# FOGAP1
# SEISMIC RISK ASSESSMENT

SUMMARY OF PROCEDURES IMPLEMENTED ON SOUTH AFRICAN
AU AND PGM MINES

F. ESSRICH, 11/06/2024 (TEAMS)

CSIR
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FROM DATA TO KNOWLEDGE

MINERALS COUNCIL
SOUTH AFRICA

# SCOPE

- Item C – Task 20: Literature study on publications/research wrt. local seismic hazard assessment systems ✓
- Item C – Task 30: Review summary by IMS on data collated wrt. current SHA systems and practices on local mines; fill gaps where required ✓
- Item C – Task 40: Present summary and provide feedback to research team on local practice
- Item D – Task 50: Perform detailed review and gap analysis between currently implemented SHA procedures and best practice
- Item E – Task 60: Provide feedback to RETC and assist with drafting a proposed system / procedure for the industry.

# FEEDBACK

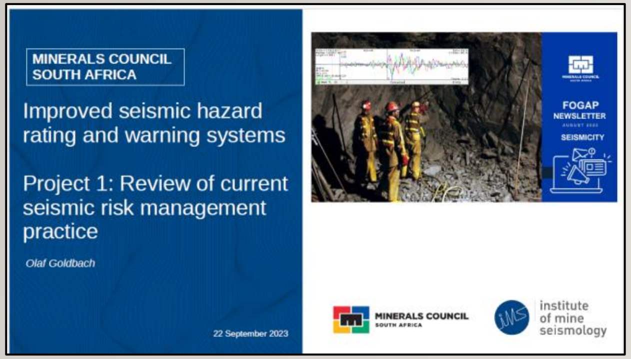
- Item C – Task 20: Literature study on publications/research wrt. local seismic hazard assessment systems ✓

Three main categories are evident in the over one hundred local publications suggested for this review (past 30 years, after the introduction of digital seismic systems):

A. Fundamental research into mechanisms and underlying principles relevant to dynamic rockmass failure, wave propagation and damage to mining excavations;
B. Experimental research proposing new methodologies and procedures that could potentially improve seismic hazard quantification and risk mitigation, e.g. pre-conditioning, secondary source parameters and rock mass modelling;
C. Guidelines and best practice recommendations based on Category A and B outcomes.

# FEEDBACK

- Item C – Task 30: Review summary* by IMS on data collated wrt. current SHA systems and practices on local mines; fill gaps where required ✓



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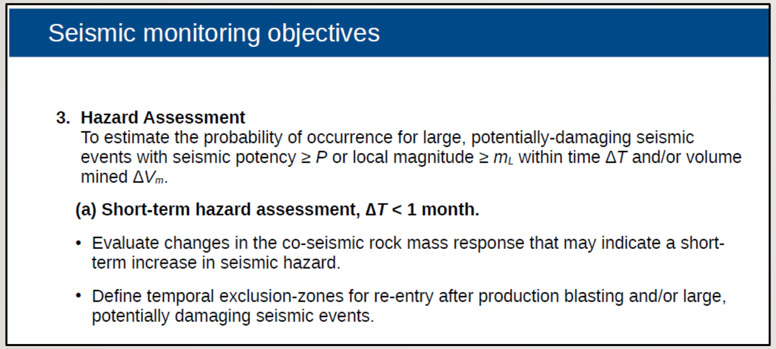
Improved seismic hazard rating and warning systems

Project 1: Review of current seismic risk management practice

*Olaf Goldbach*

22 September 2023

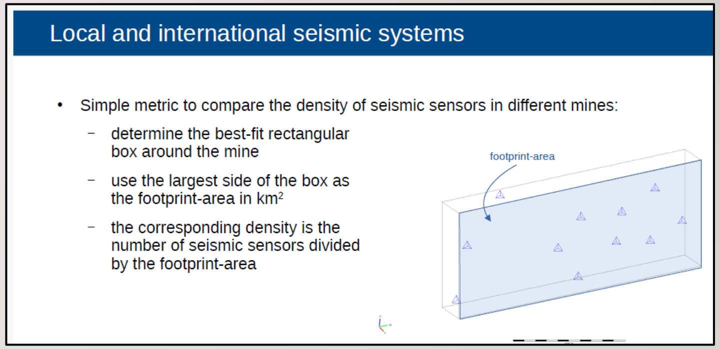


## Seismic monitoring objectives

3. **Hazard Assessment**
   To estimate the probability of occurrence for large, potentially-damaging seismic events with seismic potency ≥ $P$ or local magnitude ≥ $m_L$ within time $\Delta T$ and/or volume mined $\Delta V_m$.

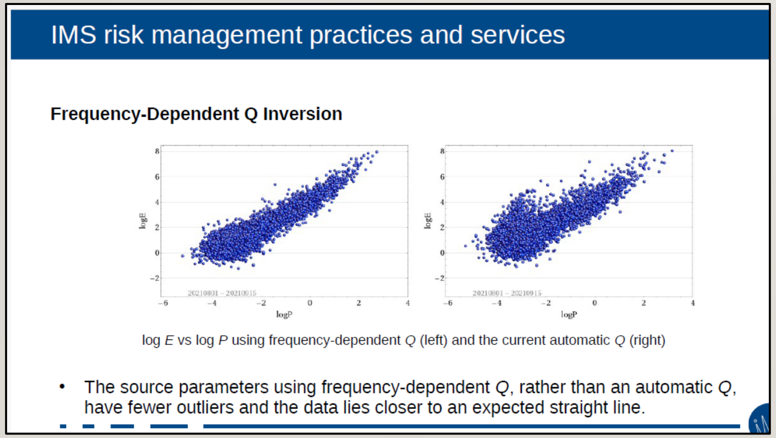
**(a) Short-term hazard assessment, $\Delta T$ < 1 month.**

- Evaluate changes in the co-seismic rock mass response that may indicate a short-term increase in seismic hazard.
- Define temporal exclusion-zones for re-entry after production blasting and/or large, potentially damaging seismic events.



## Local and international seismic systems

- Simple metric to compare the density of seismic sensors in different mines:
  - determine the best-fit rectangular box around the mine
  - use the largest side of the box as the footprint-area in km$^2$
  - the corresponding density is the number of seismic sensors divided by the footprint-area

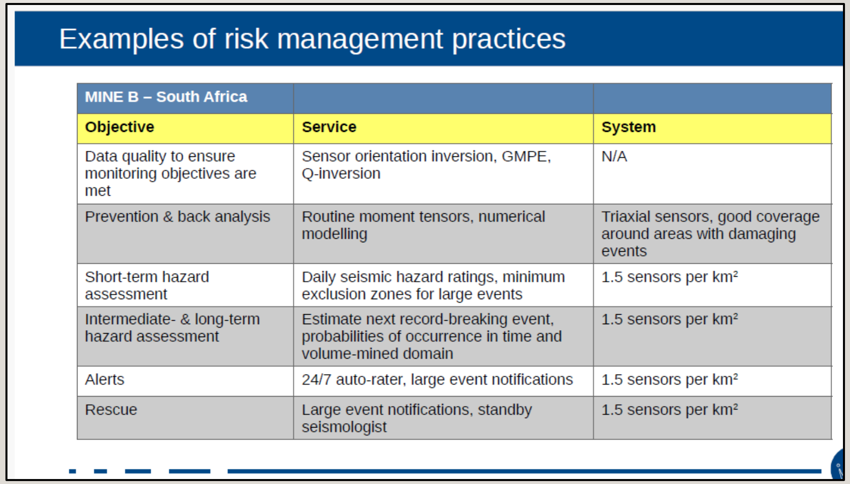


## IMS risk management practices and services

**Frequency-Dependent Q Inversion**

log $E$ vs log $P$ using frequency-dependent $Q$ (left) and the current automatic $Q$ (right)

- The source parameters using frequency-dependent $Q$, rather than an automatic $Q$, have fewer outliers and the data lies closer to an expected straight line.



## Examples of risk management practices

| MINE B – South Africa | | |
|---|---|---|
| **Objective** | **Service** | **System** |
| Data quality to ensure monitoring objectives are met | Sensor orientation inversion, GMPE, Q-inversion | N/A |
| Prevention & back analysis | Routine moment tensors, numerical modelling | Triaxial sensors, good coverage around areas with damaging events |
| Short-term hazard assessment | Daily seismic hazard ratings, minimum exclusion zones for large events | 1.5 sensors per km$^2$ |
| Intermediate- & long-term hazard assessment | Estimate next record-breaking event, probabilities of occurrence in time and volume-mined domain | 1.5 sensors per km$^2$ |
| Alerts | 24/7 auto-rater, large event notifications | 1.5 sensors per km$^2$ |
| Rescue | Large event notifications, standby seismologist | 1.5 sensors per km$^2$ |

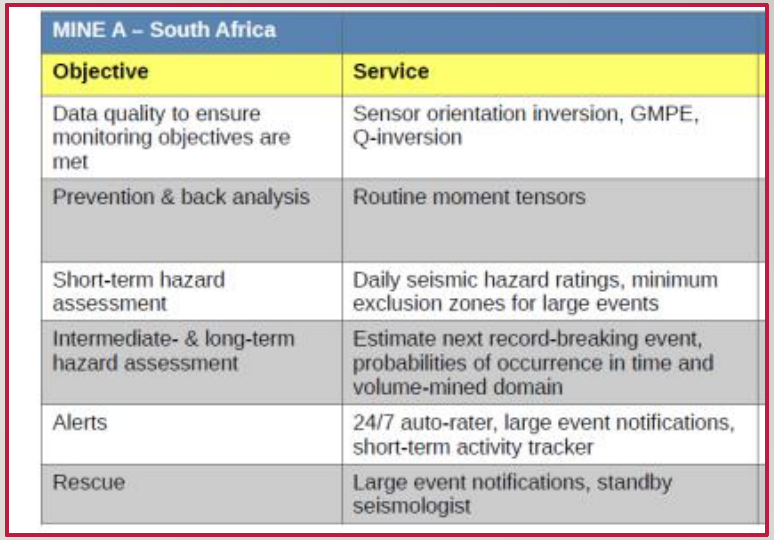
**FOGAP Project 1_IMS.pdf*, 22/09/2023

# FEEDBACK

- Item C – Task 30: Review summary* by IMS on data collated wrt. current SHA systems and practices on local mines; fill gaps where required ✓

The IMS report provides details on its customer base (340 in 42 countries, 51 systems in SA), including their network sizes and sensor densities. Seismic monitoring objectives are proposed in five categories.

