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PIONEERING PROGRESS :
THE FUTURE OF ROCK ENGINEERING

Klipgat boxcut portal entrance and decline system: Long-term stability assessment and monitoring

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BOKONI PLATINUM MINES

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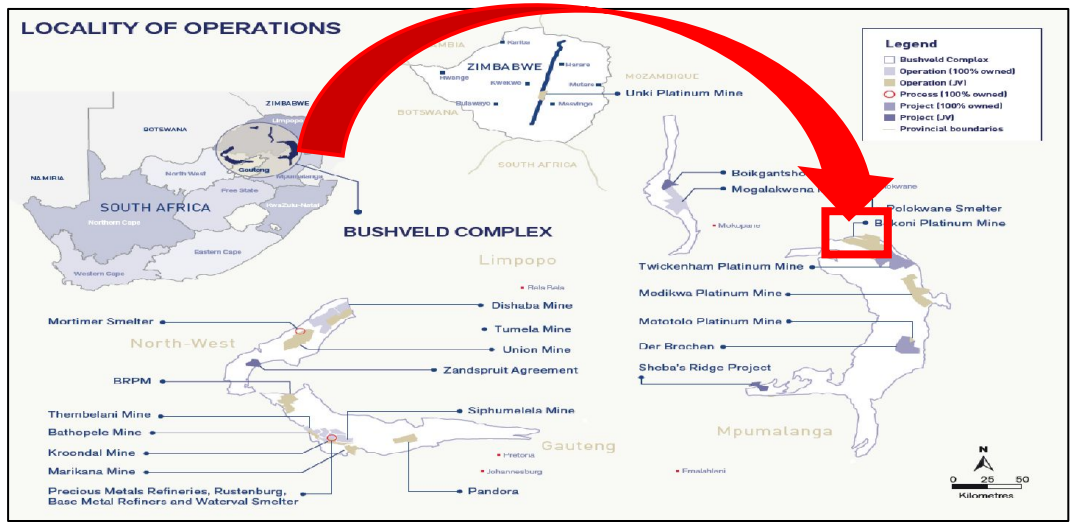
Presentation Outline

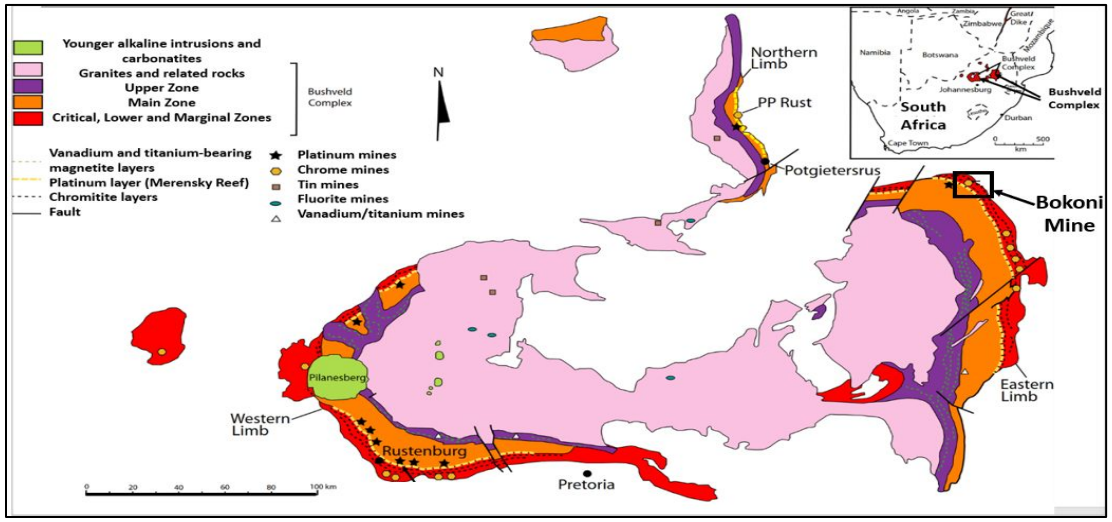
- General Overview
- Geotechnical evaluation and Considerations
- Geotechnical Assessment
- Geotechnical Monitoring
- Conclusion
- Acknowledgements

