Rockbursts Characterization in the Merensky Reef: A Case Study in Siphumelele Platinum Mine, South Africa

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Introductions

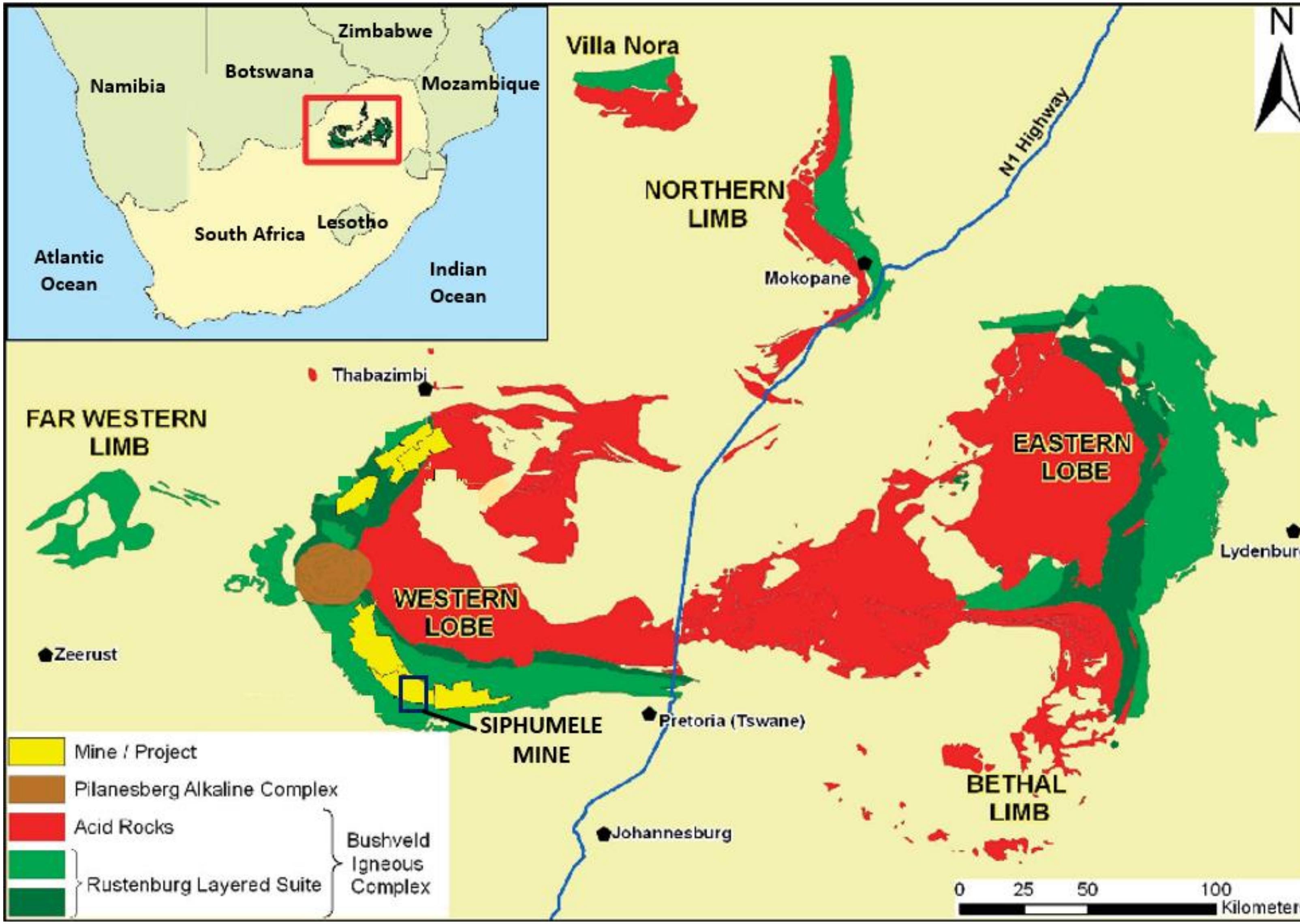
- There are things we know that we know, and they are implemented, or should be.
- There are things we know that we don't know, and they are researched, or should be. (Emphasis placed on more knowledge production than re-production)
- There are things we don't know that we don't know, and, we don't know.
- We are trying to solve challenges that were solved before and never were documented.
- Void is left in system when generation retires/leaves without having shared relevant skills.