Examples of implemented procedures are provided for two local mines ➔



| MINE A – South Africa | |
|---|---|
| **Objective** | **Service** |
| Data quality to ensure monitoring objectives are met | Sensor orientation inversion, GMPE, Q-inversion |
| Prevention & back analysis | Routine moment tensors |
| Short-term hazard assessment | Daily seismic hazard ratings, minimum exclusion zones for large events |
| Intermediate- & long-term hazard assessment | Estimate next record-breaking event, probabilities of occurrence in time and volume-mined domain |
| Alerts | 24/7 auto-rater, large event notifications, short-term activity tracker |
| Rescue | Large event notifications, standby seismologist |

The IMS report does not represent the current state of implementation of recommended procedures across the AU and PGM mining operations.

The report lacks clarity about the distinction between seismic hazard and seismic risk.

**FOGAP Project 1_IMS.pdf,* 22/09/2023

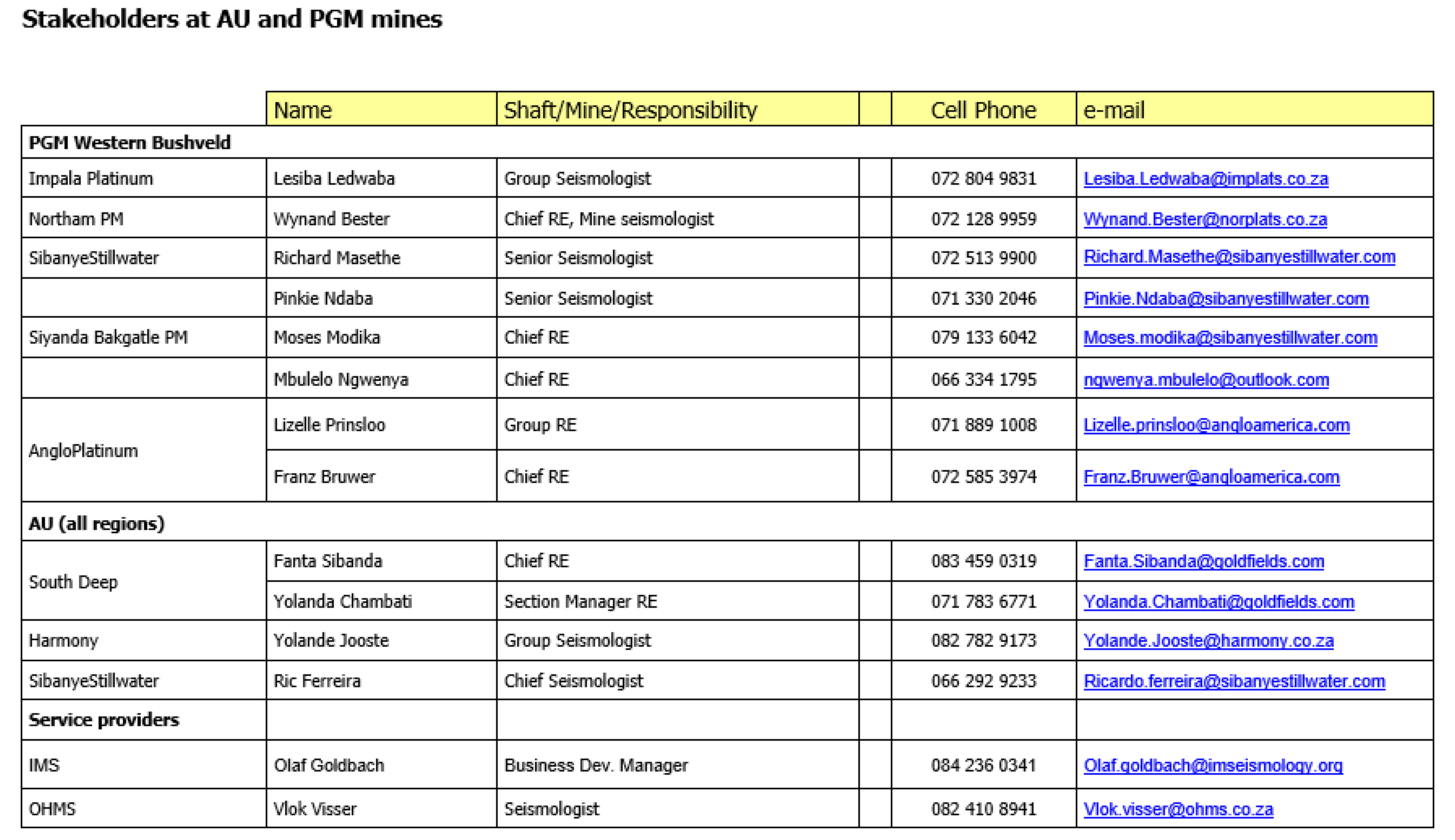
# FEEDBACK

- Item C – Task 40: Present summary and provide feedback to research team on local practice

## KEY QUESTIONS

1. What is current common practice ito. Seismic Hazard and Risk Assessment?
2. What constitutes best practice?
3. Are there discrepancies between CoPs and applied procedures?

# STAKEHOLDERS

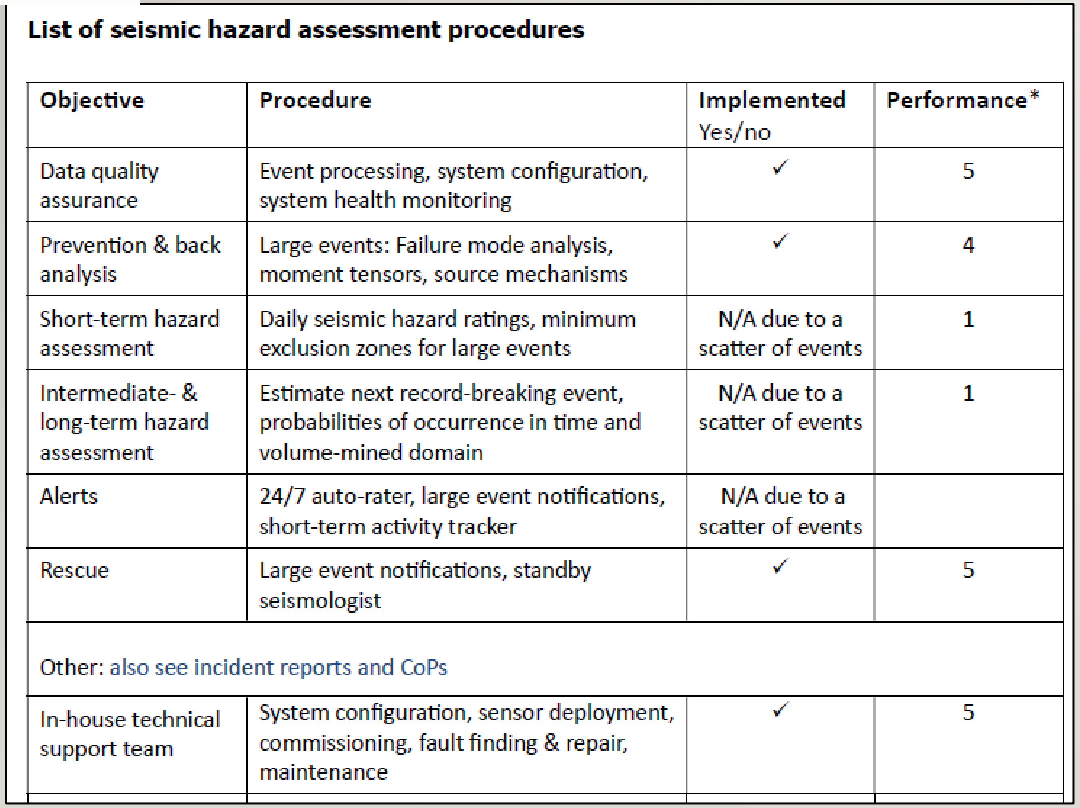


### Stakeholders at AU and PGM mines

| | Name | Shaft/Mine/Responsibility | | Cell Phone | e-mail |
|---|---|---|---|---|---|
| **PGM Western Bushveld** | | | | | |
| Impala Platinum | Lesiba Ledwaba | Group Seismologist | | 072 804 9831 | Lesiba.Ledwaba@implats.co.za |
| Northam PM | Wynand Bester | Chief RE, Mine seismologist | | 072 128 9959 | Wynand.Bester@norplats.co.za |
| SibanyeStillwater | Richard Masethe | Senior Seismologist | | 072 513 9900 | Richard.Masethe@sibanyestillwater.com |
| | Pinkie Ndaba | Senior Seismologist | | 071 330 2046 | Pinkie.Ndaba@sibanyestillwater.com |
| Siyanda Bakgatle PM | Moses Modika | Chief RE | | 079 133 6042 | Moses.modika@sibanyestillwater.com |
| | Mbulelo Ngwenya | Chief RE | | 066 334 1795 | ngwenya.mbulelo@outlook.com |
| AngloPlatinum | Lizelle Prinsloo | Group RE | | 071 889 1008 | Lizelle.prinsloo@angloamerica.com |
| | Franz Bruwer | Chief RE | | 072 585 3974 | Franz.Bruwer@angloamerica.com |
| **AU (all regions)** | | | | | |
| South Deep | Fanta Sibanda | Chief RE | | 083 459 0319 | Fanta.Sibanda@goldfields.com |
| | Yolanda Chambati | Section Manager RE | | 071 783 6771 | Yolanda.Chambati@goldfields.com |
| Harmony | Yolande Jooste | Group Seismologist | | 082 782 9173 | Yolande.Jooste@harmony.co.za |
| SibanyeStillwater | Ric Ferreira | Chief Seismologist | | 066 292 9233 | Ricardo.ferreira@sibanyestillwater.com |
| **Service providers** | | | | | |
| IMS | Olaf Goldbach | Business Dev. Manager | | 084 236 0341 | Olaf.goldbach@imseismology.org |
| OHMS | Vlok Visser | Seismologist | | 082 410 8941 | Vlok.visser@ohms.co.za |

