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PIONEERING PROGRESS : THE FUTURE OF ROCK ENGINEERING

Pillar Assessment at Trojan Mine

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Agenda

Project Background

- Locality
- Geological Setting
- Historical Mining
- Proposed Mine Design Layout

Key Objectives

Study Methodology

Underground Geotechnical Investigation

Numerical Analysis of Historical Mining Layout

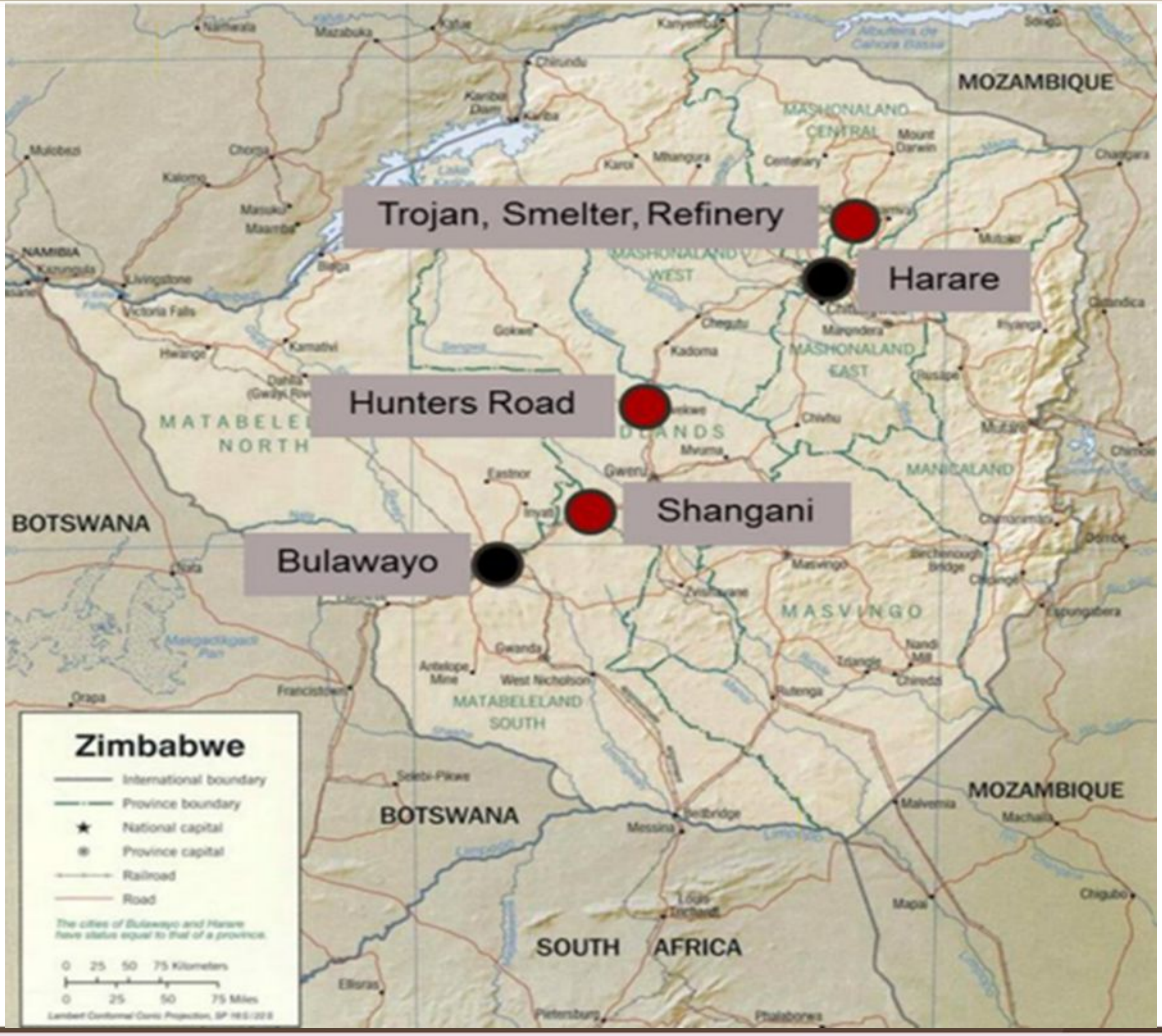
Proposed Extraction Sequence

Recommendations

Conclusions

Locality

- Trojan Mine is situated in Bindura, in the northern limp of the Great Dyke, Zimbabwe, 100 km northeast of Harare.
- Brownfield project dating back to the 1960s.
- At the time of the study, the operation was undergoing a major restructure.