Big Questions:

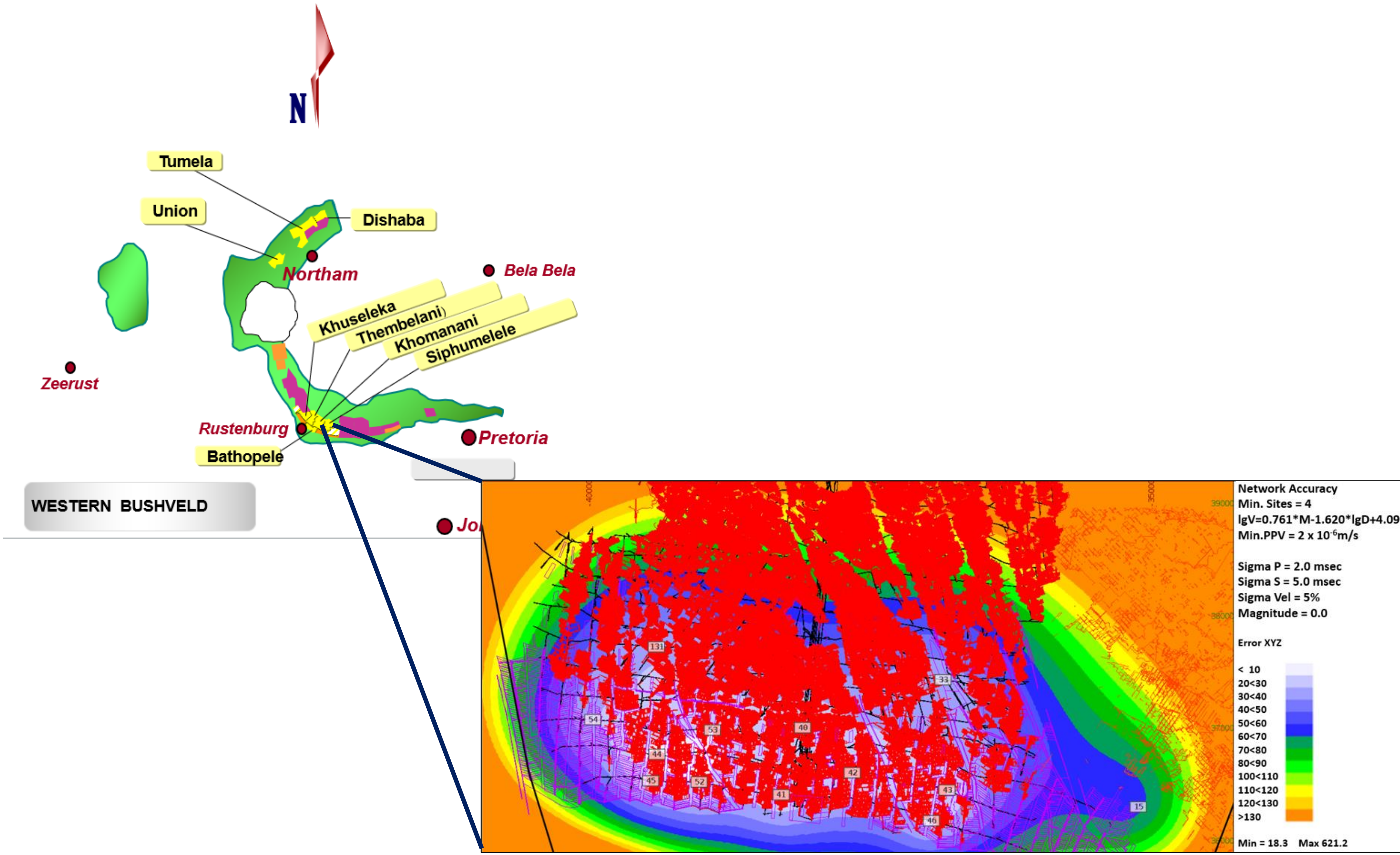
- Are we transferring and sharing enough of the knowledge we have built up?
- How quickly is the process of knowledge transfer taking place?