General Overview-Objectives

- Assess the long-term stability of the Klipgat portal entrance and decline cluster.
- Integrate monitoring using extensometers and InSAR data.
- Pilot Tunnel Reflection Tomography (TRT) for early detection of adverse ground conditions.
- Develop an integrated framework combining empirical, numerical, and monitoring approaches to geotechnical risk management.

General Overview-Locality

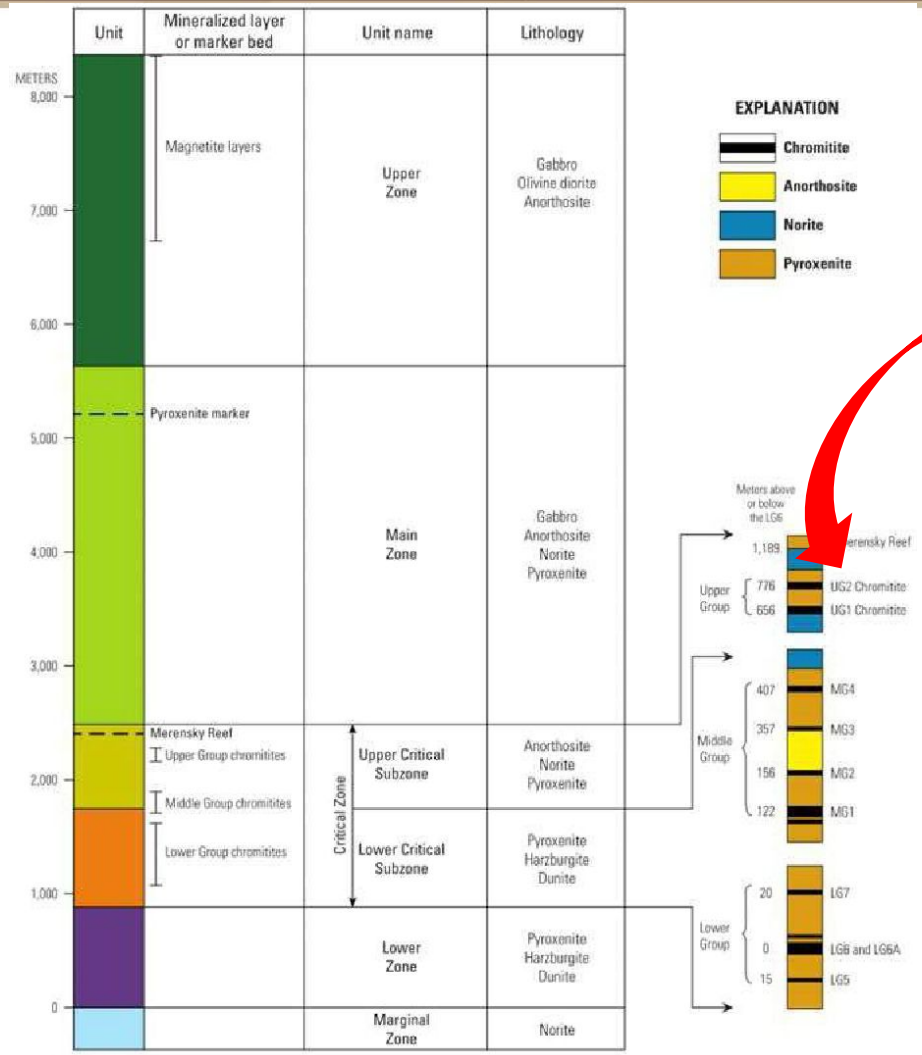


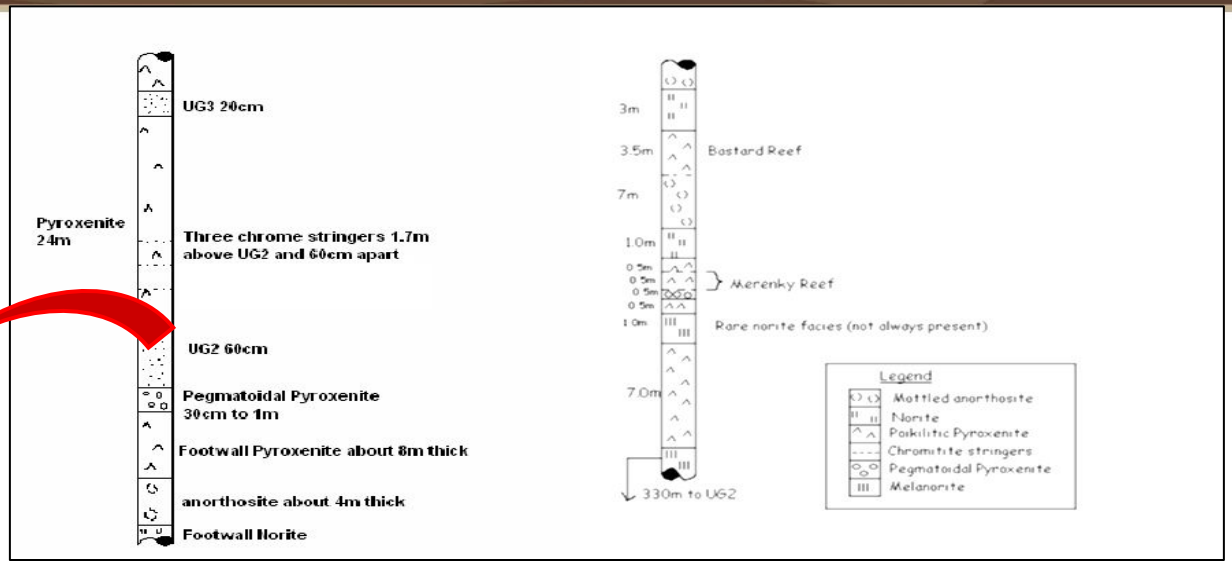


Klipgat Longterm Stability Analyses:

- The Eastern Limb of the Bushveld Complex is located in the Limpopo Province of South Africa