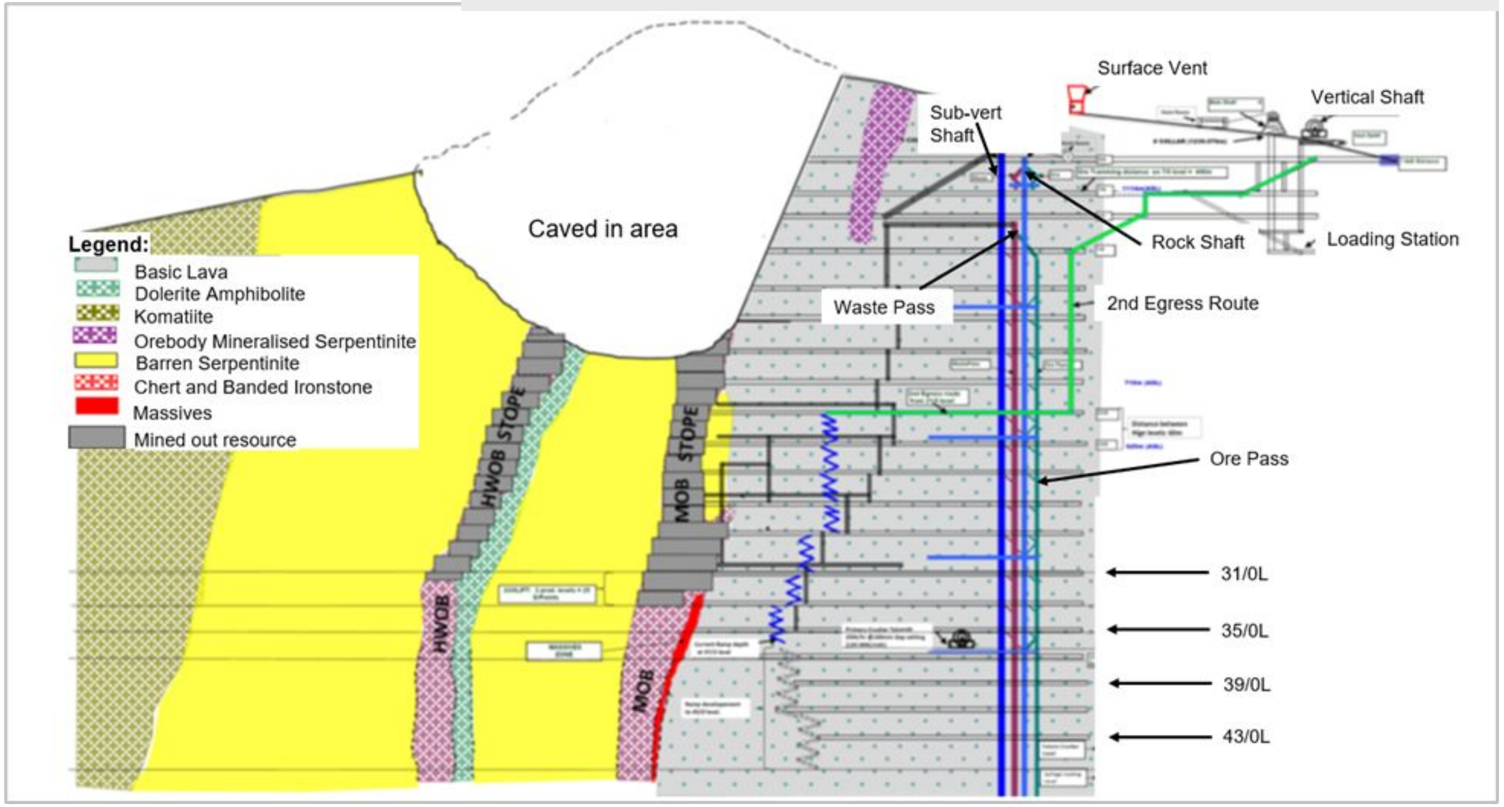


Geological Setting

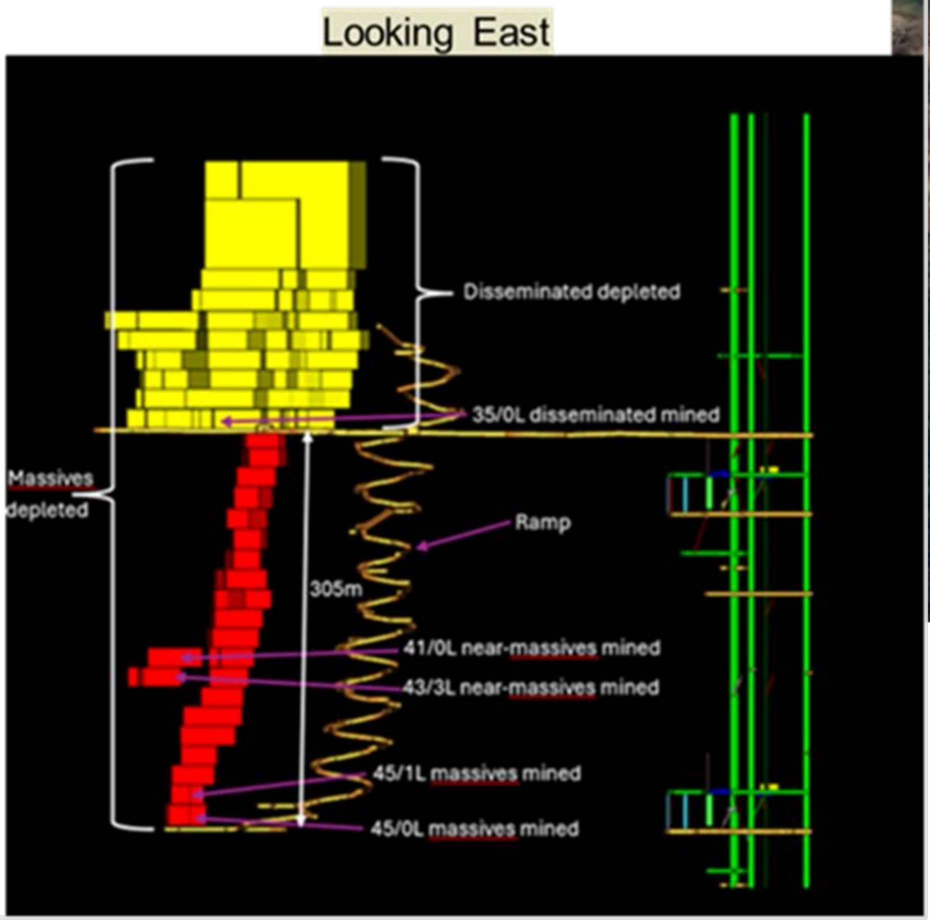
- HWOB strike length ~ 200 m
- MOB strike length ~ 250 m
- Massives strike length ~ 80m
- A 20 – 60 m wide shear zone separating HWOB and MOB

- Nickel sulphide mineralization within ultramafic lavas
- **Ore bodies targeted:** Hangingwall Orebody (HWOB), Main Orebody (MOB), and Massives Orebody
    - Steeply dipping ore bodies (75°–85°)
- **Host rocks:** Serpentinite, basalt, and associated shear zones
- Presence of doleritic dykes and three persistent joint sets

Cross section of Trojan geology and infrastructure
(*Trojan Nickel Mine COP, 2018*)



Historical Mining

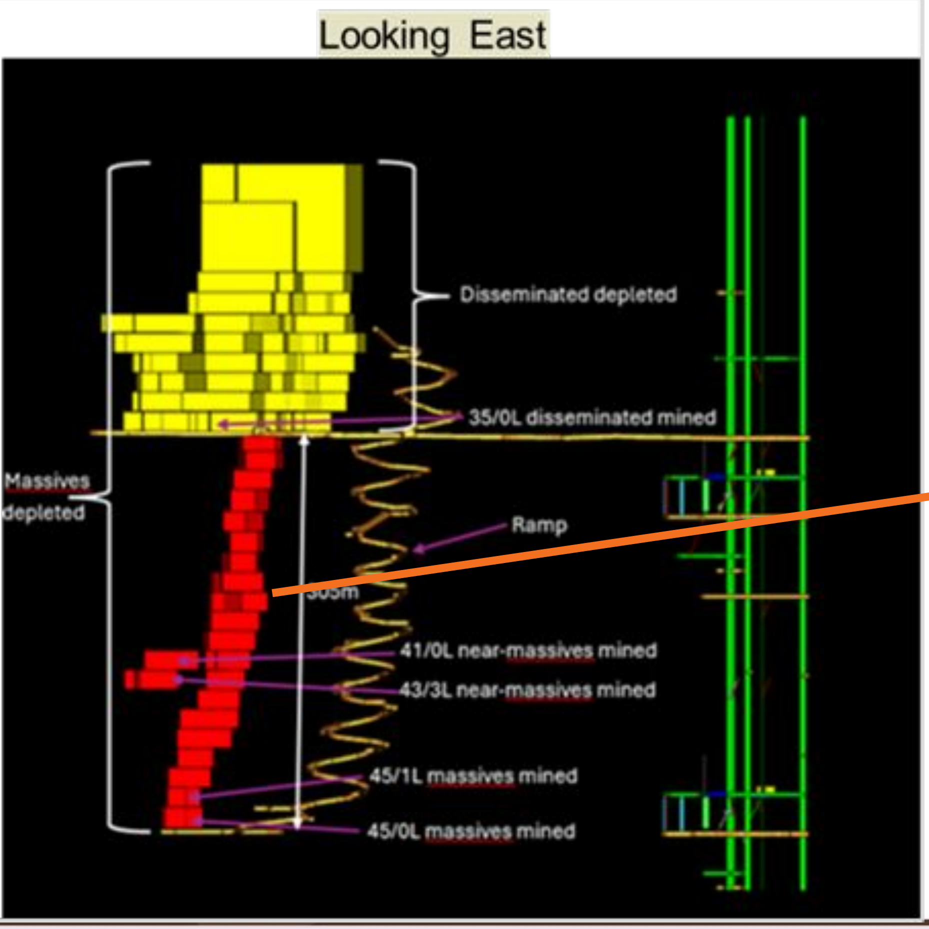


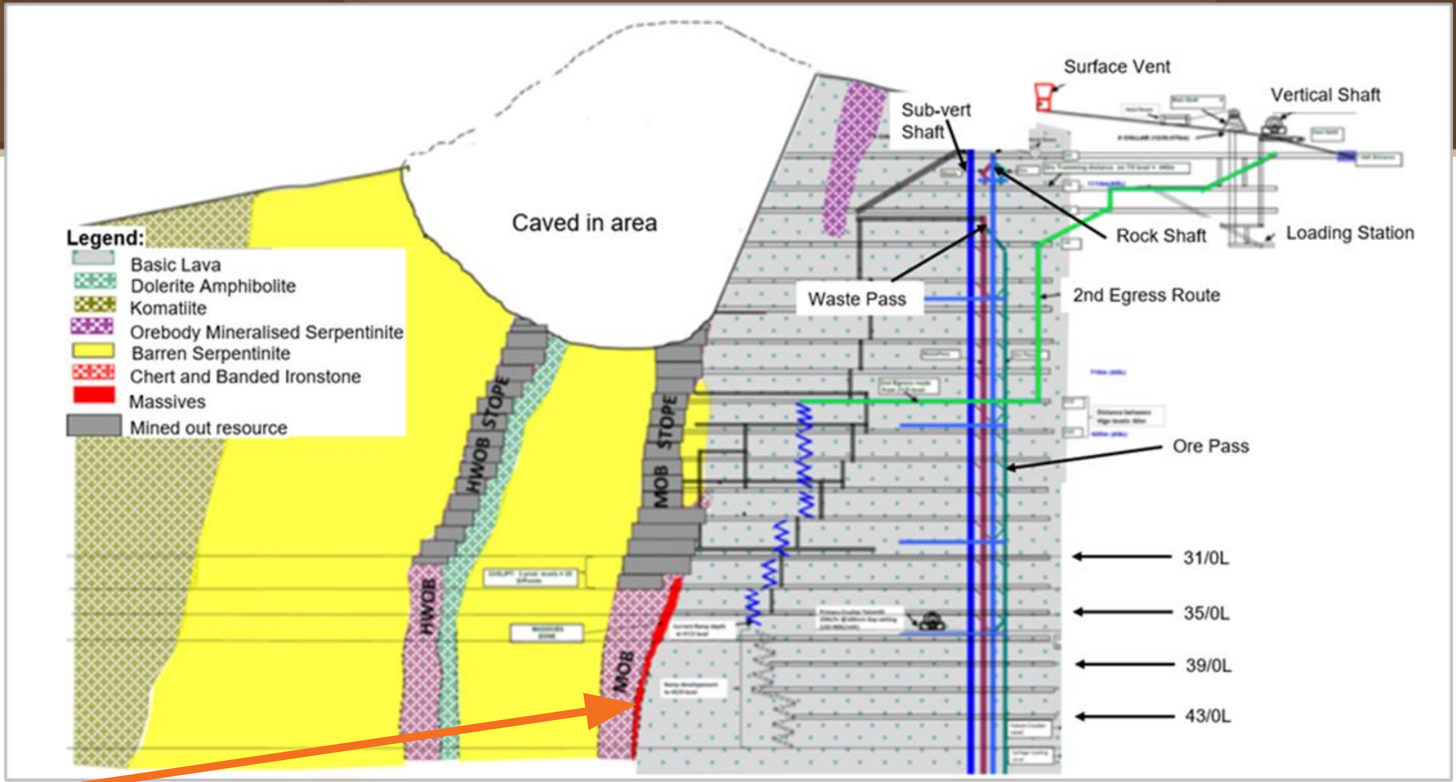
Shallow to intermediate depth underground mine.