Consequences of poor or lack of knowledge transfer in organizations and society = **Knowledge Gap OR Knowledge Crash**

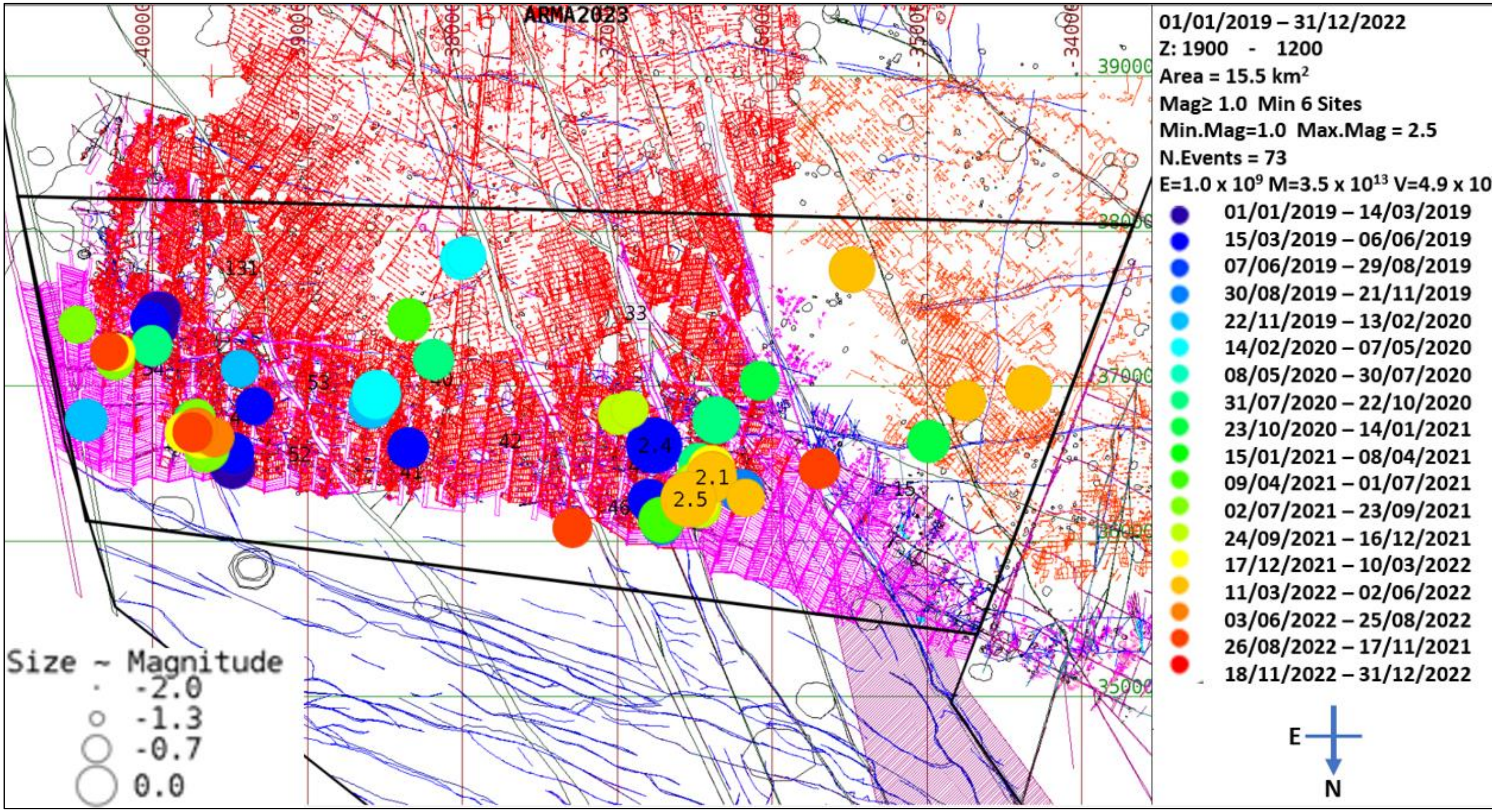
Locality: Western Bushveld Complex



Locality and System Location Accuracy



Subset of seismic events within the Merensky Reef



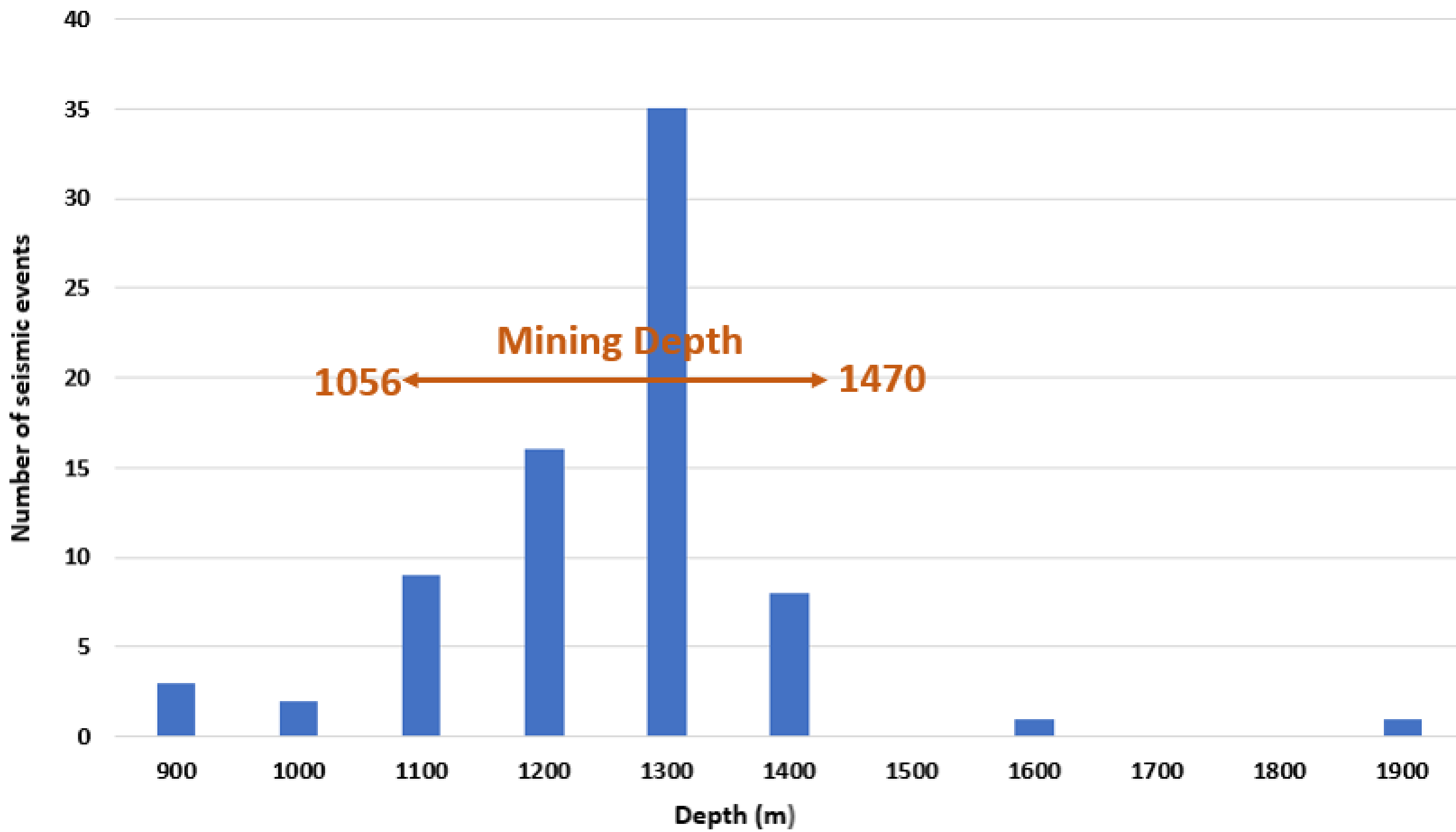
Data selection criteria

- This system comprises 17 4.5 Hz tri-axial geophones sampling at 6 kHz
- The study focused on 73 large ($1.0 \leq M_L \leq 2.5$) seismic events recorded at 12 or more sites and located within the central part of the in-mine seismic network
- Only seismograms with a good signal-to-noise ratio of both P- and S-wave arrivals were used to ensure accurate picks of arrival times
- Sorting the seismic events by the number of recording stations with verified sensor orientations
- The locations were determined manually using the Trace processing software using the body wave arrival times.
- The picks were checked and refined until the location residual was less than 100 m, or 3% of the average distance between the event and the sites.

Moment Tensor Inversion and the (Es/Ep) ratio

- The Energy ratio (Es/Ep) together with Moment Tensor Inversion were both used to classify seismic events.
- Because the Es/Ep parameter alone is too unstable to be used as the classification method.
- This is because when the sensor, path, and source effects are not properly monitored, the calculation of the P- and S-waves energy can be influenced.
- This can impact the confidence in using the parameter Es/Ep ratio alone to characterize seismic events.
- Moment Tensor is more stable parameter to characterize seismic events as compared to the Es/Ep, but the combination is better when in Unison.

The distribution of seismic events in different mining levels within the Merensky Reef orebody