- Bokoni Platinum Mine(previously known as Atok Platinum Mine) is located approximately 80 km southeast of Polokwane, the provincial capital, and approximately 330 km northeast of Johannesburg.
- African Rainbow Minerals owns the mine and has a total strike length of approximately 24.5 km in the northwest-southeast orientation. The critical zone layer dips undisturbed to the south.
- Platinum Group Elements (PGEs), gold, and associated nickel and copper were produced from the Merensky Reef, and lesser amounts from the UG2, before being placed in care and maintenance in 2017.
- The Merensky and UG2 reefs are the two platinum-bearing reefs, and only UG2 is currently being mined.

General Overview-Geology





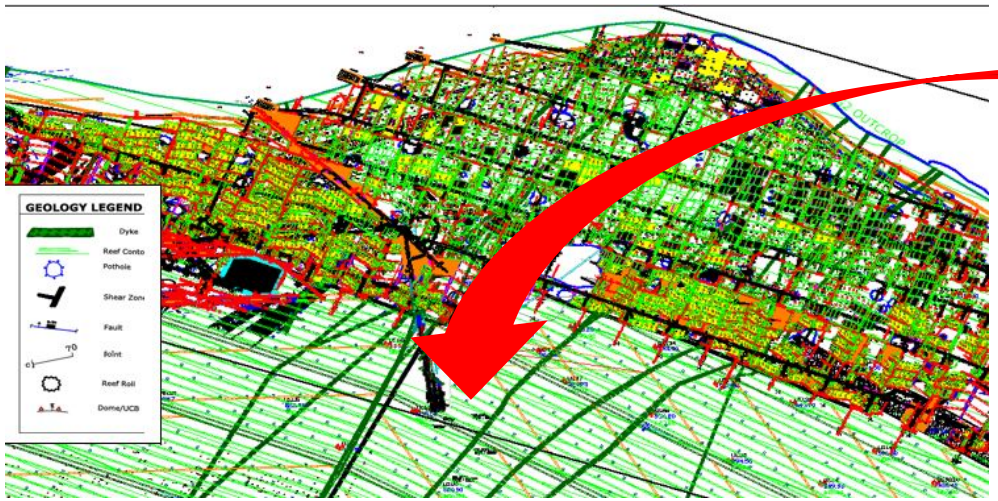
Merensky Reef:

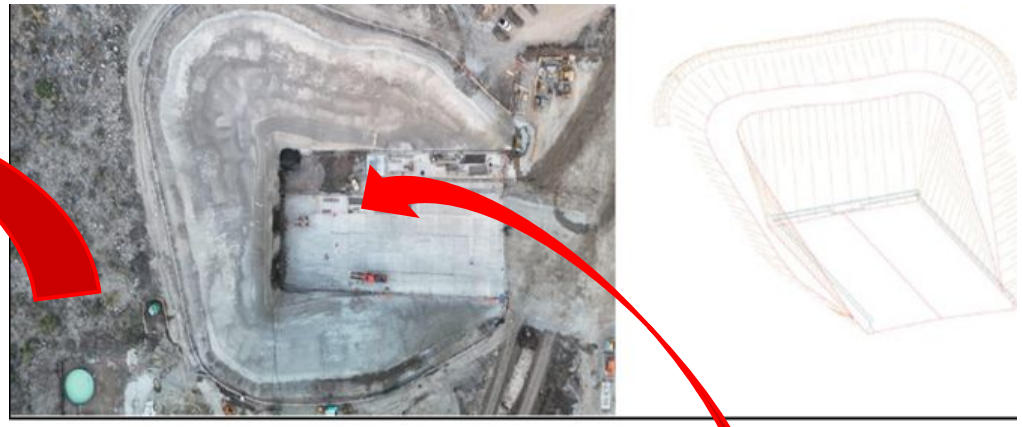
- Merensky Pyroxenite is a stratigraphic unit that occurs in the Upper Critical.
- The high-grade Merensky reef has been extensively exploited, with mining depths between 60 m and 500 m
- The reef dipping between 15° to 25°. It is a persistent, tabular orebody composed of pegmatoid, chromitite, and pyroxenite layers.

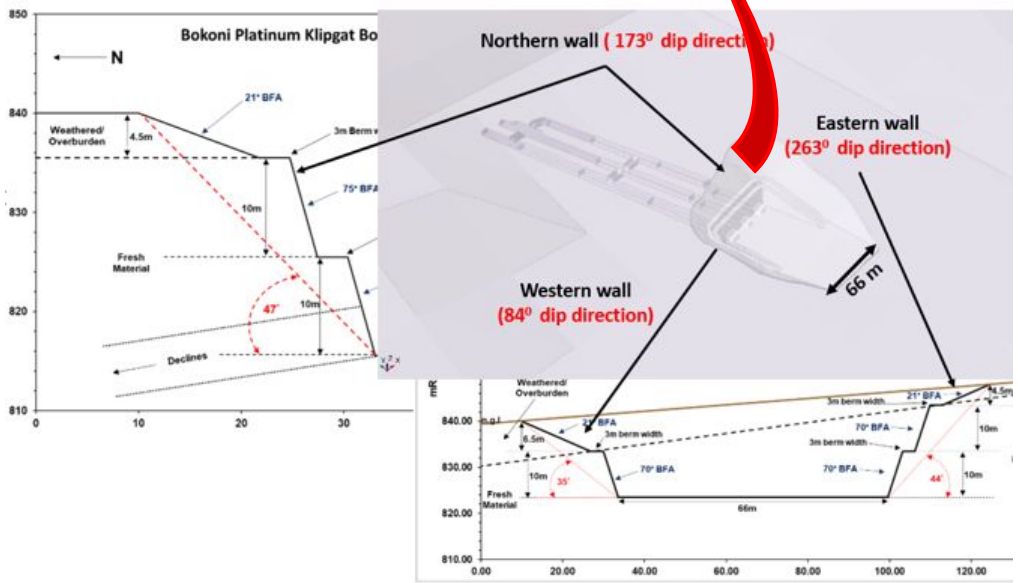
UG2 Reef:

- The UG2 Chromitite Layer occurs as a tabular massive chromitite layer in the Upper Critical Zone.
- The approximate middling between the Merensky and UG2 reefs is about 350 m.
- The UG2 reef historic mining depths vary between 40 m and 290 m and dips between 14° to 22° south.

Geotechnical evaluation and Considerations







Geotechnical Considerations:

- Major geological structures such as dykes, major joint sets, and faults predominantly trend North-West to South-East
- Dyke and shear zones strike length extend over several kilometers, cutting across multiple levels.
- Faults are generally with small throws <2.0m and align parallel to major dykes following the same trend

Geotechnical Assessment: Data Collection and Analyses

	RMR (Mean)	Q(Mean)	Q'(Mean)	GSI (Mean)
Norite (Hanging Wall)	63.55	2.06	-	58.55
Pyroxenite (Hangingwall)	78.25	11.31	22.79	61.61
UG2 Chromitite	62.75	13.73	13.73	57.75
Pegmatoid (Footwall)	76.75	36.18	36.18	71.75

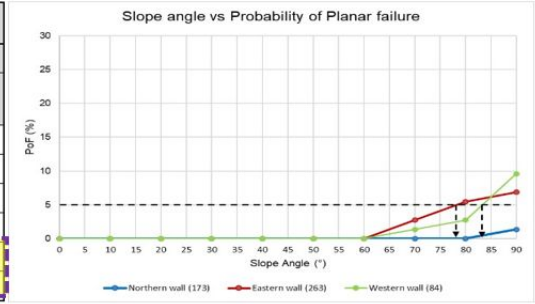
Data Collection and Assessment:

- Core logging and scanline mapping conducted across key lithologies
- Data focused on Hanging wall, foot wall, and reef contact zones
- Utilised RMR, Q-system, and GSI ratings for comparative rock mass quality assessment
- Sample testing and strength characterisation conducted.
- Strength and classification gaps addressed by benchmarking with nearby mines.
- Strength parameters validated using published data and site-specific trends

Rock Properties	Units	Pyroxenite (Intact)	Main UG2 Orebody and Chromitite Leaders (Intact)
GSI	N/A	61.61	57.75
UCS	MPa	140.00	84.02
Tensile Strength	MPa	10	5
mi	N/A	18	15
D	N/A	0	0
M_b	N/A	4.569	3.317
S	N/A	0.014	0.00915
a	N/A	0.503	0.503
Rock Density (p)	Kg/m^3	3250	4000
Unit Weight	kN/m^3	0.03188	0.03924
Cohesion (c)	MPa	7.914	5.941
Friction angle	degrees	41.895	34.852
Young's Modulus	MPa	106500	70290
Poisson's Ratio	-	0.23	0.28
Rock Mass Modulus	MPa	59270	32969
Bulk Modulus	MPa	65741	53250
Shear Modulus	MPa	24089	12881