Sublevel caving mining method

- Above the 35L, the entire strike length of all three deposits, have been mined using the SLC method.
- As a result, the geological hanging wall is caving, extending to the surface and forming a subsidence crater.
- Waste rock from the subsidence crater flows into mined out stopes during stoping, acting as natural backfill and provides support to mined out stopes.

Historical Mining





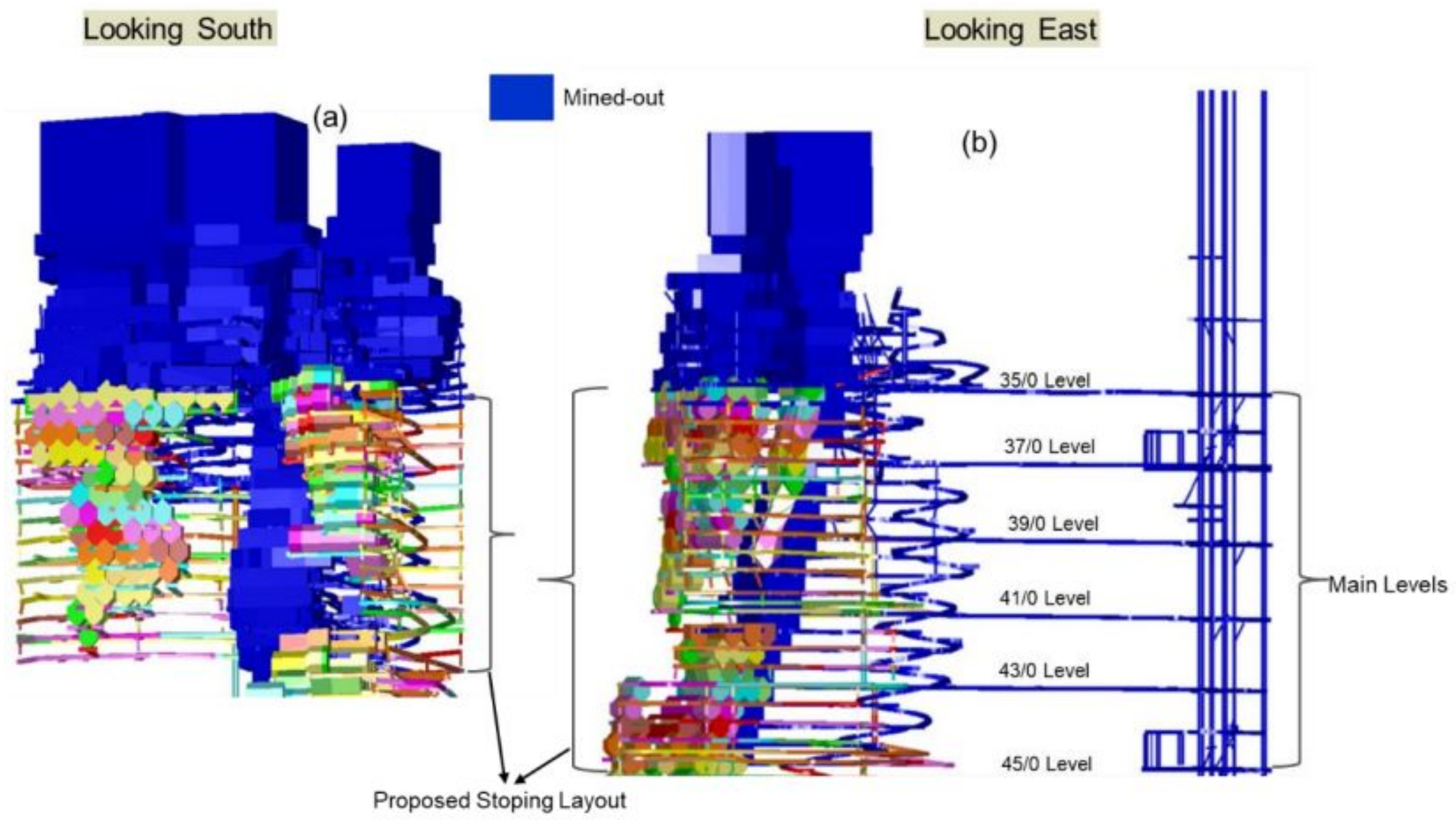
Principal shaft structures and excavations are located in the foot wall of the deposit.

Below the 35L, Massives in the footwall of the MOB have been mined first due to high grade and nickel price.

Undercutting of the Main Orebody by the Massives stopes.

- Create adverse geotechnical conditions

Proposed Mine Design Layout



- Proposed design targets the MOB and the HWOB.
- Geotechnical concerns during undercutting the mined out Massives stopes.

Question

- How much of the MOB can be safely extracted?

Key objectives

- The high-level study aimed to investigate the feasibility of mining the areas around the mined Massives stopes and identify potential geotechnical risks.
- Determine whether a pillar should be left between the designed MOB stopes and the already mined out Massives stopes.
  - If so, what is the optimum pillar size?
- Assessing the adequacy of the installed support at the time of the study.

Study Methodology

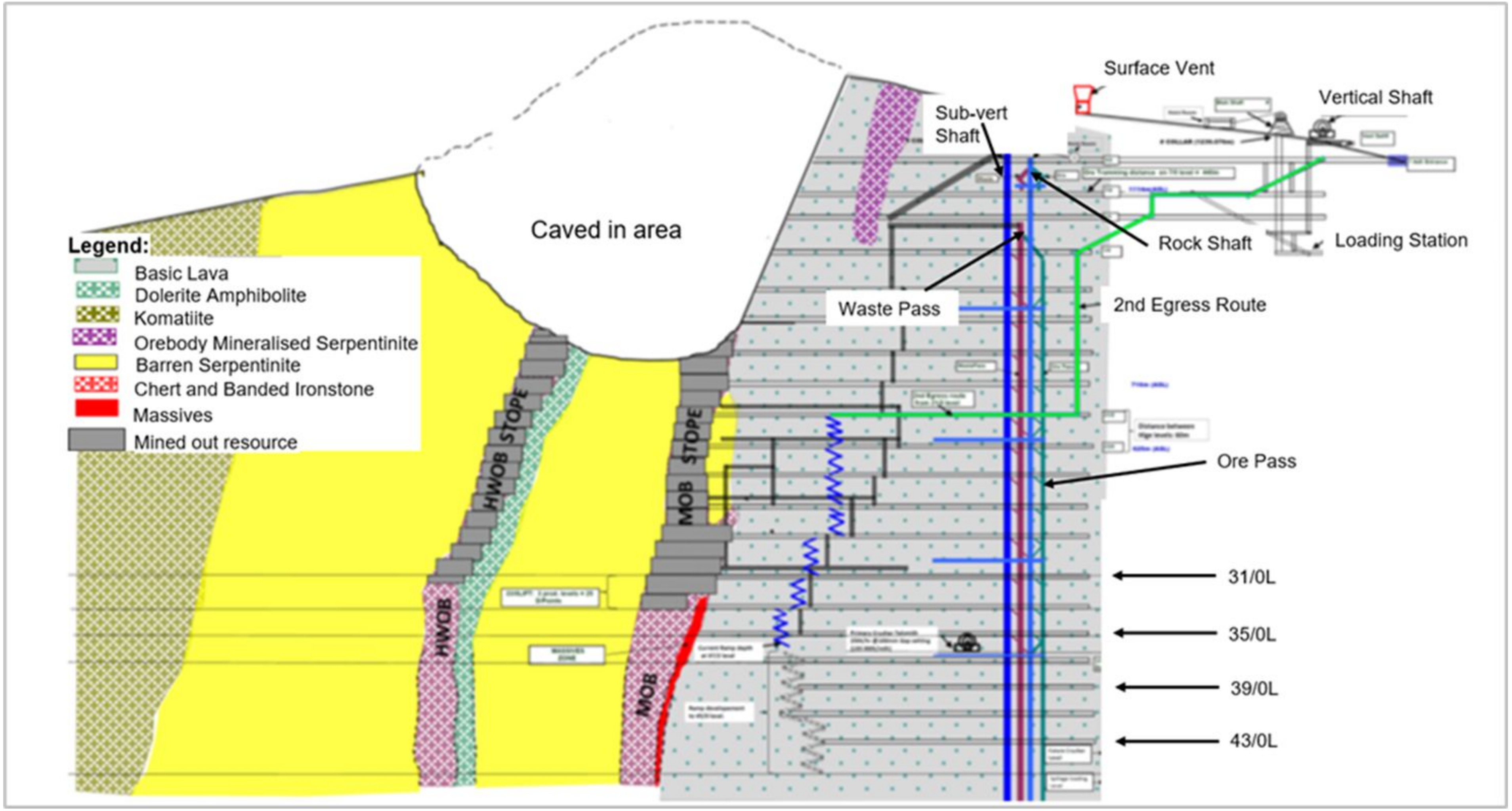
- Site visit to understand geotechnical environment, assess ground conditions (areas close to mine out stopes) and identify problematic areas.
- Investigate support performance underground.
- Geotechnical data collection, review and QAQC.
- 3D finite element numerical analysis was conducted to analyze stress interactions to explain the underground observations and to extrapolate the potential risks.
- Develop optimal extraction sequence to ensure maximum recovery while maintaining safety.
- Recommend an effective support system for each geotechnical environment.