# Q1 CURRENT PRACTICE

## SURVEY QUESTIONNAIRE



**List of seismic hazard assessment procedures**

| **Objective** | **Procedure** | **Implemented**<br>Yes/no | **Performance*** |
|---|---|---|---|
| Data quality assurance | Event processing, system configuration, system health monitoring | ✓ | 5 |
| Prevention & back analysis | Large events: Failure mode analysis, moment tensors, source mechanisms | ✓ | 4 |
| Short-term hazard assessment | Daily seismic hazard ratings, minimum exclusion zones for large events | N/A due to a scatter of events | 1 |
| Intermediate- & long-term hazard assessment | Estimate next record-breaking event, probabilities of occurrence in time and volume-mined domain | N/A due to a scatter of events | 1 |
| Alerts | 24/7 auto-rater, large event notifications, short-term activity tracker | N/A due to a scatter of events | |
| Rescue | Large event notifications, standby seismologist | ✓ | 5 |
| Other: also see incident reports and CoPs | | | |
| In-house technical support team | System configuration, sensor deployment, commissioning, fault finding & repair, maintenance | ✓ | 5 |

$\sum 21$

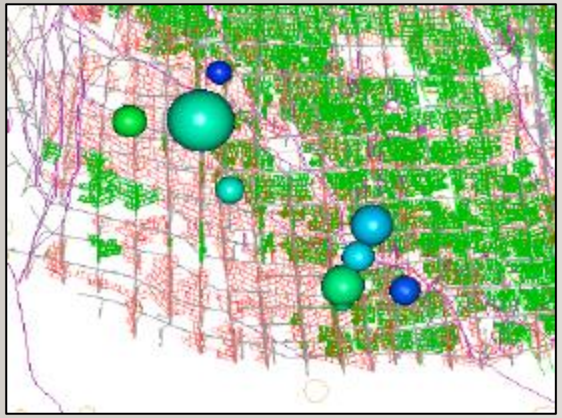
*Score on a scale of 1 to 5: **1**=**not successful/inaccurate/no value-add** and **5**=**successful/reliable/objectives met**

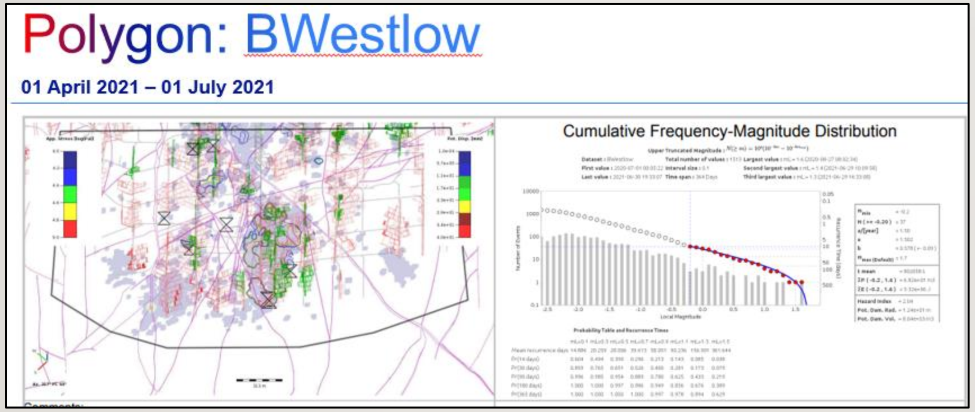
### Comments:

- The quality of Moment Tensors is normally low.
- It remains an issue to get reliable seismic source mechanisms.
- Rating systems can only add value when there are foreshocks or accelerated deformation before large events.
- Short-term assessments are regarded as unreliable and seen as problematic for production employees.
- Not to predict, but to raise awareness of seismic damage potential.

# Q1 CURRENT PRACTICE

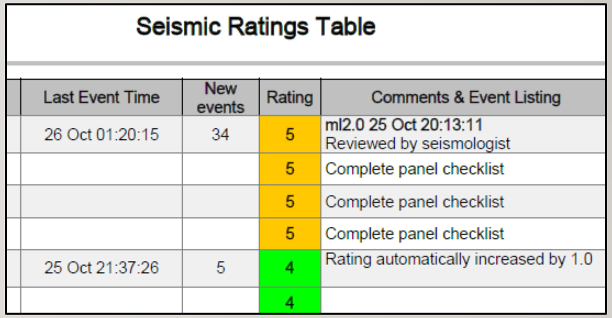
## SHIFTLY, DAILY, WEEKLY, MONTHLY, QUARTERLY REPORTS





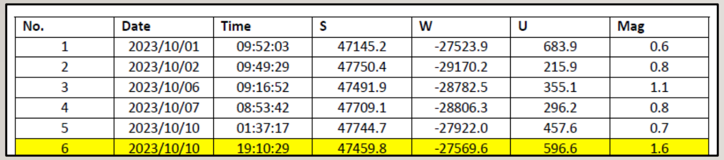
**Polygon: BWestlow**

01 April 2021 – 01 July 2021

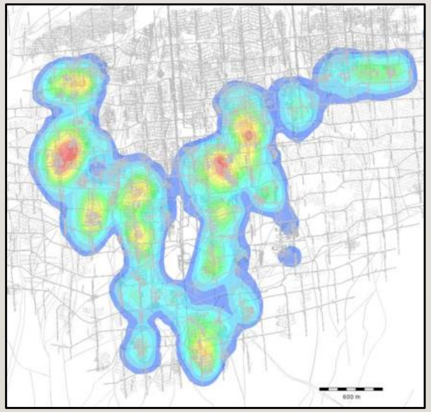


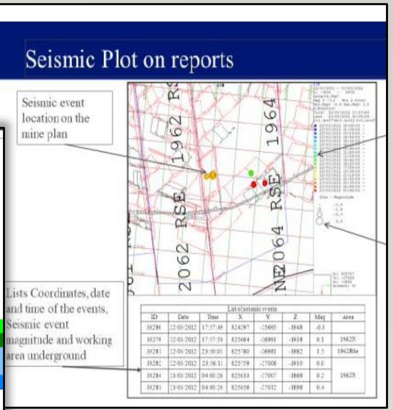
### Seismic Ratings Table

| Last Event Time | New events | Rating | Comments & Event Listing |
|---|---|---|---|
| 26 Oct 01:20:15 | 34 | 5 | ml2.0 25 Oct 20:13:11<br>Reviewed by seismologist |
| | | 5 | Complete panel checklist |
| | | 5 | Complete panel checklist |
| | | 5 | Complete panel checklist |
| 25 Oct 21:37:26 | 5 | 4 | Rating automatically increased by 1.0 |
| | | 4 | |



| No. | Date | Time | S | W | U | Mag |
|---|---|---|---|---|---|---|
| 1 | 2023/10/01 | 09:52:03 | 47145.2 | -27523.9 | 683.9 | 0.6 |
| 2 | 2023/10/02 | 09:49:29 | 47750.4 | -29170.2 | 215.9 | 0.8 |
| 3 | 2023/10/06 | 09:16:52 | 47491.9 | -28782.5 | 355.1 | 1.1 |
| 4 | 2023/10/07 | 08:53:42 | 47709.1 | -28806.3 | 296.2 | 0.8 |
| 5 | 2023/10/10 | 01:37:17 | 47744.7 | -27922.0 | 457.6 | 0.7 |
| 6 | 2023/10/10 | 19:10:29 | 47459.8 | -27569.6 | 596.6 | 1.6 |





**Seismic Plot on reports**

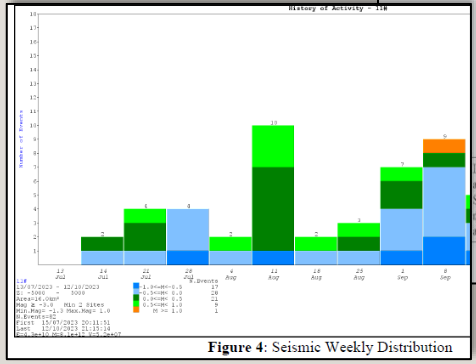
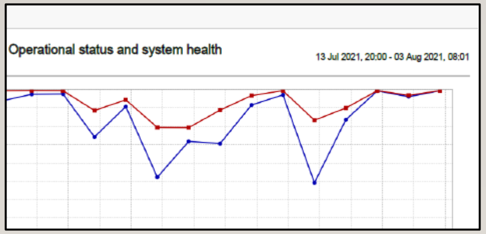
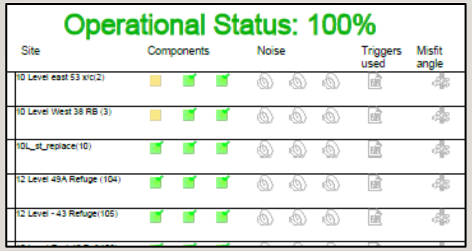