Geotechnical Assessment: Stability Analysis Approach

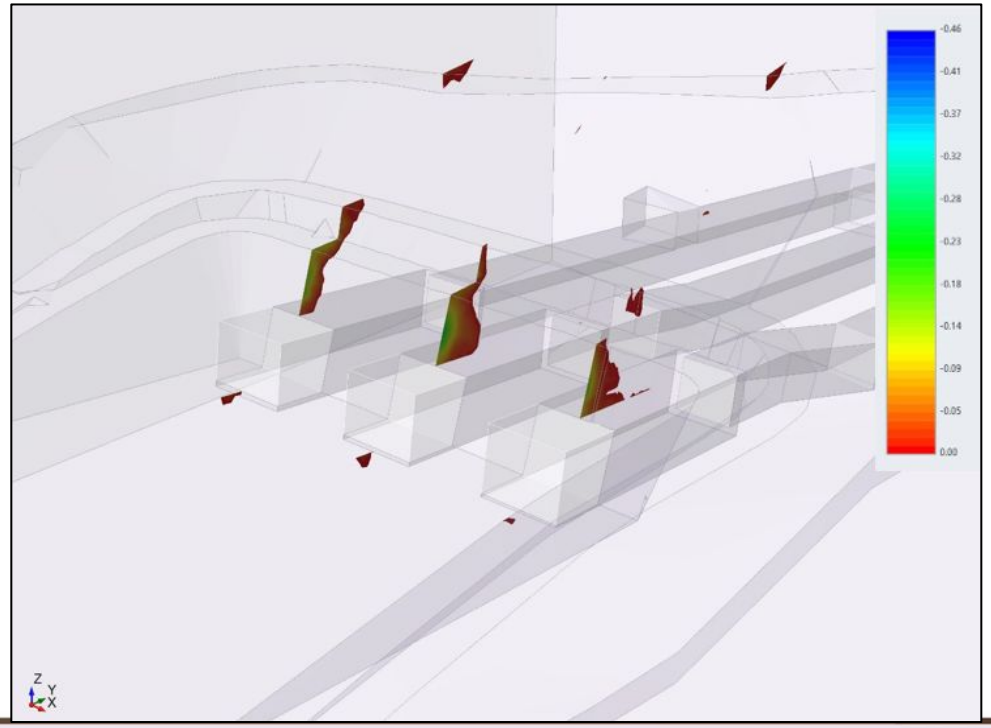
Kinematic analysis - Planar Sliding					
Northern wall (173°)		Eastern wall (263°)		Western wall (84°)	
Dip angle (°)	PoF (%)	Dip angle (°)	PoF (%)	Dip angle (°)	PoF (%)
40	0	40	0	40	0
50	0	50	0	50	0
60	0	60	0	60	0
70	0	70	2.74	70	1.37
80	0	80	5.48	80	2.74
90	1.37	90	6.85	90	9.59



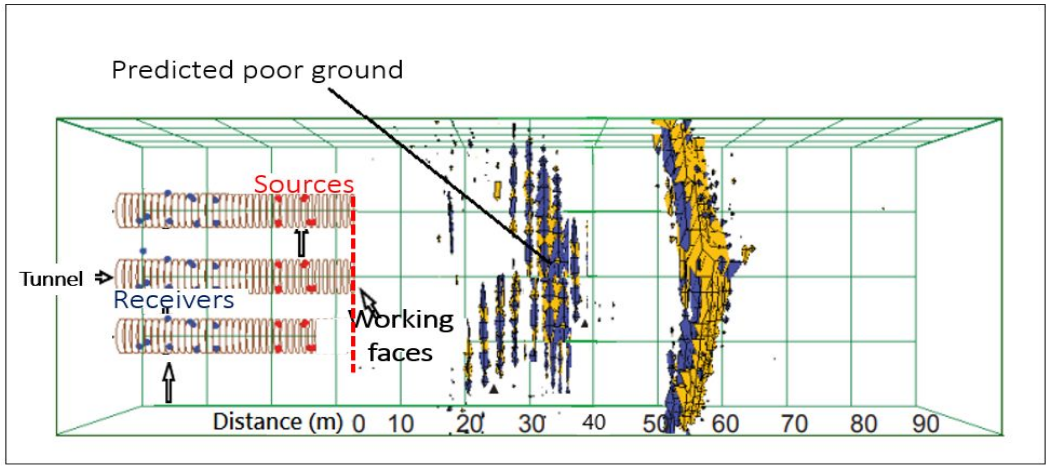
Slope Stability Analysis						
Hydrology	Non-Saturated (Dry)		Saturated		Method Used	Failure Criteria
Geotechnical Design sector	Overall slope Dip angle (°)	FoS	Overall slope Dip angle (°)	FoS		
Northern wall	47	10.51	47	9.57	Janbu Simplified	Mohr Coulomb + Hoek Brown
Eastern wall	44	11.07	44	10.57	Janbu Simplified	Mohr Coulomb + Hoek Brown
Western wall	35	14.89	35	13.89	Janbu Simplified	Mohr Coulomb + Hoek Brown