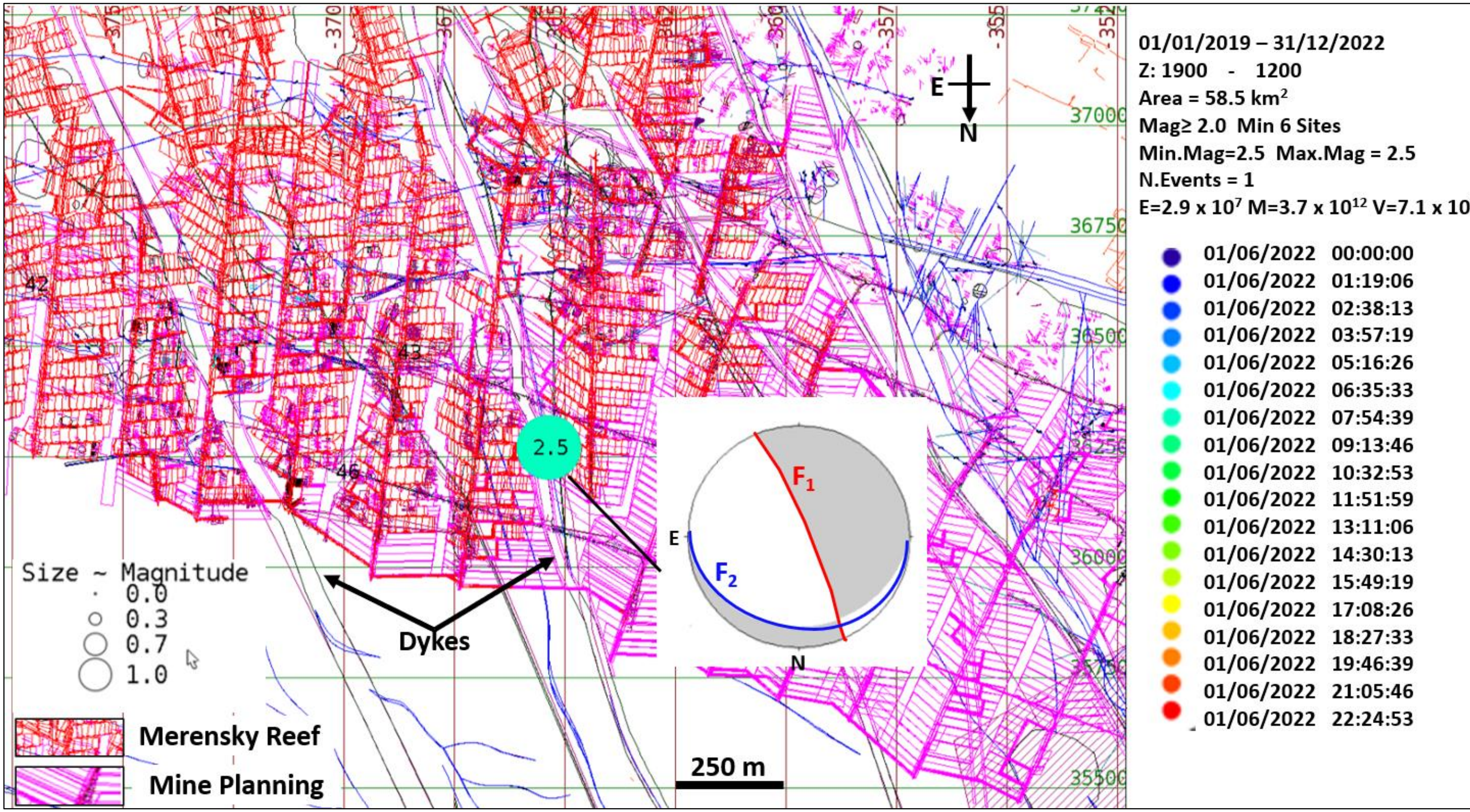


Causes and contributing factors

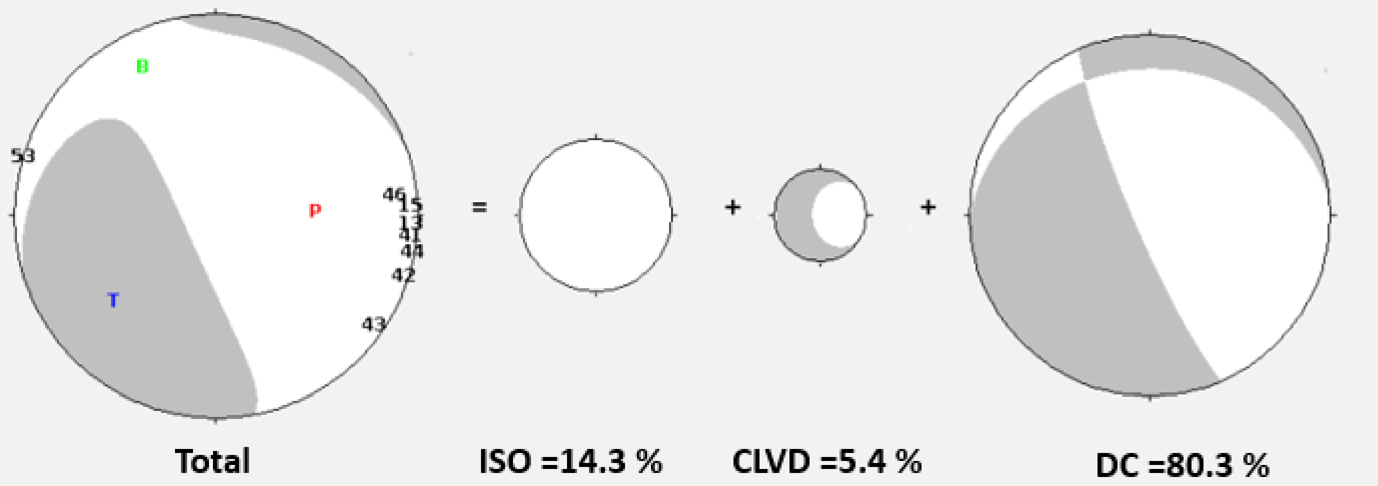
- Pillars & remnants
  - Current pillar cutting discipline?
  - Influence of oversize crush pillar?
  - Influence of rock type?
  - Influence of rockmass competence?

- Geological structures?
- Rockmass conditions?
- Influence of stress?

Fault Plane Solutions (FPS)



Moment Tensor Analysis



- **Nodal Planes**
  - **1: Strike = 157^0 Dip = 83^0 Rake = -71^0**
  - **2: Strike = 256^0 Dip = 20^0 Rake = -158^0**

The fault plane solution (F_1) is compatible in orientation with the North-West striking dyke.