Geotechnical assessments conducted on 35/0L, 37/3L and 41/0L, levels.

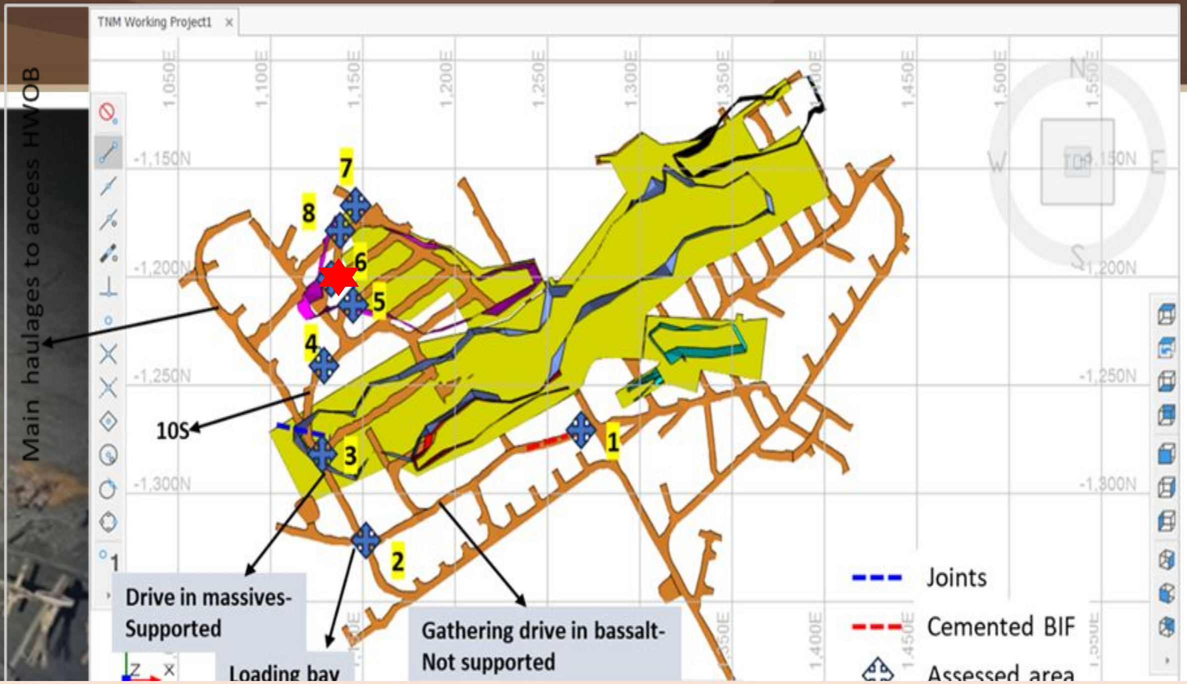
Summary of underground assessment:

- Stable competent basalt zones vs. fair serpentinite zones.
- Significant stress damage observed on roof and sidewalls of gathering drives and production drifts close to stope boundaries, particularly in areas lacking skin support.
- Massive stopes are filled with waste rock from upper levels.
- Deterioration of pillars between mined out stopes.
- Inconsistent and damaged support.

Underground Geotechnical Investigation



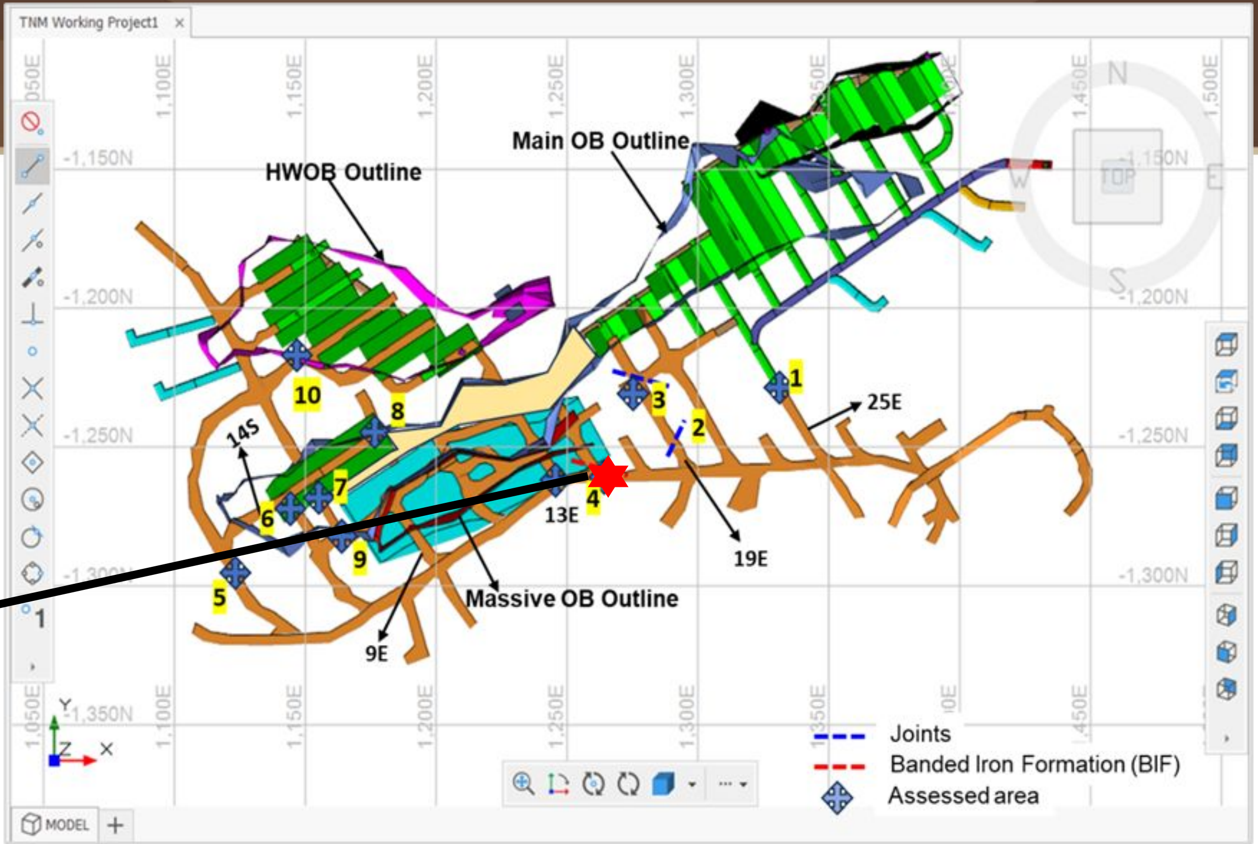
Geotechnical Investigation_35/0L



- Massives mined out first and subsequently mined the HWOB and MOB successfully.
- Good ground condition in Basalt, massive with no support.
- Fair rock mass in Serpentinite, not significantly altered. Drives supported with rebars and cable anchors. No mesh present.
- Stress-induced failure in the roof at point 6.