Stability Analysis Approach :

- Kinematic Analysis assessed the probability of failure (PoF) for planar sliding and wedge failure.
- Used discontinuous orientation data and boxcut wall dip and dip direction to determine kinematic plausibility.
- Key risk identified when slope angles exceed 70-80°.
  - Maximum PoF for planar sliding:~ 9,95% and wedge failure ~27.45% on western wall.
- Overall slope boxcut stability evaluated using M-C and H-B with Slide 6.0
- Factor of Safety (FoS) ranged from 9.57-13.89 for both dry and saturated conditions.
- Finite Element Modelling simulated stress distribution and deformation in decline pillars and the surrounding ground
- Simulated Sigma 3 contours identify critical zones.
- Peak tensile stress observed in the upper 4.0m and enabled evaluation of excavation-induced deformation and reinforcement needs



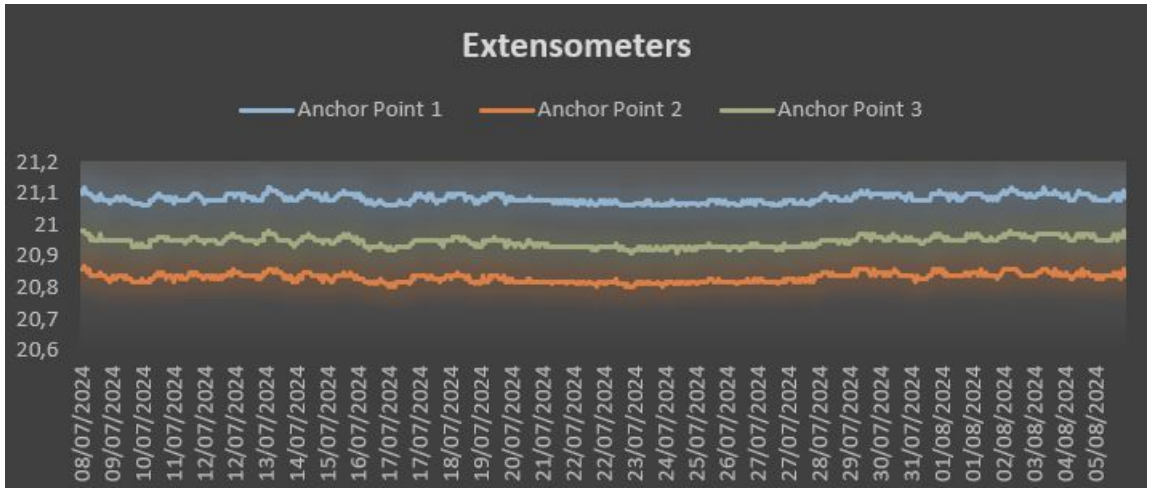
Geotechnical Assessment: Multifaceted Stability Approach