Energy Ratio (Es/Ep) of the M2.5

Sibanye Stillwater — we are one

Location	
South [m]	36270.8
West [m]	-36537.1
Up [m]	-71.0
Residual [m]	18.1
% of AHD	1.8
Origin Time	08:39:25.562009

Source (Manual, omega-square)	
Local Magnitude	2.5
Moment Magnitude	2.3
Seismic Moment [Nm]	3.7×10^{12}
Radiated Energy [J]	2.9×10^{7}
Log Potency	2.1
Static Stress Drop [MPa]	1.1
Log Energy	7.5

Information

01 Jun 2022

08:39:25.741693016

Details

Local Magnitude	2.5	Corner Frequency (f_0)	13.2 Hz
Moment Magnitude	2.3	Log Potency	2.1
Potency (P)	1.1×10^{2} m^3	Energy Ratio (E_S/E_P)	17.3
Moment (M)	3.7×10^{12} Nm	Max Slip Velocity ($\acute{U}_{max}$)	6.3×10^{-2} m/s
Energy (E)	2.9×10^{7} J	Corner Freq Ratio (f_{0P}/f_{0S})	0.7
Apparent Stress (σ_A)	2.6×10^{-1} MPa		
Static Stress Drop ($\Delta\sigma$)	1.1 MPa	Source Size (L)	1.2×10^{2} - 2.2×10^{2} m
Dynamic Stress Drop ($\Delta\sigma_H$)	1.4 MPa		

P Wave		S Wave	
Moment [Nm]	5.2×10^{12}	Moment [Nm]	2.2×10^{12}
Log Potency	2.2	Log Potency	1.8
Energy [J]	1.6×10^{6}	Energy [J]	2.8×10^{7}
Corner Freq [Hz]	9.6	Corner Freq [Hz]	13.2
Ω_0	3.1×10^{-4}	Ω_0	8.8×10^{-4}

The following summary of the source mechanisms observed at Siphumelele Mine emerged

- 68% relates to elements of the mining geometry (pillars, abutments, and back-areas);
- 32% - located near known geological structures (faults, dykes).
- Shear component (DC) dominated most $M_L>2.0$, corresponding to a higher energy ratio ($Es/Ep \geq 10$).
- Fifty-one seismic events ($1.0 \leq M_L \leq 2.5$) with non-shear, related to pillar bursts and/or foundation failure, were identified at 907≤depth(m) ≤1460 beneath and above the Merensky Reef.
- Twenty-two seismic events ($1.0 \leq M_L \leq 2.5$) were identified to have a dominating shear component. Locates at 1226 ≤ depth(m) ≤ 1470
- Approximately 70% of these seismic events are located in or close to the previously investigated falls of ground and damaged pillars.
- About 30% of these seismic events were not associated with any identifiable damage.

Summary (cont…..)

- For the M_L2.5 seismic event, the Fault Plane Solution (FPS) aligned with a dyke striking North-West. Dynamic loading on the structure and the build-up of stress over time might have triggered the seismic event.
- About 70% of the 51 non-shear events indicates a dominant isotropic (ISO) component (high volume change).
- Of the 22 shear-type events, only 64% indicated a dominant DC component with a low CLVD (indicating that uniaxial deformation did not formed part of the event).
- Most low CLVD observed at shallower depth than those that are CLVD dominant, plotting mainly between 1000 and 1400 m, close to the orebody horizon.
- Thirty-five of the 51 non-shear (68%) seismic events were related to the Merensky Reef's pillars, abutments, and back areas.
- Some events plotting near the geological structure had their FPS not align with either structure but rather with the abutment of the irregular-shaped pillars in the back areas.

Designs & mitigating measures

- Crush pillar design
- Mining layouts & support
- Haulage location
- Regional stability

Future:

- Mine deeper
- Mining more extensive
- Larger stress influence
- Stress fracturing
- Structurally controlled seismicity?
- Natural seismicity?
- Backfilling?

Acknowledgement

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QUESTIONS?