Figure 4: Seismic Weekly Distribution



Operational status and system health

13 Jul 2021, 20:00 - 03 Aug 2021, 08:01

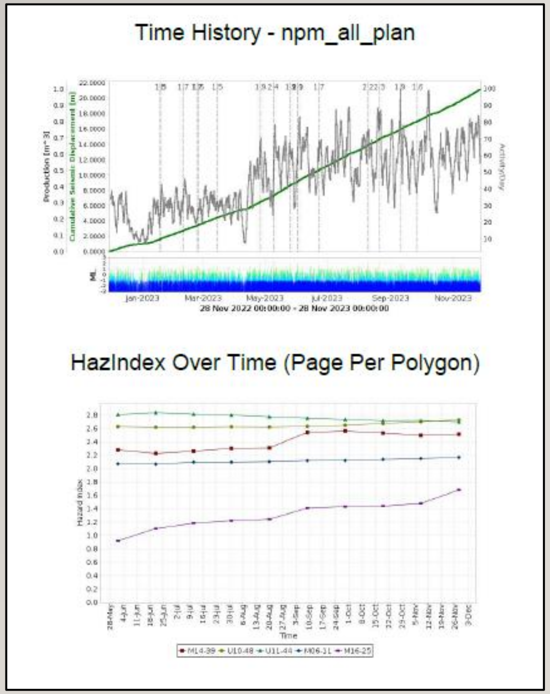


**Operational Status: 100%**

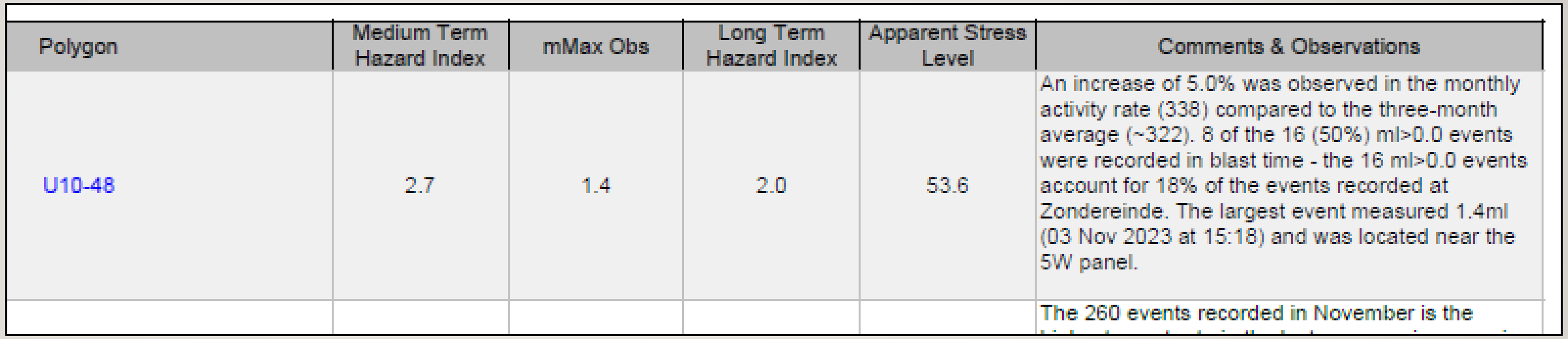
| Site | Components | Noise | Triggers used | Misfit angle |
|---|---|---|---|---|
| 10 Level east 53 x/c(2) | 🟨 ☑ ☑ | | | |
| 10 Level West 38 RB (3) | 🟨 ☑ ☑ | | | |
| 10L_st_replace(10) | ☑ ☑ ☑ | | | |
| 12 Level 49A Refuge (104) | ☑ ☑ ☑ | | | |
| 12 Level - 43 Refuge(105) | ☑ ☑ ☑ | | | |

# Q1 CURRENT PRACTICE

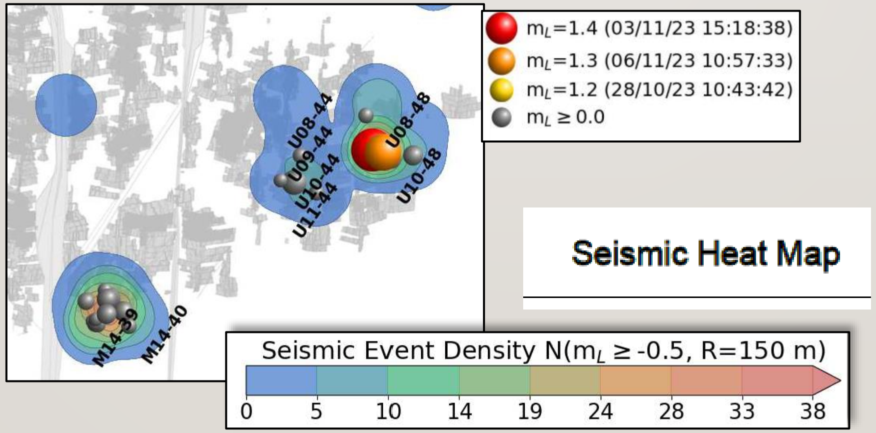
## SHIFTLY, DAILY, WEEKLY, MONTHLY, QUARTERLY REPORTS


Time History - npm_all_plan

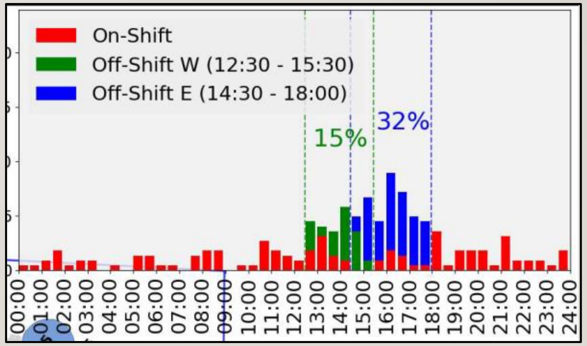
HazIndex Over Time (Page Per Polygon)



| Polygon | Medium Term Hazard Index | mMax Obs | Long Term Hazard Index | Apparent Stress Level | Comments & Observations |
|---|---|---|---|---|---|
| U10-48 | 2.7 | 1.4 | 2.0 | 53.6 | An increase of 5.0% was observed in the monthly activity rate (338) compared to the three-month average (~322). 8 of the 16 (50%) ml>0.0 events were recorded in blast time - the 16 ml>0.0 events account for 18% of the events recorded at Zondereinde. The largest event measured 1.4ml (03 Nov 2023 at 15:18) and was located near the 5W panel. |
| | | | | | The 260 events recorded in November is the |