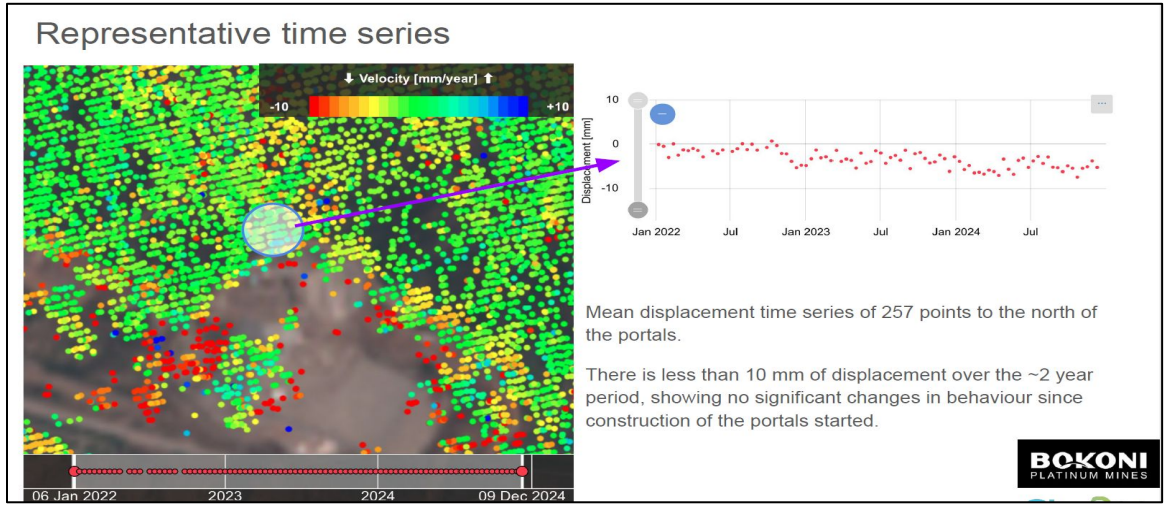


Multifaceted Stability Approach:

- Tunnel Reflection Tomography (TRT) enables real-time detection of adverse geological conditions ahead of advancing decline tunnel faces. using seismic refraction to map fractures.
- using seismic refraction to map structures and weak zones and predicting ground conditions between 40-60m.
- Enhances support design by identifying unfavorable ground conditions before excavation.
- When combined with other tools such as numerical modeling, TRT improves decision making.

Geotechnical Monitoring: Long-term Monitoring and Early Warning





Extensometer Monitoring :

- Bluetooth-linked 3-point extensometers were used to monitor displacement at the 3 declines and the Early Warning extensometer.
- Bluetooth-linked extensometer captured minimal displacement of <1mm over one month.
- Minor fluctuations can be attributed to thermal effects, natural stress redistribution, or rock mass adjustment
- Early warning extensometers are used as part of the entry examination. Flashes light based on the trigger level.
- Trigger levels are linked to a TARP system.
- No visual alert triggered – indicates stable ground conditions

InSAR Monitoring:

- Tracked displacement across 257 ground points.
- Detected <10mm/year displacement- within safe limits.
- Slight movement near the portal attributed to vegetation removal and boxcut excavation.
- Confirms no significant change in behavior since construction began.

Conclusions

- Integrated approach combined geological surveys, numerical modelling, TRT imaging, and real-time monitoring to assess tunnel and excavation stability.
- Rock mass showed minimal displacement but localized weak zones due to weathering may still require adaptive reinforcement.
- Support system (Rock bots, blast-on mesh, shotcrete) has proven effective, especially at the decline entrances.
- Finite element modelling enabled simulation of stress distribution and identification of failure zones.
- TRT enhanced proactive planning by detecting adverse geological conditions ahead of mining.
- Kinematic analyses identified key failure modes: Planar sliding, wedge failure, and toppling.
- Application of empirical classification systems (RMR89, Q, GSI) supported site specific support design.
- Emphasised need for ongoing refinement of classification models due to variability in rock mass conditions.
- Future integration of AI and machine learning will enhance predictive monitoring and risk management.

Acknowledgements

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