Geotechnical Investigation_37/3L

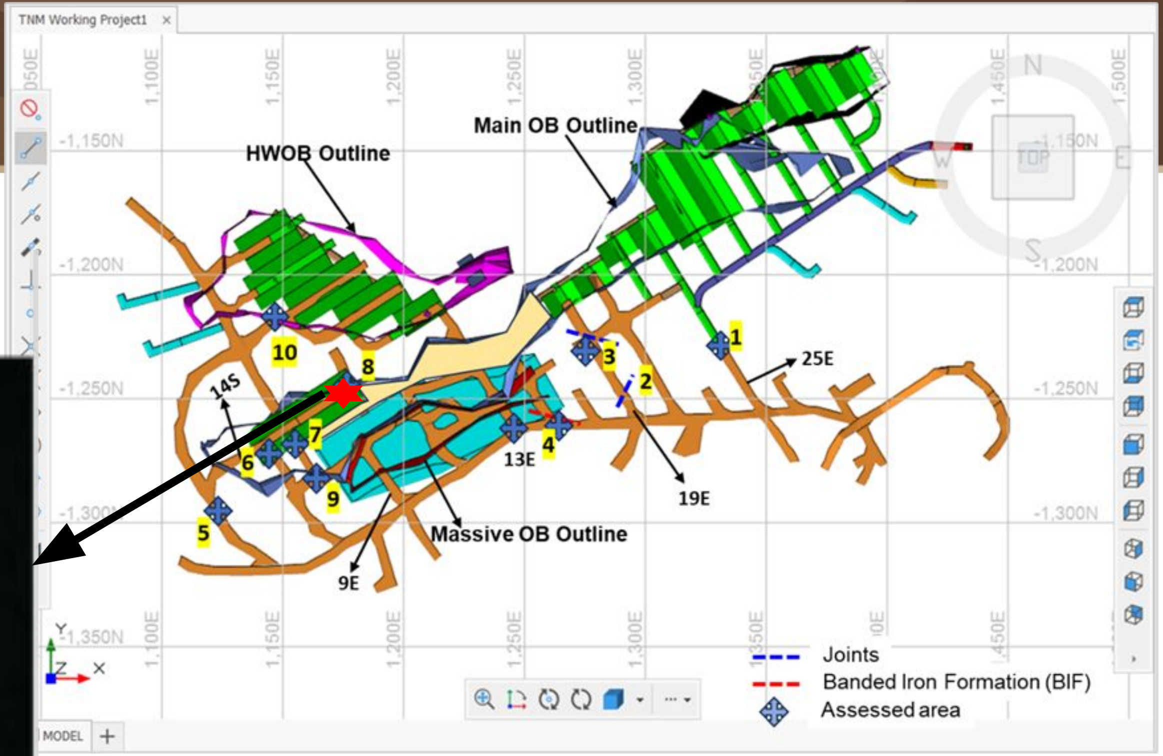
Observation Point4



- Blue is the mined out Massives.
- Green represents design stopes, not yet mined.
- Yellow potential pillar area. Can it be mined safely?
- Mining one sub-level below 35/0L.
- Stress fracturing at point 4 in Basalt- adjacent to mined out stope.

Geotechnical Investigation_37/3L

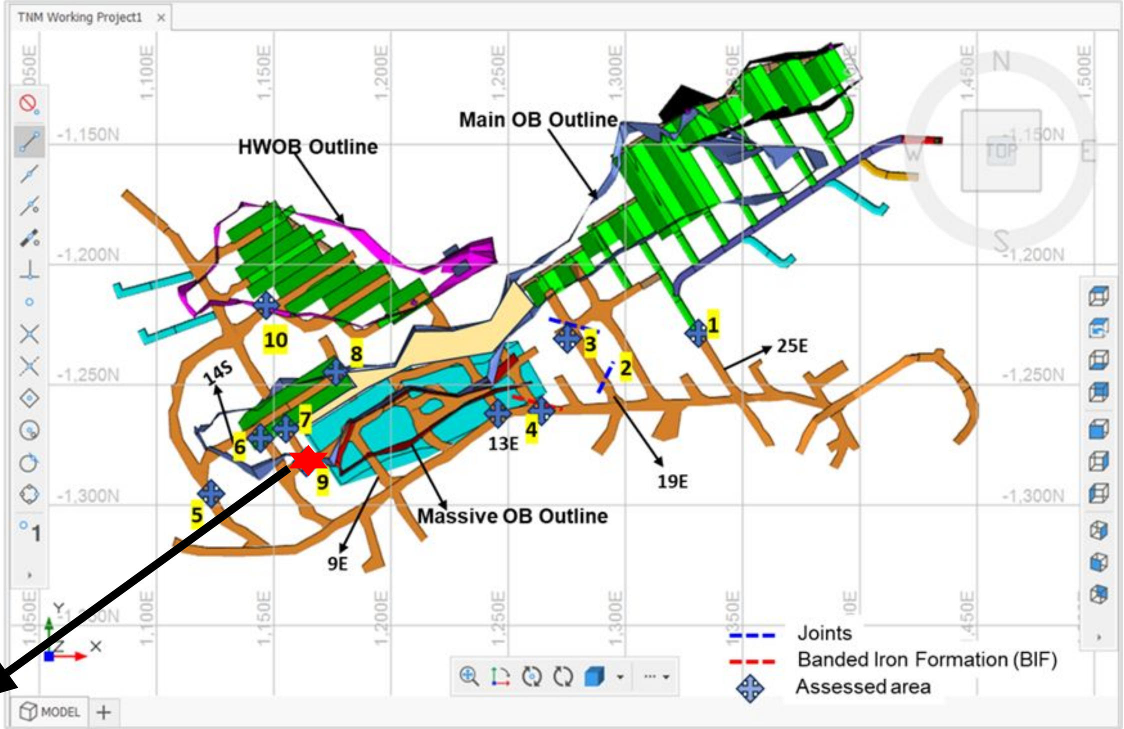
Observation Point8



- Drill holes intended for a slot drive at point 8 were closing due to stope relaxation