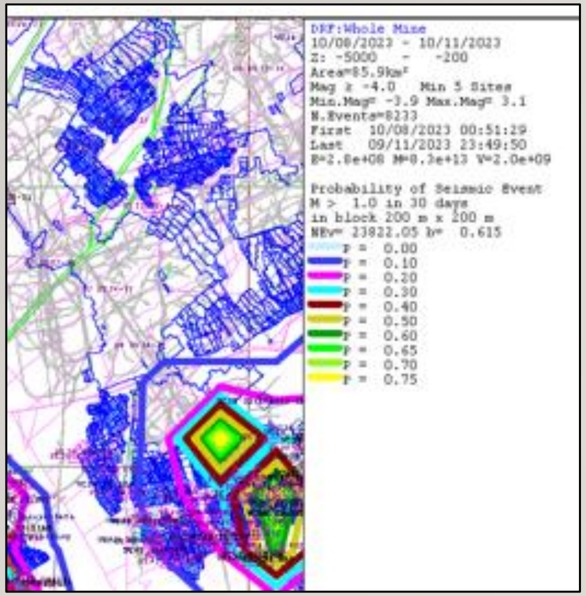


Seismic Heat Map

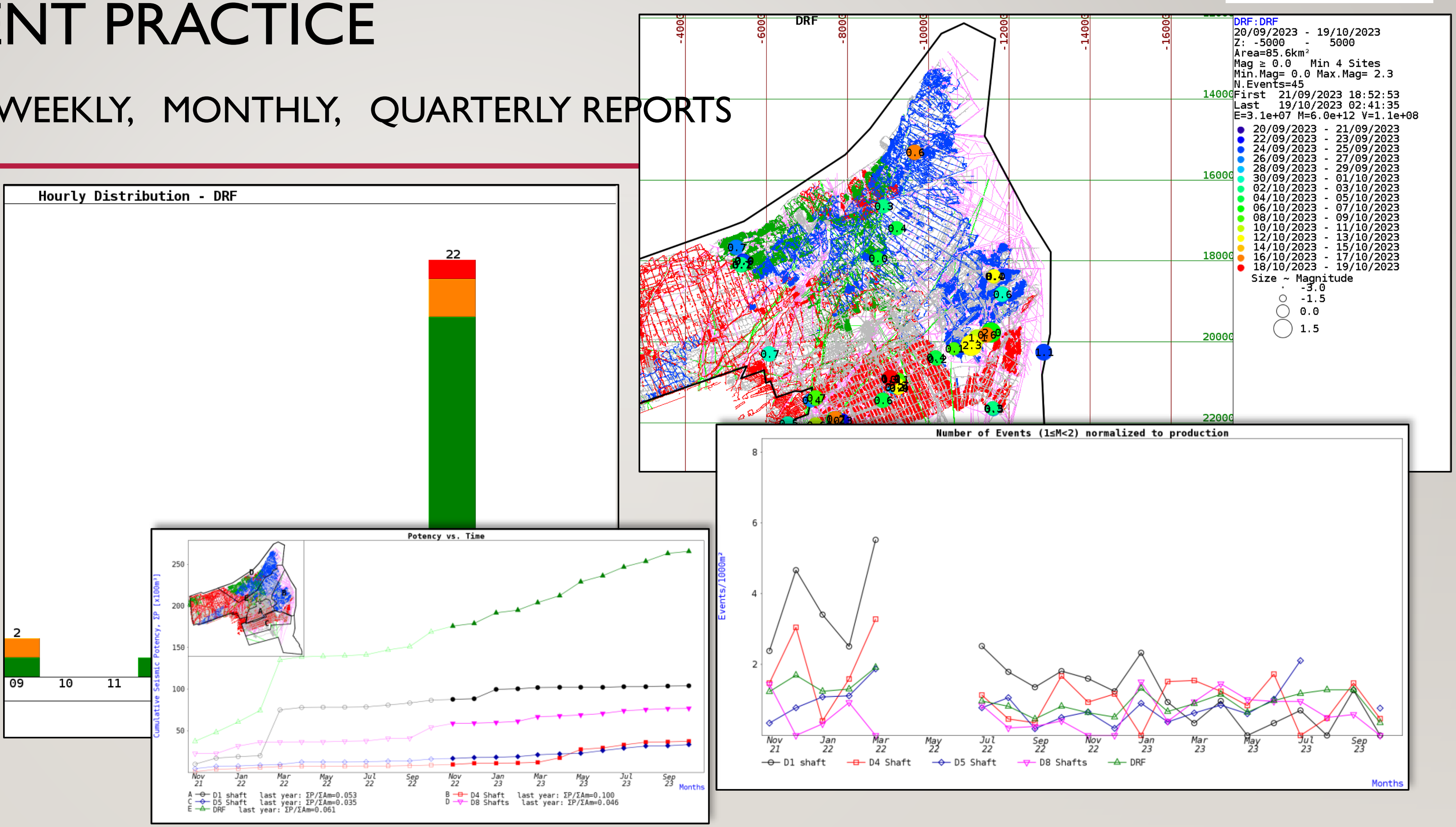


# Q1 CURRENT PRACTICE

## SHIFTLY, DAILY, WEEKLY, MONTHLY, QUARTERLY REPORTS

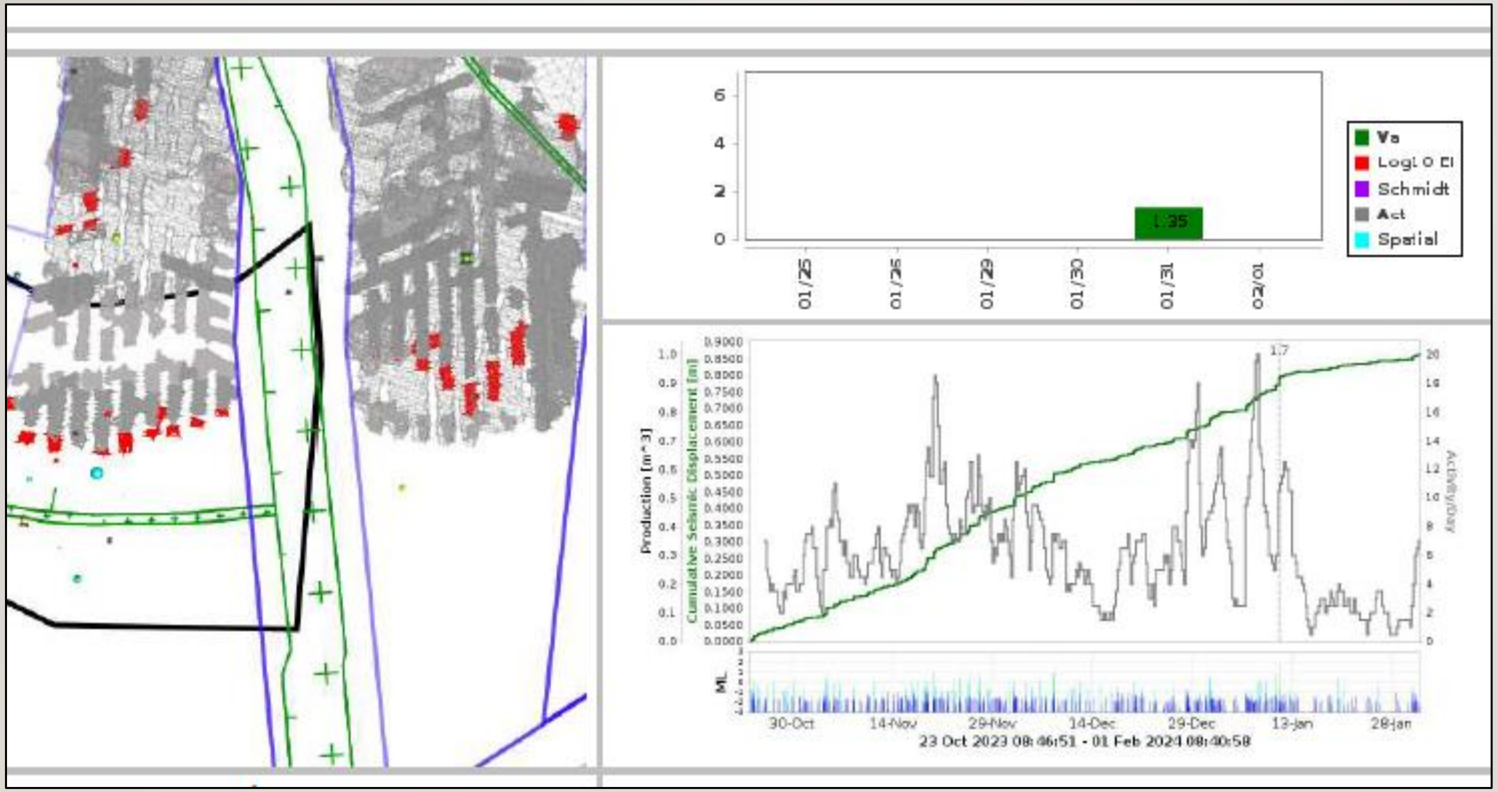


Hazard Maps



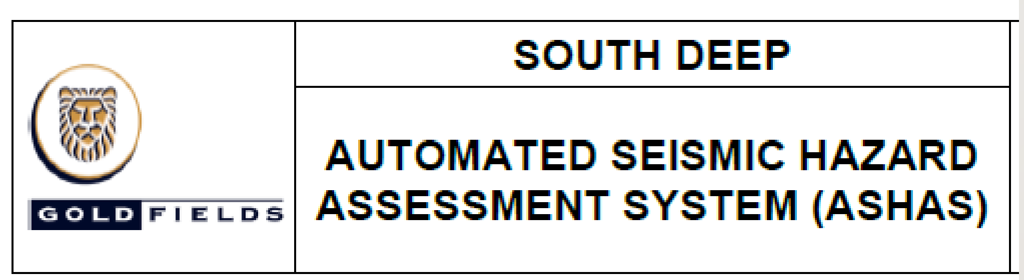
# Q1 CURRENT PRACTICE

## PROBLEM: INSUFFICIENT DATA



# Q1 CURRENT PRACTICE

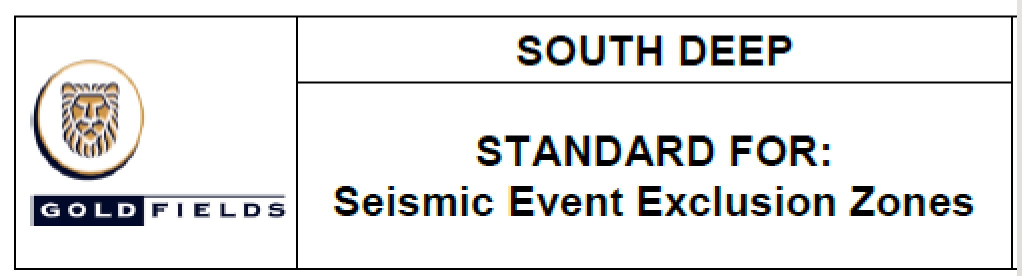
## OTHER REPORTS



GOLD FIELDS

**SOUTH DEEP**

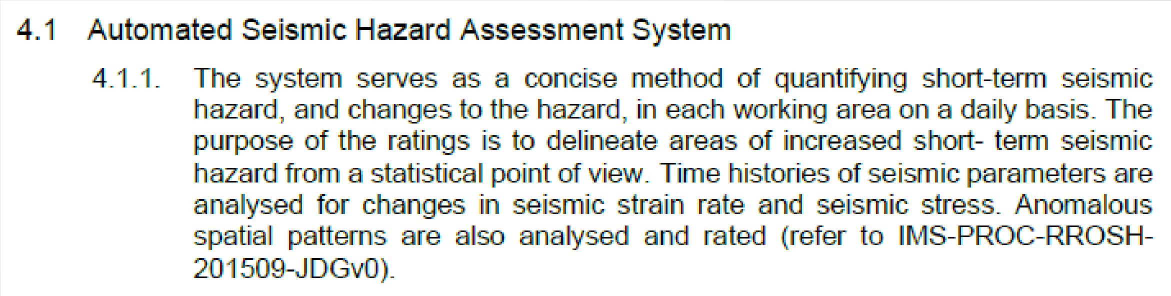
**AUTOMATED SEISMIC HAZARD ASSESSMENT SYSTEM (ASHAS)**



GOLD FIELDS

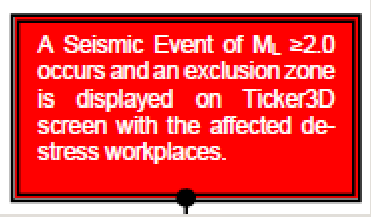
**SOUTH DEEP**

**STANDARD FOR:**
**Seismic Event Exclusion Zones**

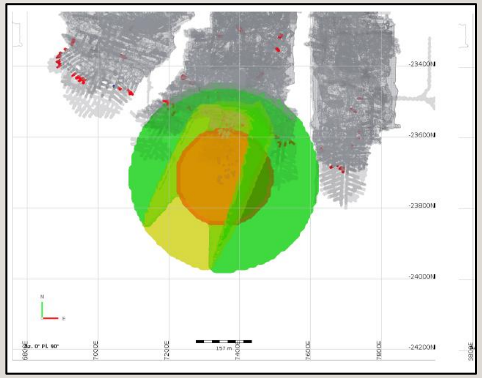


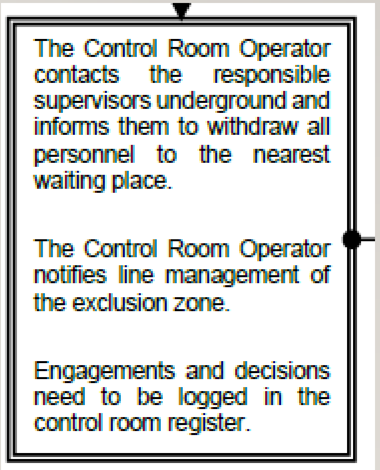
4.1 Automated Seismic Hazard Assessment System

4.1.1. The system serves as a concise method of quantifying short-term seismic hazard, and changes to the hazard, in each working area on a daily basis. The purpose of the ratings is to delineate areas of increased short- term seismic hazard from a statistical point of view. Time histories of seismic parameters are analysed for changes in seismic strain rate and seismic stress. Anomalous spatial patterns are also analysed and rated (refer to IMS-PROC-RROSH-201509-JDGv0).



A Seismic Event of $M_L$ ≥2.0 occurs and an exclusion zone is displayed on Ticker3D screen with the affected de-stress workplaces.





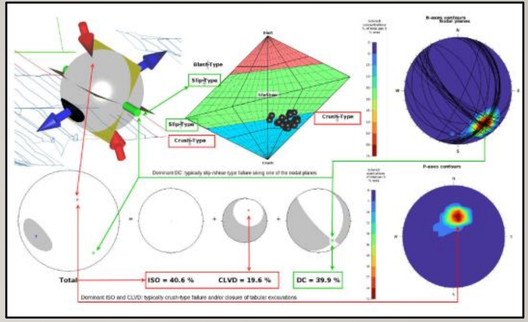
The Control Room Operator contacts the responsible supervisors underground and informs them to withdraw all personnel to the nearest waiting place.

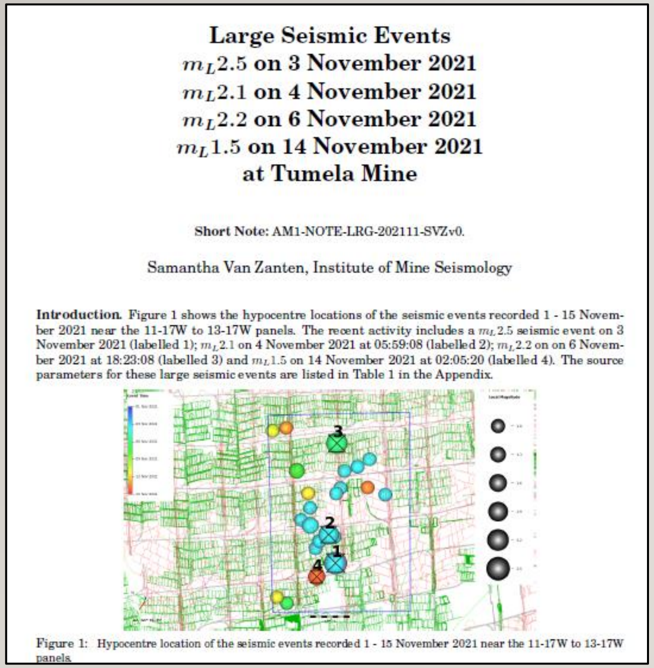
The Control Room Operator notifies line management of the exclusion zone.

