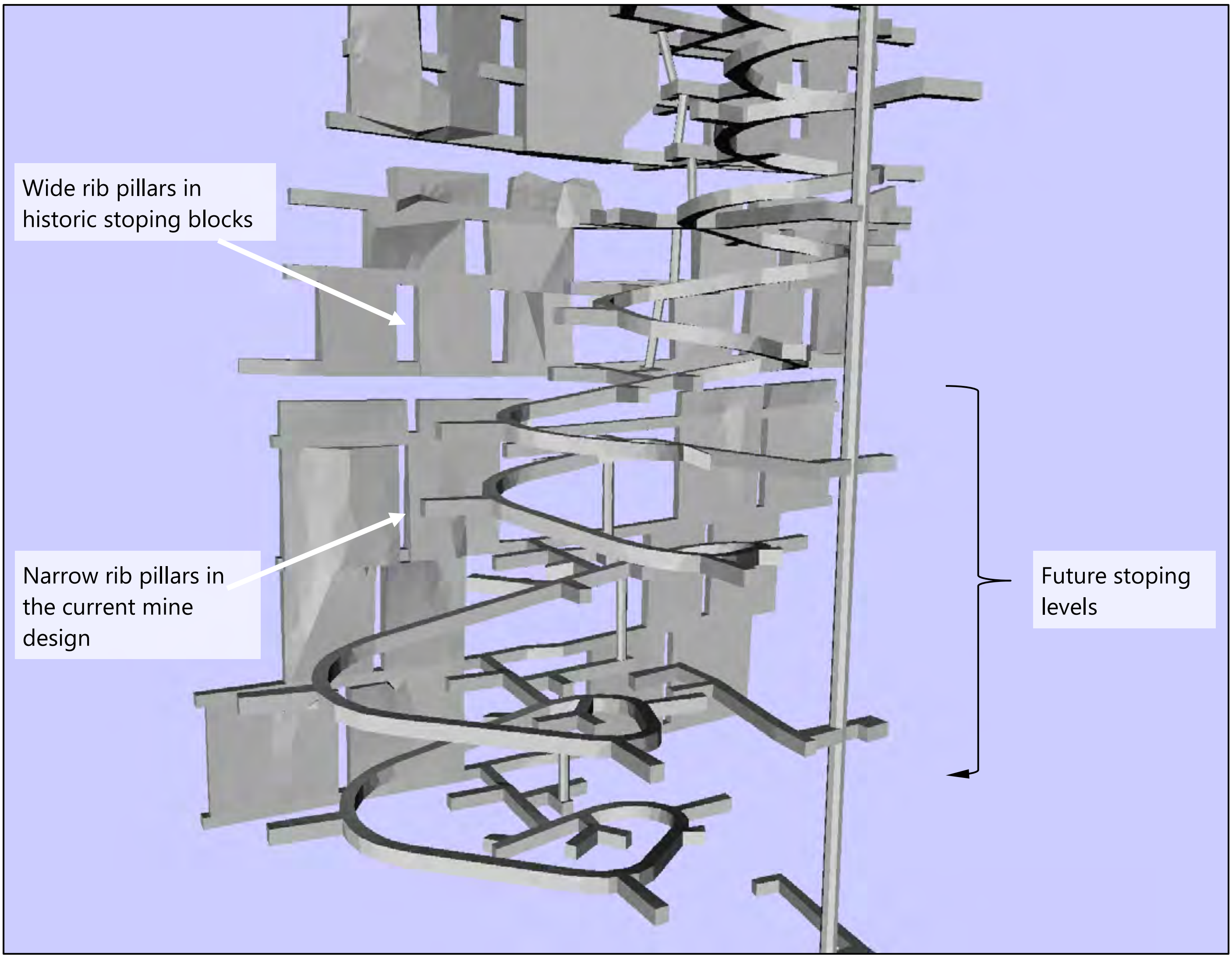


Figure 3.37. Lower Chesney mine showing relative pillar dimensions in old and planned stoping blocks

4 CONCLUSIONS, RECOMMENDATIONS & LIMITATIONS

Main findings

The main findings of our assessment include:

- Surface subsidence forecasts are less than 15mm and are considered negligible. We note that this level of deformation is within the levels of precision of a mine scale model.
- Negligible subsidence is expected for the proposed underground mining due to:
  - Small footprint of future underground mining.
  - Relatively strong rockmass conditions.
  - Small (narrow) stopes with a small footprint.
  - Low extraction ratio due to the narrow stopes and small amount of rock planned to be mined (compared to other larger stoping mines).
  - Use of backfill.
- Planned underground mining is not in proximity to the New Cobar open cut and there is no significant stress interaction and minimal subsidence in the vicinity of the open cut. Proposed underground mining does not result in instability in the open cut in the model forecasts.
- Minor to moderate levels of rockmass damage is forecast in proximity to some stopes. This increases with depth. Forecast levels of damage would generally be associated with minor dilution and stope overbreak. This is normal in most stoping mines. Moderate level of rockmass damage with potential for increased levels of stope overbreak is forecast along the Great Chesney and Great Cobar faults which bounds the hangingwall of some future stopes.
- There are stopes at New Cobar and Gladstone which are close to, or intersect the weathered/oxidised layers near surface. The rockmass in the oxidised layers is weaker and more susceptible to instability and chimneying. We note these stopes are conceptual only and were designed based on the Inferred Mineral Resource and may not be economic or become part of the Ore Reserve and executable mine design.
- Diminishing pillars are formed at Great Cobar and Gladstone mines due to the mining sequence. These diminishing pillars form as stopes are retreated to a central access. These stopes will likely have elevated levels of stope overbreak and dilution compared to nearby stopes due to the stress concentration that occurs as the pillar diminishes. However, due to the rockmass conditions, depth and small number of stopes with this sequence, this is not considered to be a significant problem for the mine.

Recommendations

- Rigorous subsidence monitoring such as regular surveying, laser scanning or InSAR is not recommended given the model forecasts and negligible amount of subsidence expected. Low levels of monitoring such as annual survey pick-ups of key locations should be considered by PGM.
- Review mining of any stopes near the top of fresh rock boundary. Any stopes planned close to the oxidised layers should be risk assessed and have a stable crown pillar.
- Ongoing stope stability assessment and observation of stope performance. The mine should adjust the stope design, including stope dimensions should instability and overbreak be excessive.
- Backfill stopes in a timely manner and minimise the total mine void at each mine as far as practical.
- Review the design and dimensions of rib pillars and sill pillars in the current mine design. We note that some rib pillars in the Chesney mine design are very narrow and likely to fail during stope production.

- Based on the model forecasts for stress, strain and deformation and our experience at other mines in similar conditions, ground support requirements for the future mine will be similar to those used in previous mining to date. We do not expect damaging levels of seismicity or dynamic support to be required due to the rockmass properties, low extraction ratio and mining depth.
- The mine should adopt an observational approach and continuously evaluate the rockmass response to mining and adjust the mine plan, if required, as mining continues and as additional geotechnical information becomes available.

Limitations

In addition to the normal resolution limits associated with the current mine-scale finite element model, the main limitations of this project are:

- The current understanding of rockmass properties and the in-situ stress field.
- Resolution of the structural model. We note the structural model will evolve over time with progressive mining.
- A site inspection has not been undertaken.

5 REFERENCES

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