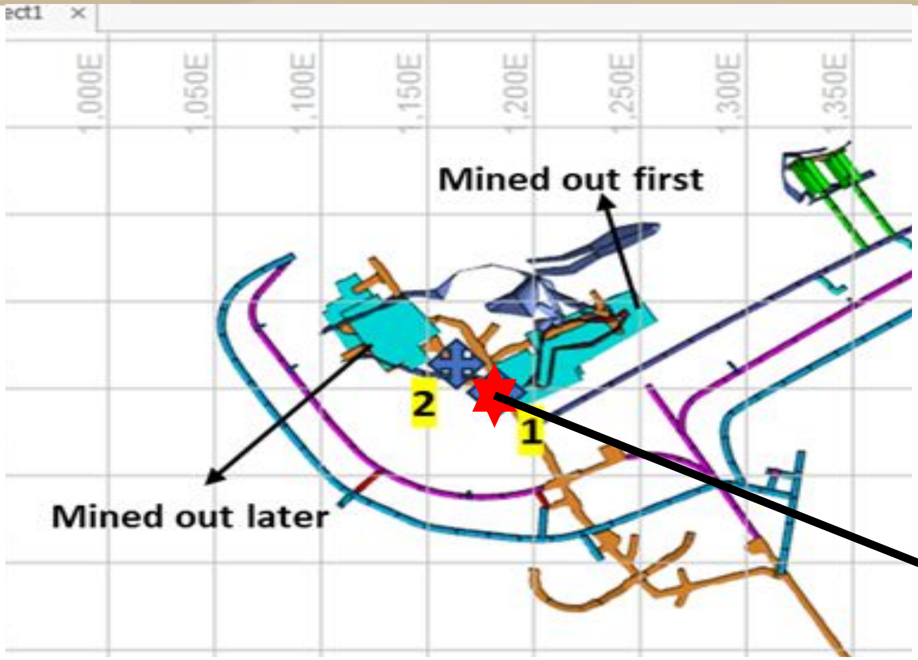
Geotechnical Investigation_37/3L

Observation Point9



- Spalling in the sidewall at point 9, due to the stope abutment

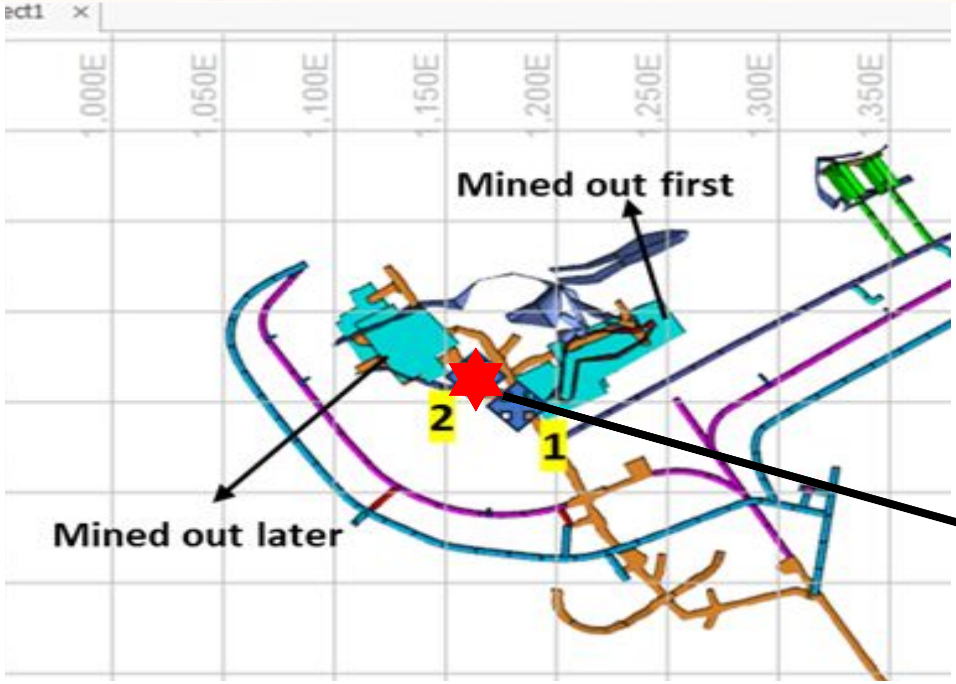
Geotechnical Investigation_41/0L



Observation Point1

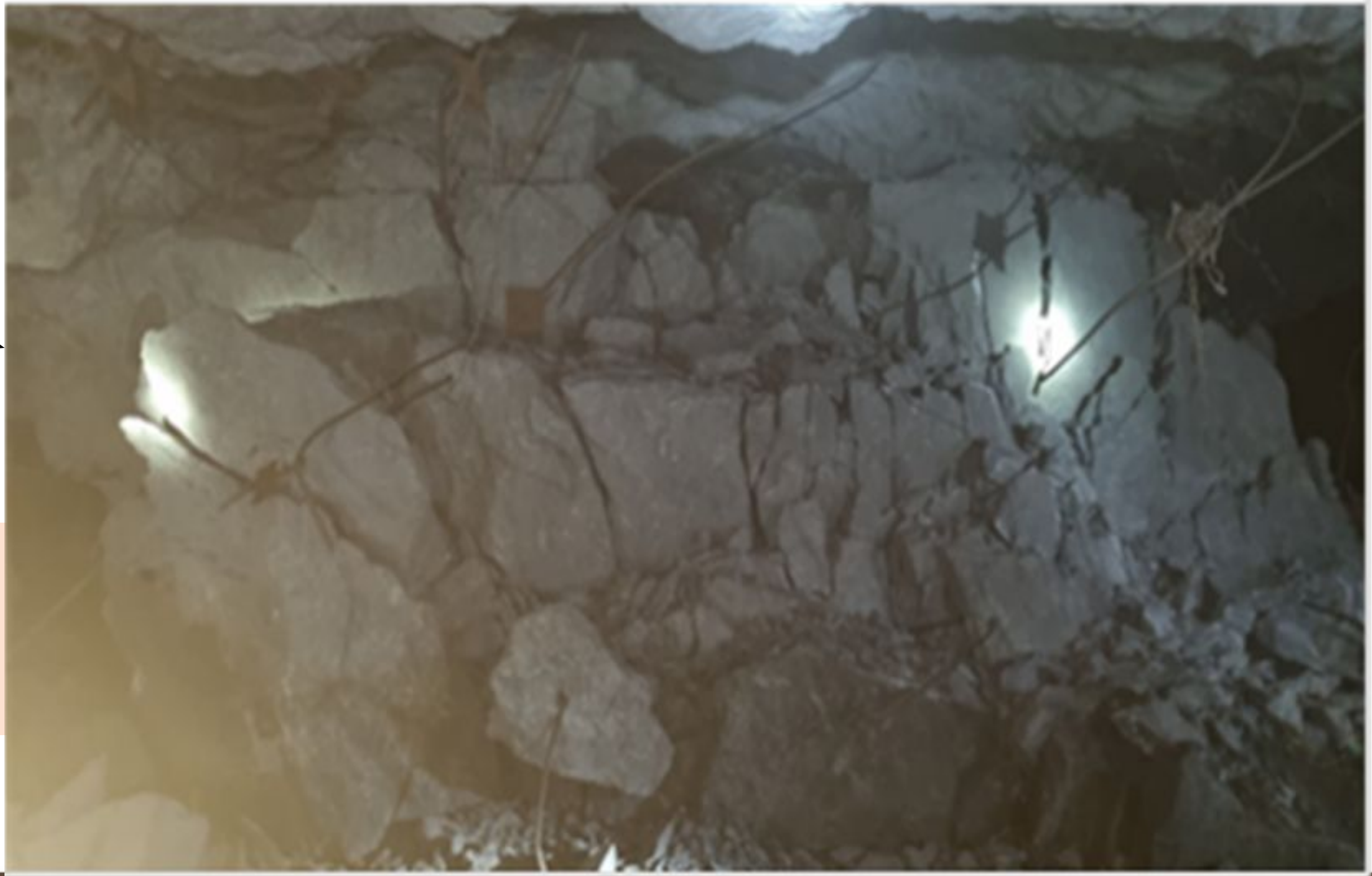
- Fractured observed, damaged support and presence of waste rock that filled the stope was noted at point 1

Geotechnical Investigation_41/0L

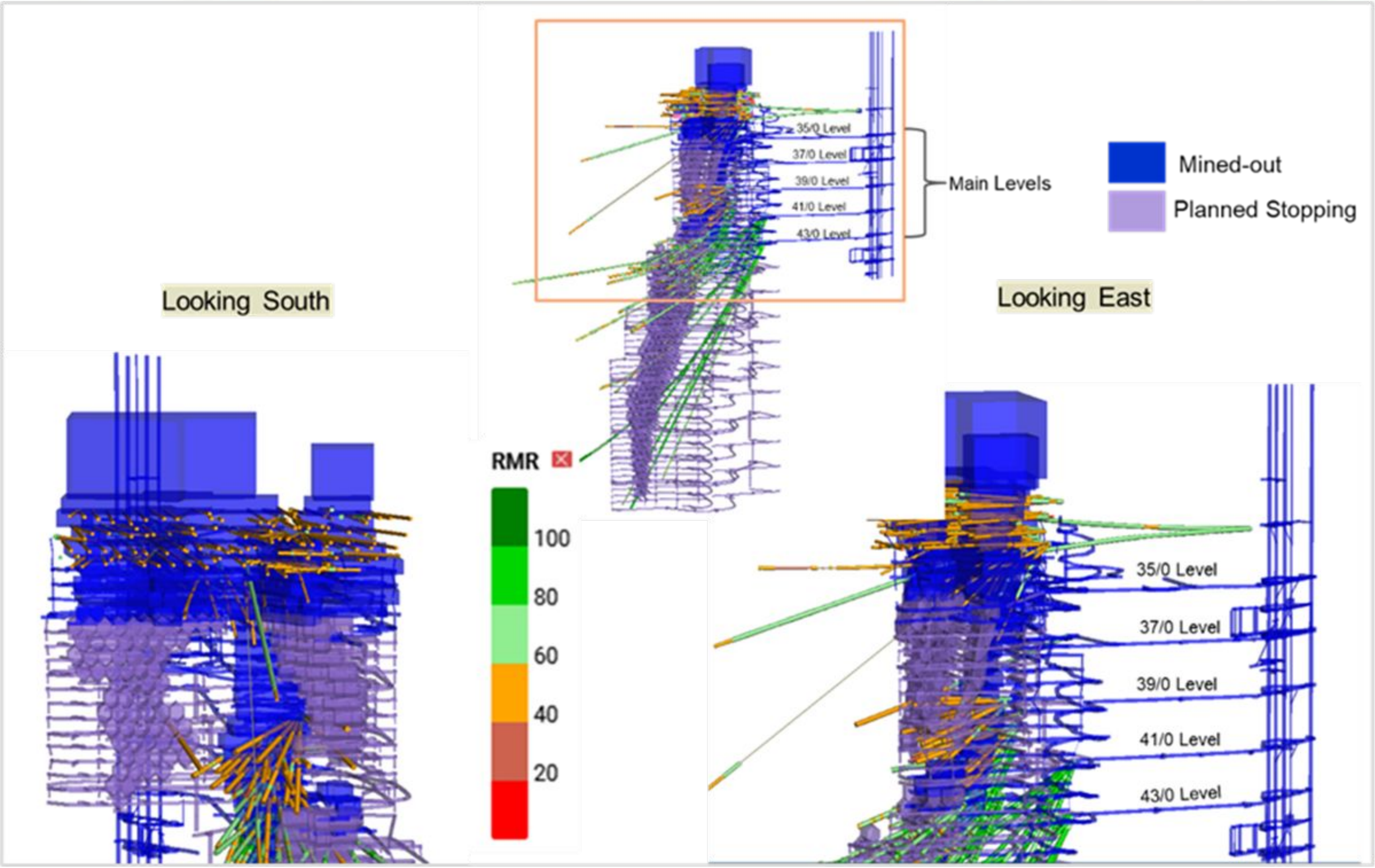


- Thin pillar left between mined-out stope and gathering drive, completely collapsed, causing damage to the drive at point 2

Observation Point2



Geotechnical Data Review



Limited site-specific rock mechanics data.

Designs based on historical mining practices and standards.

Historical exploration drilling targeted high grade Massives orebody (footwall).