Engagements and decisions need to be logged in the control room register.

# Q1 CURRENT PRACTICE

## LARGE EVENTS





### Large Seismic Events
### $m_L$2.5 on 3 November 2021
### $m_L$2.1 on 4 November 2021
### $m_L$2.2 on 6 November 2021
### $m_L$1.5 on 14 November 2021
### at Tumela Mine

**Short Note:** AM1-NOTE-LRG-202111-SVZv0.

Samantha Van Zanten, Institute of Mine Seismology

**Introduction.** Figure 1 shows the hypocentre locations of the seismic events recorded 1 - 15 November 2021 near the 11-17W to 13-17W panels. The recent activity includes a $m_L$2.5 seismic event on 3 November 2021 (labelled 1); $m_L$2.1 on 4 November 2021 at 05:59:08 (labelled 2); $m_L$2.2 on on 6 November 2021 at 18:23:08 (labelled 3) and $m_L$1.5 on 14 November 2021 at 02:05:20 (labelled 4). The source parameters for these large seismic events are listed in Table 1 in the Appendix.

Figure 1: Hypocentre location of the seismic events recorded 1 - 15 November 2021 near the 11-17W to 13-17W panels.

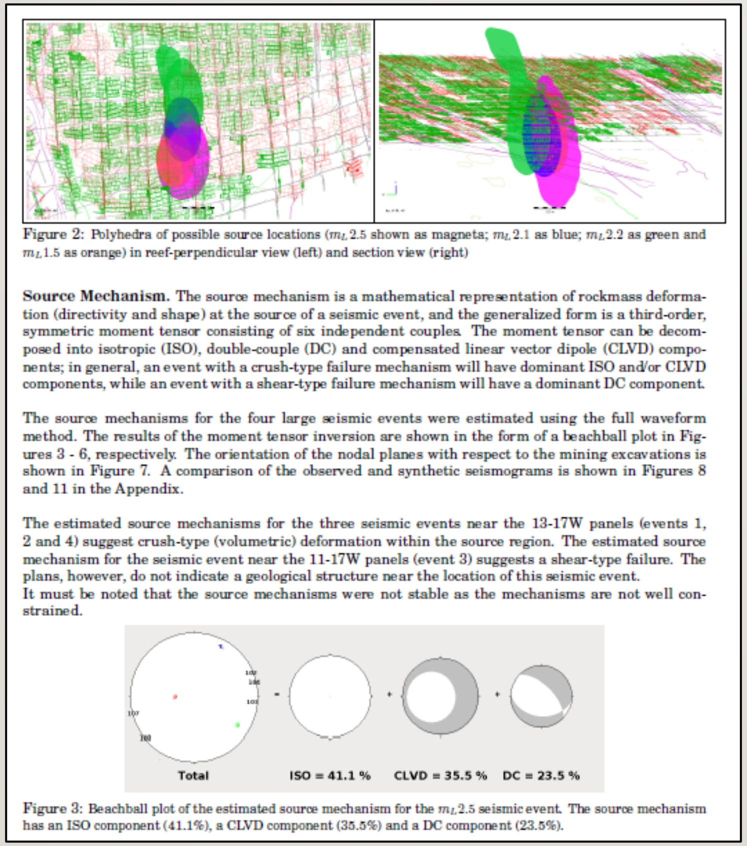


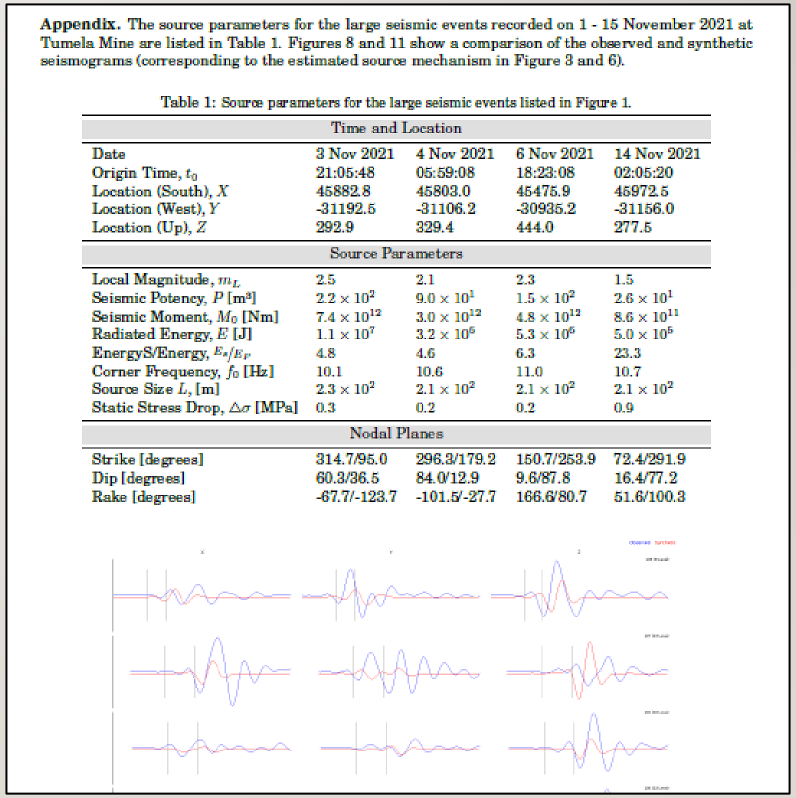
Figure 2: Polyhedra of possible source locations ($m_L$2.5 shown as magneta; $m_L$2.1 as blue; $m_L$2.2 as green and $m_L$1.5 as orange) in reef-perpendicular view (left) and section view (right)

**Source Mechanism.** The source mechanism is a mathematical representation of rockmass deformation (directivity and shape) at the source of a seismic event, and the generalized form is a third-order, symmetric moment tensor consisting of six independent couples. The moment tensor can be decomposed into isotropic (ISO), double-couple (DC) and compensated linear vector dipole (CLVD) components; in general, an event with a crush-type failure mechanism will have dominant ISO and/or CLVD components, while an event with a shear-type failure mechanism will have a dominant DC component.

The source mechanisms for the four large seismic events were estimated using the full waveform method. The results of the moment tensor inversion are shown in the form of a beachball plot in Figures 3 - 6, respectively. The orientation of the nodal planes with respect to the mining excavations is shown in Figure 7. A comparison of the observed and synthetic seismograms is shown in Figures 8 and 11 in the Appendix.

The estimated source mechanisms for the three seismic events near the 13-17W panels (events 1, 2 and 4) suggest crush-type (volumetric) deformation within the source region. The estimated source mechanism for the seismic event near the 11-17W panels (event 3) suggests a shear-type failure. The plans, however, do not indicate a geological structure near the location of this seismic event.
It must be noted that the source mechanisms were not stable as the mechanisms are not well constrained.

Figure 3: Beachball plot of the estimated source mechanism for the $m_L$2.5 seismic event. The source mechanism has an ISO component (41.1%), a CLVD component (35.5%) and a DC component (23.5%).



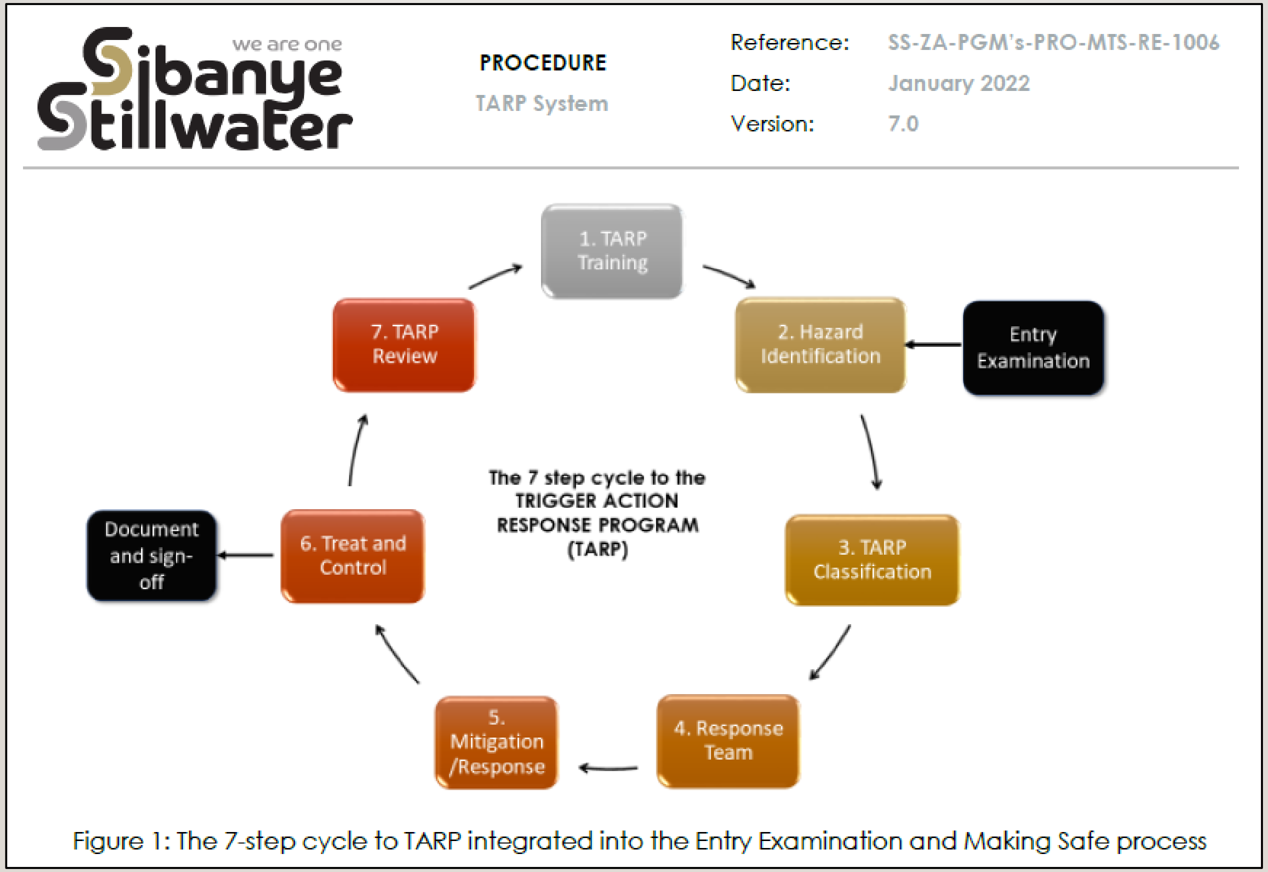
**Appendix.** The source parameters for the large seismic events recorded on 1 - 15 November 2021 at Tumela Mine are listed in Table 1. Figures 8 and 11 show a comparison of the observed and synthetic seismograms (corresponding to the estimated source mechanism in Figure 3 and 6).