Rock Mass Ratings:

- Basalt: Good (RMR 60–80)
- Serpentinite: Fair (RMR 40–60)
- Talc serpentinite which was deteriorated in some sections

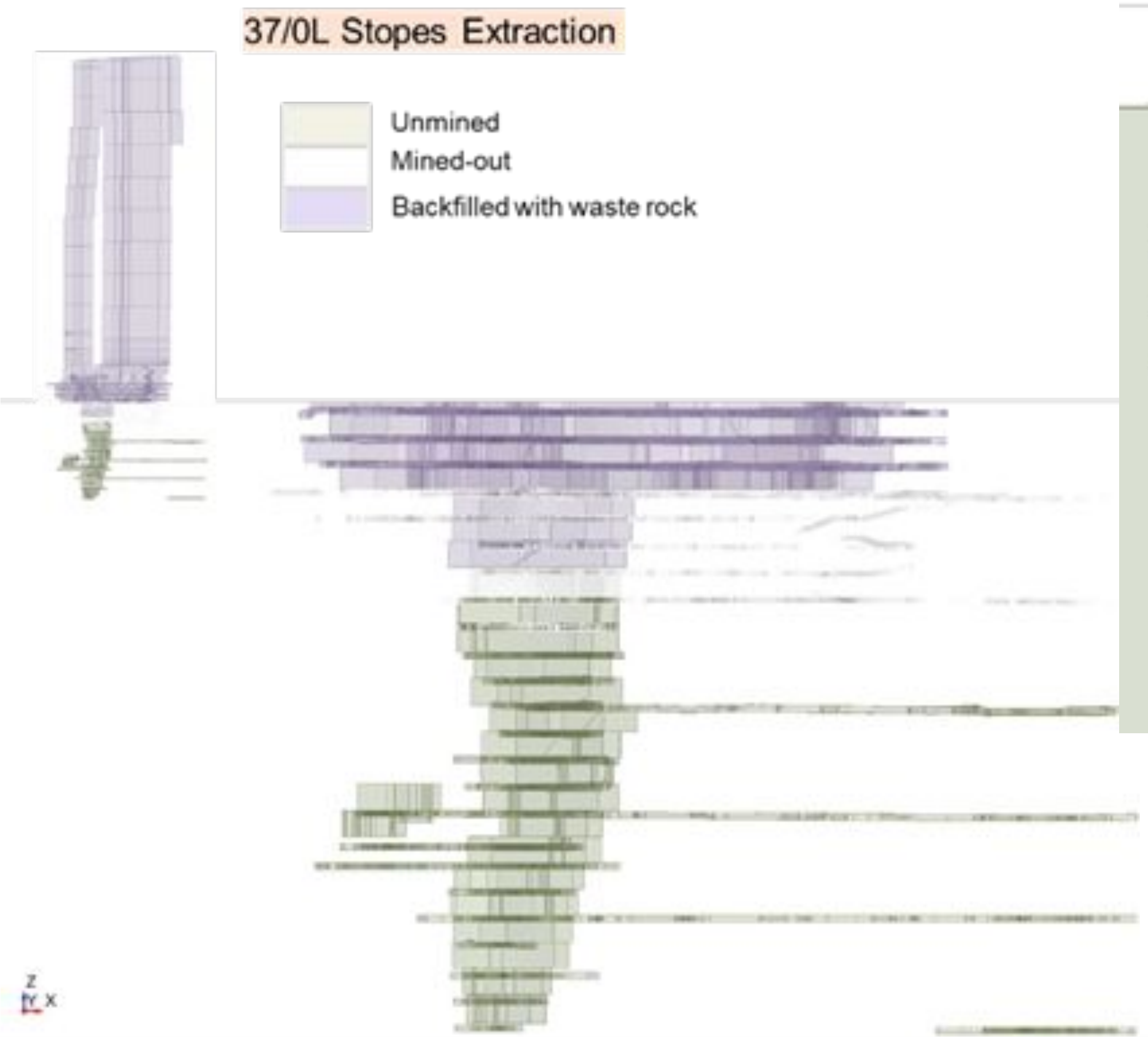
Methodology

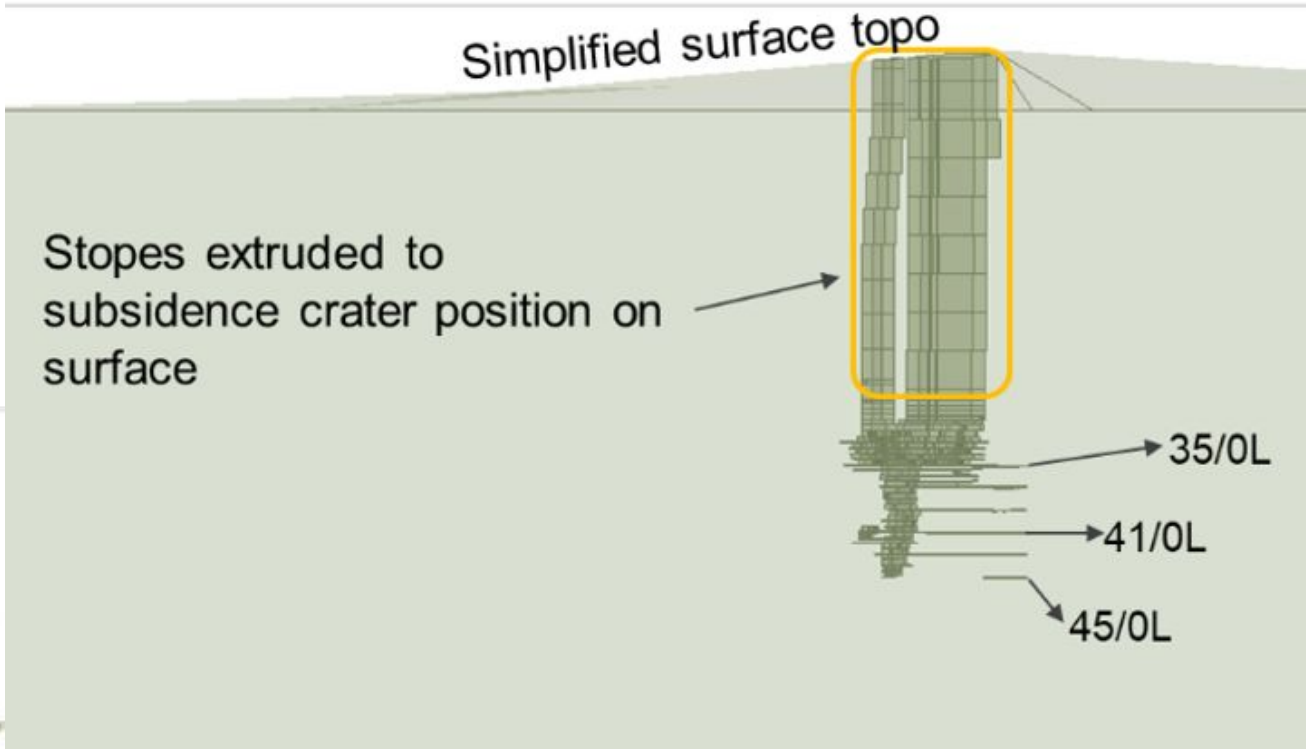
- 3D finite element modelling using RS3 software.
- Elastic modelling to simulate stress build-up during historical mining.

Material Properties

Material	Density (MN/m^3)	H-B properties			M-C properties		E_i (MPa)	Poisson's ratio
		σ_{ci} (MPa)	GSI	m_i	C (MPa)	Φ (°)		
Serpentinite	0.026	80	55	8	-	-	60 000	0.25
Waste Rock	0.016	-	-	-	0.06	30	20	0.35

Numerical Modelling Extraction Sequence





- DXF files of the historical mine design from 31/0L to 45/0L level and surface topography.
- Historical mining between 31/0L and the surface topography was represented by extruding the 31/0L footprint upwards to connect with the surface topography.

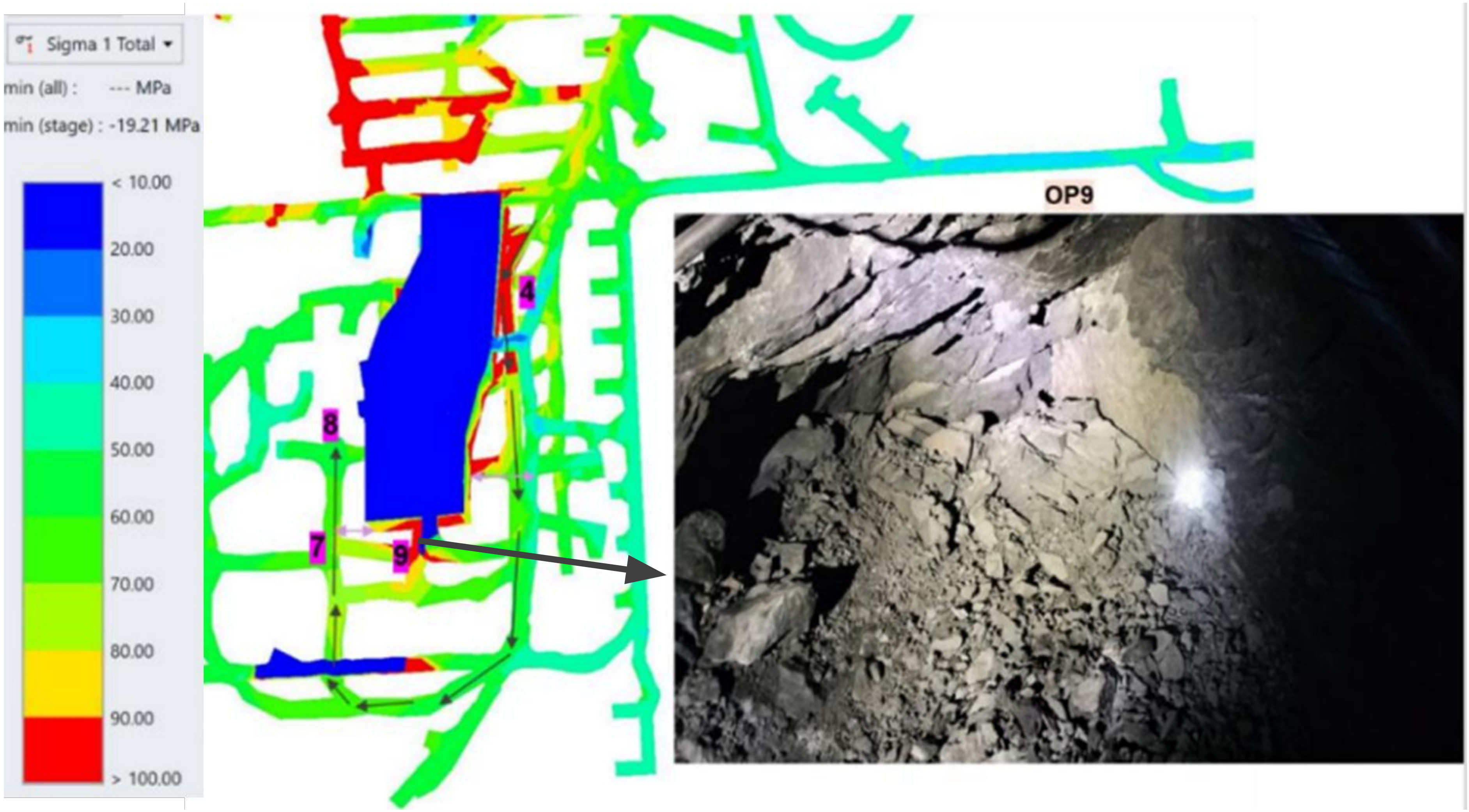
Numerical Modelling Results_37/3L

Plan view of Principal Stresses

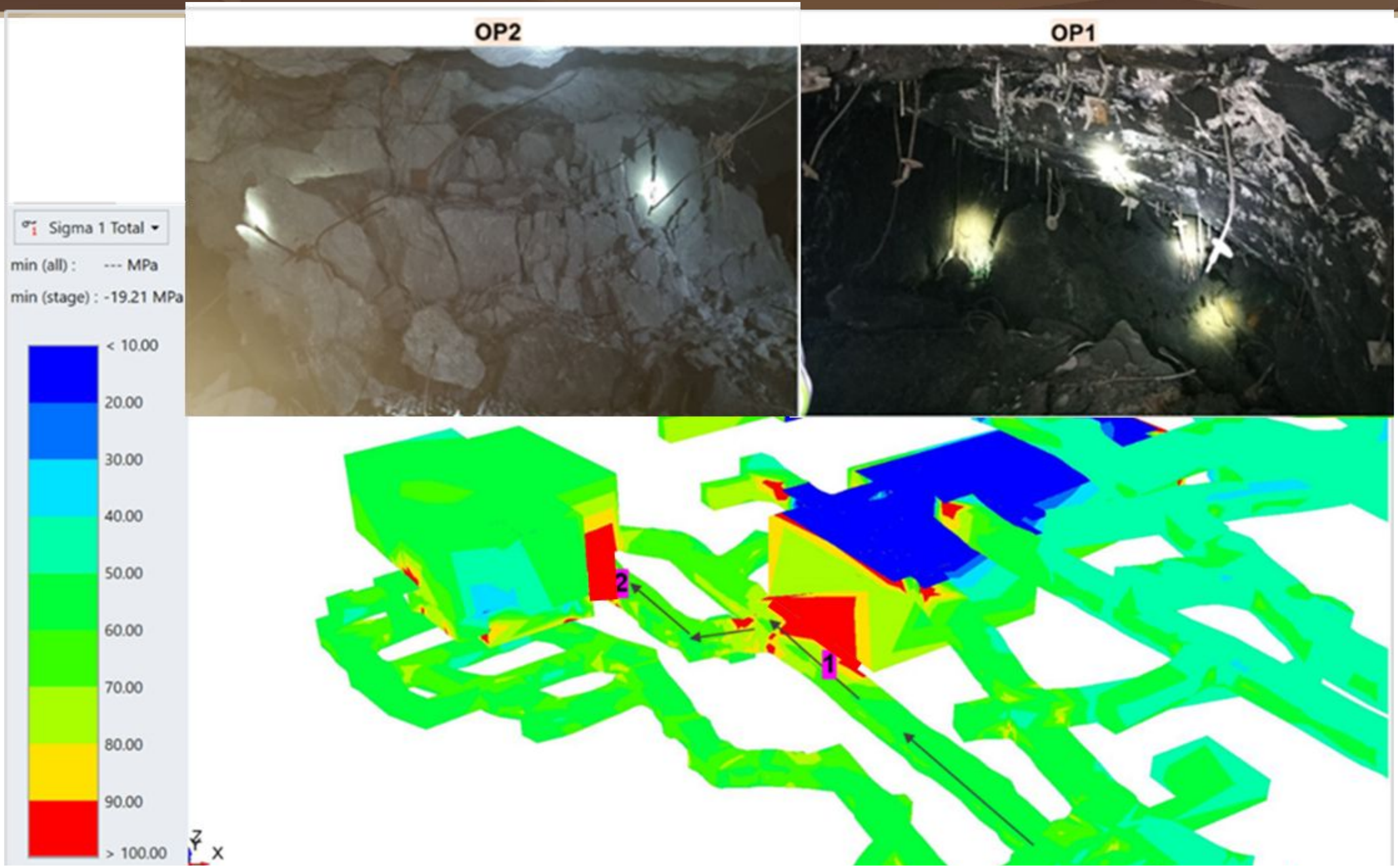
- Stress damage is expected when stress levels exceed 70 MPa, as benchmarked against underground observations.

Stress damage in gathering drive is anticipated when they are located less than 10m from the stope boundary.

Numerical Modelling Results_37/3L



Numerical Modelling Results_41/0L



Proposed Stope Extraction Sequence

- The extraction of stopes should be carefully sequenced to prevent the formation of pillars.
- Mining operations should progress from areas of previously mined stopes towards solid, unmined ground.
- The leads and lags should be planned to limit severe stress damage to the unmined sections.
- In situations where drilling becomes challenging due to relaxation of adjacent stope, a small pillar may be left in place. This pillar will naturally self-mine and can be extracted from the level below.

Proposed Stope Extraction Sequence_37/3L

- Extend the drive from block1 to connect to block2.
- Block 1 is to be mined out in both directions, towards solid ground. Probe drilling to confirm ground conditions.
- Blocks 1, 2 and 3 can be mined concurrently towards solid ground.

Recommendations

Current Challenges:

- Existing support strategies inadequate for moderate to high-stress conditions
- Backlog in mesh installation due to reliance on secondary support

Replace 3.15 mm diamond mesh with 5 mm gauge, weld mesh

Conditions	Support Required
Basalt (low stress)	No support required
Basalt (moderate/high stress)	Rebar, weld mesh in cycle, and cable anchors
Serpentinite (mod/high stress)	Rebar, weld mesh in cycle, and cable anchors
Intersections/Large Spans	Cable anchors and weld mesh in cycle

- **Geotechnical Monitoring:** Implement TARP, regular mapping, inspections, drilling, and inelastic numerical modeling to assess conditions and identify hazards.
- **Hazard Mitigation:** Inspect for cracks, ensure adequate support, and use seismic monitoring to manage risks at deeper mining levels.

Optimal Pillar:

- No pillar required.
  - Some losses due to relaxation of hangingwall of Massives stopes. These may be recovered at lower levels.
- Recommended targeted drilling of immediate hangingwall of the mined out Massives stopes, to establish extend of zone of relaxation.

Feasibility of Mining:

- HWOB and MOB can be extracted with proper sequencing and support strategies.
  - Redevelop and/or site access drives away from influence of stope abutments.
  - Prevent unintentional formation of pillars.
  - Prioritize mining from old stopes towards solid ground, to ensure stability and maximum resource recovery.

Acknowledgements

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THANK YOU