Table 1: Source parameters for the large seismic events listed in Figure 1.

| Time and Location | | | | |
|---|---|---|---|---|
| Date | 3 Nov 2021 | 4 Nov 2021 | 6 Nov 2021 | 14 Nov 2021 |
| Origin Time, $t_0$ | 21:05:48 | 05:59:08 | 18:23:08 | 02:05:20 |
| Location (South), $X$ | 45882.8 | 45803.0 | 45475.9 | 45972.5 |
| Location (West), $Y$ | -31192.5 | -31106.2 | -30935.2 | -31156.0 |
| Location (Up), $Z$ | 292.9 | 329.4 | 444.0 | 277.5 |
| **Source Parameters** | | | | |
| Local Magnitude, $m_L$ | 2.5 | 2.1 | 2.3 | 1.5 |
| Seismic Potency, $P$ [m³] | $2.2 \times 10^2$ | $9.0 \times 10^1$ | $1.5 \times 10^2$ | $2.6 \times 10^1$ |
| Seismic Moment, $M_0$ [Nm] | $7.4 \times 10^{12}$ | $3.0 \times 10^{12}$ | $4.8 \times 10^{12}$ | $8.6 \times 10^{11}$ |
| Radiated Energy, $E$ [J] | $1.1 \times 10^7$ | $3.2 \times 10^6$ | $5.3 \times 10^6$ | $5.0 \times 10^5$ |
| EnergyS/Energy, $E_s/E_P$ | 4.8 | 4.6 | 6.3 | 23.3 |
| Corner Frequency, $f_0$ [Hz] | 10.1 | 10.6 | 11.0 | 10.7 |
| Source Size $L$, [m] | $2.3 \times 10^2$ | $2.1 \times 10^2$ | $2.1 \times 10^2$ | $2.1 \times 10^2$ |
| Static Stress Drop, $\Delta\sigma$ [MPa] | 0.3 | 0.2 | 0.2 | 0.9 |
| **Nodal Planes** | | | | |
| Strike [degrees] | 314.7/95.0 | 296.3/179.2 | 150.7/253.9 | 72.4/291.9 |
| Dip [degrees] | 60.3/36.5 | 84.0/12.9 | 9.6/87.8 | 16.4/77.2 |
| Rake [degrees] | -67.7/-123.7 | -101.5/-27.7 | 166.6/80.7 | 51.6/100.3 |

# Q1 CURRENT PRACTICE

## RISK MITIGATION - TARP



we are one Sibanye Stillwater

**PROCEDURE**

TARP System

Reference: SS-ZA-PGM's-PRO-MTS-RE-1006
Date: January 2022
Version: 7.0

1. TARP Training
2. Hazard Identification
3. TARP Classification
4. Response Team
5. Mitigation /Response
6. Treat and Control
7. TARP Review

Entry Examination

Document and sign-off

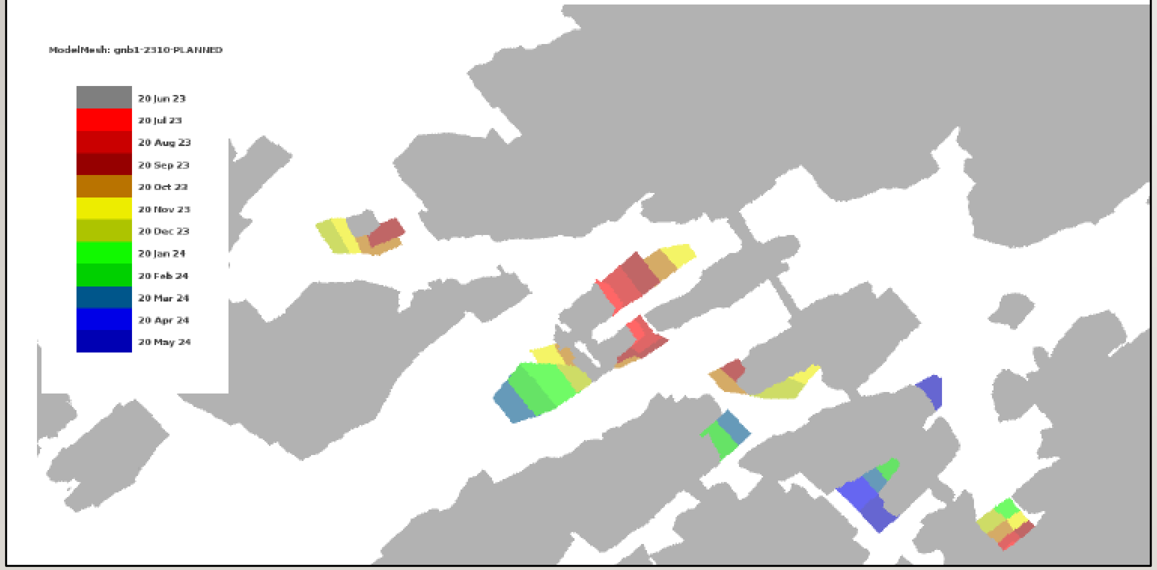
**The 7 step cycle to the TRIGGER ACTION RESPONSE PROGRAM (TARP)**

Figure 1: The 7-step cycle to TARP integrated into the Entry Examination and Making Safe process

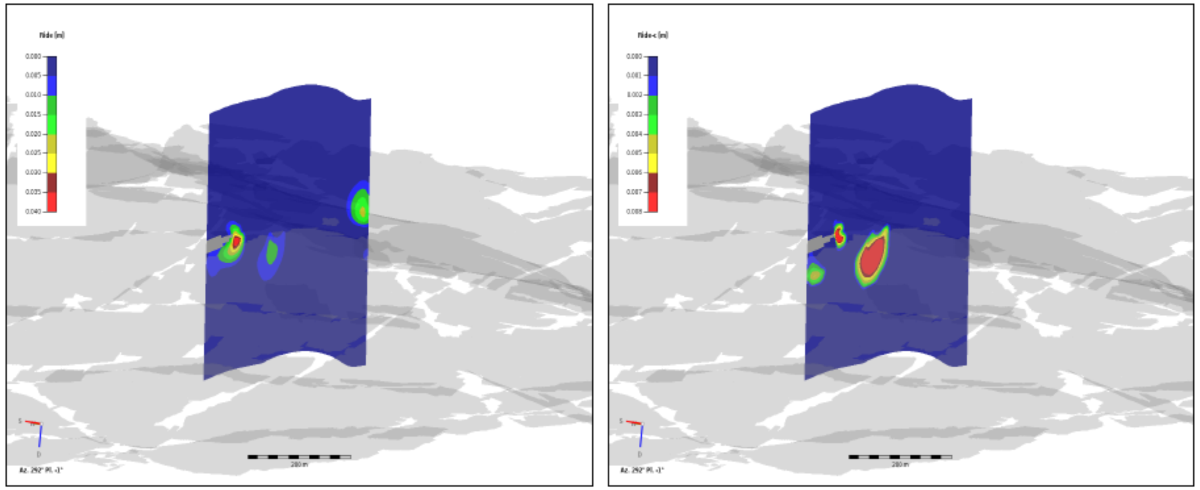
# Q1 CURRENT PRACTICE

## GEO-SEISMIC HAZARD ASSOCIATED WITH PLANNED MINING

### Mining Sequence Around the 64FW44 Area



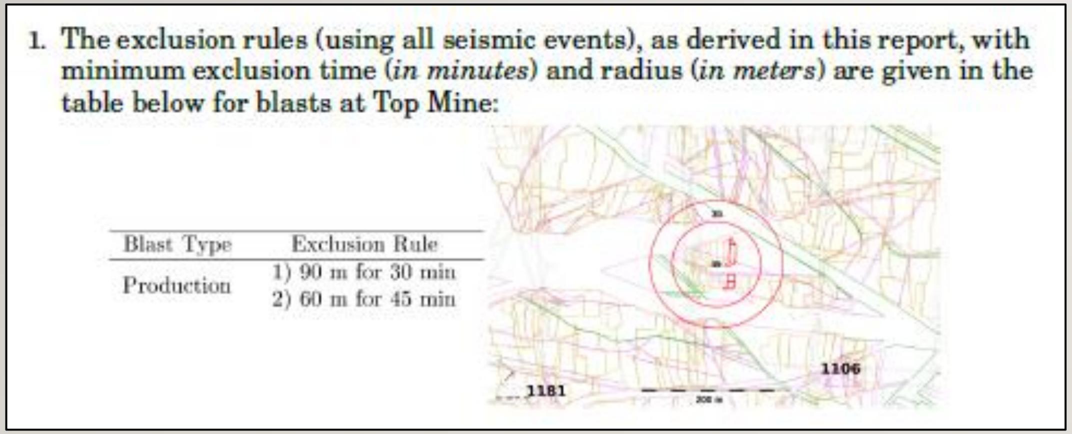
### Total and Change in Ride on the Kerval Dyke



Parameters used:
Static Friction Angle: 30 deg
Static Cohesion: 5 MPa
Dynamic Friction Angle: 25 deg
Dynamic Cohesion: 0 MPa

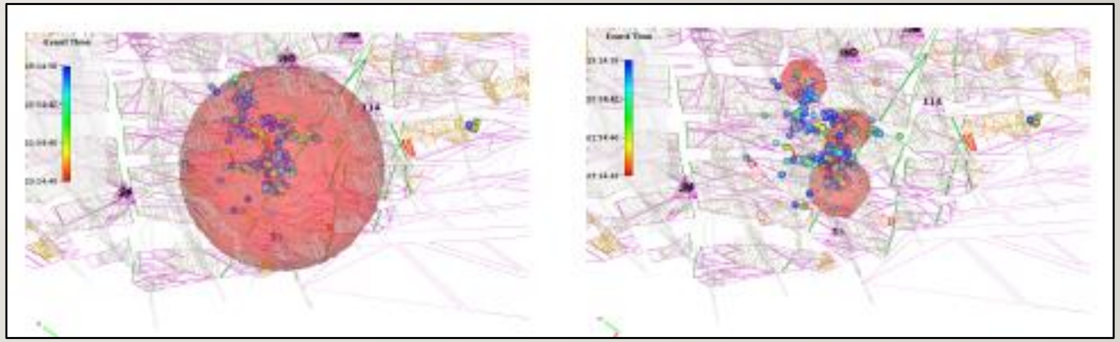
# Q1 CURRENT PRACTICE

## EXCLUSION TIMES AND ZONES (GMAP*)



1. The exclusion rules (using all seismic events), as derived in this report, with minimum exclusion time (*in minutes*) and radius (*in meters*) are given in the table below for blasts at Top Mine:

| Blast Type | Exclusion Rule |
|---|---|
| Production | 1) 90 m for 30 min<br>2) 60 m for 45 min |



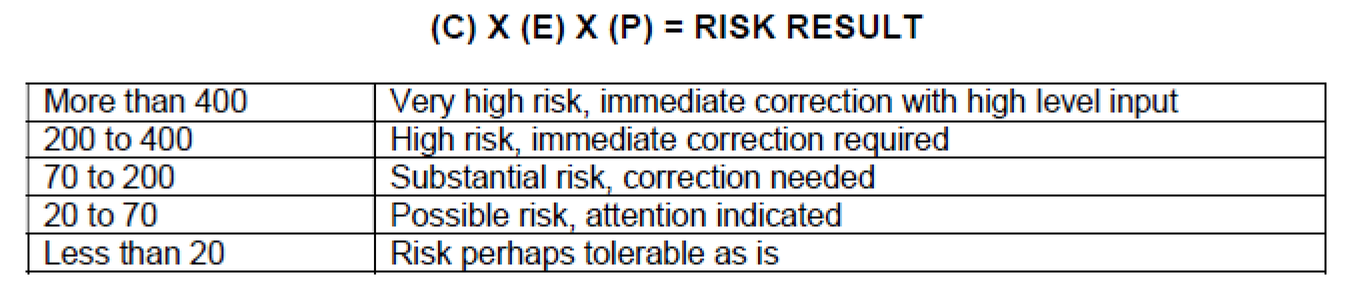
*Ground Motion Alerts Program

# Q1 CURRENT PRACTICE

## HAZARD OR RISK ASSESSMENT?

Not formalised

RISK = CONSEQUENCE * EXPOSURE * PROBABILITY



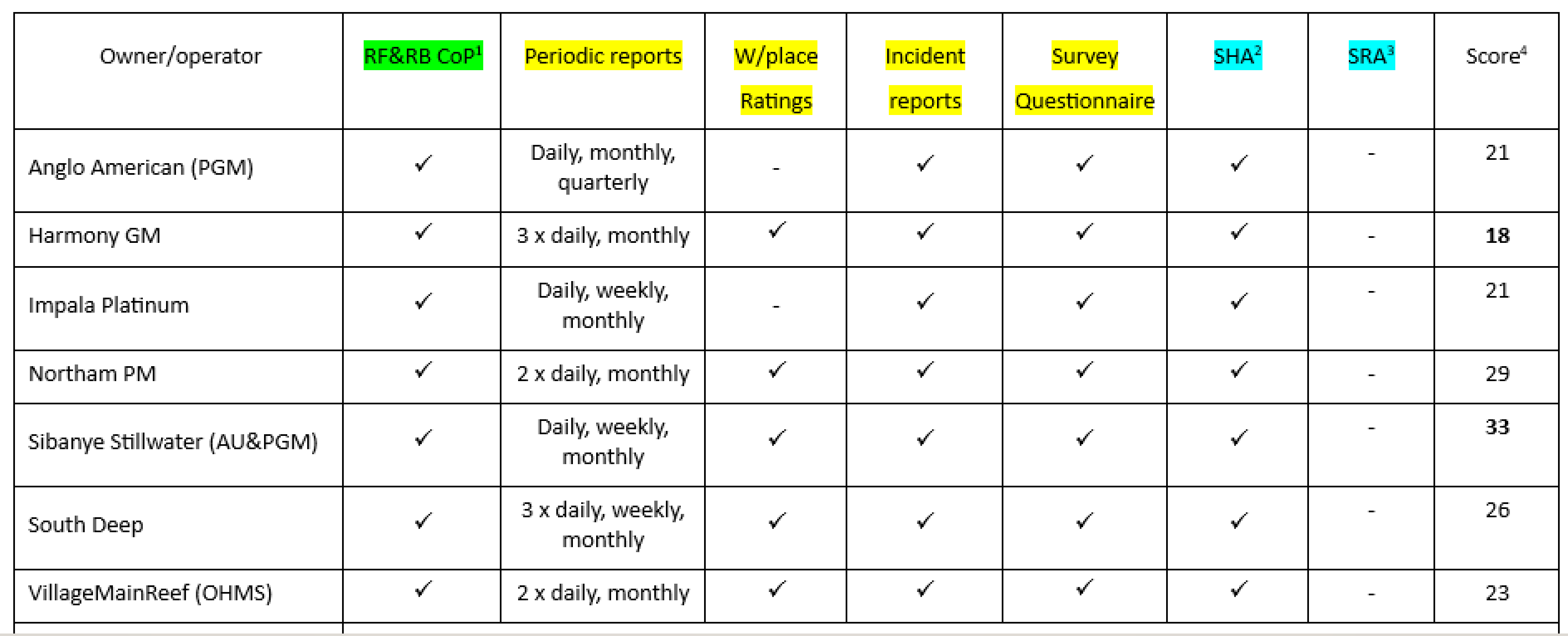
**(C) X (E) X (P) = RISK RESULT**

| | |
|---|---|
| More than 400 | Very high risk, immediate correction with high level input |
| 200 to 400 | High risk, immediate correction required |
| 70 to 200 | Substantial risk, correction needed |
| 20 to 70 | Possible risk, attention indicated |
| Less than 20 | Risk perhaps tolerable as is |

TAU LEKOA

# Q2 BEST PRACTICE

## PERFORMANCE OF METHODS



| Owner/operator | RF&RB CoP[1] | Periodic reports | W/place Ratings | Incident reports | Survey Questionnaire | SHA[2] | SRA[3] | Score[4] |
|---|---|---|---|---|---|---|---|---|
| Anglo American (PGM) | ✓ | Daily, monthly, quarterly | - | ✓ | ✓ | ✓ | - | 21 |
| Harmony GM | ✓ | 3 x daily, monthly | ✓ | ✓ | ✓ | ✓ | - | **18** |
| Impala Platinum | ✓ | Daily, weekly, monthly | - | ✓ | ✓ | ✓ | - | 21 |
| Northam PM | ✓ | 2 x daily, monthly | ✓ | ✓ | ✓ | ✓ | - | 29 |
| Sibanye Stillwater (AU&PGM) | ✓ | Daily, weekly, monthly | ✓ | ✓ | ✓ | ✓ | - | 33 |
| South Deep | ✓ | 3 x daily, weekly, monthly | ✓ | ✓ | ✓ | ✓ | - | 26 |
| VillageMainReef (OHMS) | ✓ | 2 x daily, monthly | ✓ | ✓ | ✓ | ✓ | - | 23 |

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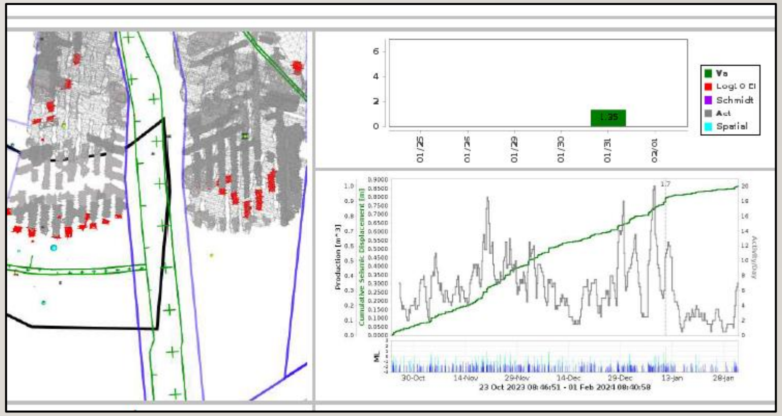
[1] and other related strategy documents
[2] Seismic Hazard Assessments
[3] Seismic Risk Assessments
[4] Self-rating by mine stakeholders (see Questionnaire)

# Q2 BEST PRACTICE

## PERFORMANCE OF METHODS

1. Accuracy of source parameters: Time and Location, Moment and Energy
2. Accurate geo-technical information: Geo-structures, rock properties, stratigraphy
3. Latest technology and methodology: Data collection, processing and analysis, r. mass modelling
4. Considerations to inherent limitations, e.g. event prediction



# Q3 GAPS BETWEEN COP AND PRACTICE

## GAPS

HARMONY

AngloAmerican

Sibanye Stillwater

we are one

**none identified**

OHMS

GOLD FIELDS

IMPLATS

NORTHAM

PLATINUM HOLDINGS LIMITED

# SUMMARY

1. All major AU and PGM producers collaborated (7)
2. Range of seismic hazard severity (intermediate PGM to ultra-deep AU)
3. Diversity in procedures with large common base (two in-house seismology teams)
4. Performance of procedures score (self-rating): 18 – 33
5. Short-term SHA rated low, no formalized seismic risk assessments, CoPs implemented
6. Define 'Best Practice': Best possible technically or meeting all of stakeholders expectations?
    - Latest technology and methodology: Data processing & analysis, modelling etc.
    - Note inherent limitations, e.g. location accuracy and event prediction