# Mine Health and Safety Council

MHSC

# Technology transfer on minimising seismic risk in the platinum mines

F Essrich, JWL Hanekom, J Bouwer

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# 3. ABBREVIATIONS AND NOMENCLATURE

- CGS: Council for Geosciences;
- CoP: Code of Practice to combat rockfall and rockburst accidents
- IMS: Institute of Mine Seismology
- MHSC: Mine Health and Safety Council
- MHSI: Mine Health and Safety Inspectorate regions
- SANS: South African National Standards
- SANSN: SA National Seismic Network

# 4. ACKNOWLEDGEMENTS

The project team would like to thank the following persons for sharing their experience and insights throughout the project:

**Anglo Platinum Mines**

| | |
|---|---|
| Riaan Carstens | Corporate Manager Rock Engineering |
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| Alan Olivier | Chief RE (School of Mines) |
| Wynand Bester | Chief RE, Mine seismologist (Tumela/Dishaba) |
| Linden Skorpen | Chief RE (Union) |
| Willie Snyman | Chief RE (Thembe/Khuseleka) |
| Rudi Rudolf | General Manager Training |
| Hennie Coetzee | HRD coordinator |
| Lebogang Baloyi | Jun. RE (Twickenham) |

**Impala Platinum Mines**

| | |
|---|---|
| Les Gardner | Project manager RE, RETC |
| Lesiba Ledwaba | RE officer / Mine seismologist |
| Petr Miovsky | RE Manager (Rustenburg) |
| Louis Bronkhorst | RE Mnager (Marula) |
| Thabo Molikeng | RE Training (HR Development Centre, Rustenburg) |

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| | |
|---|---|
| Michael du Plessis | Group Rock Engineer |
| Lou de Klerk | Training manager, Lonmin Academy |
| Willie Liebenberg | RE Manager Training |
| Otto van der Merwe | RE Manager Karee Section |

**Northam**

| | |
|---|---|
| Sanjay Singh | Chief RE (Zondereinde) |
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| Darryl Slawson | RE (Booysendal) |

**Bafokeng Rasimone PM**

| | |
|---|---|
| Theresa van Aardt | RE (North #) |

**ARM & Anglo Platinum (Modikwa JV)**
Godwin Hungwe Chief RE (Modikwa)

**ARM & Impala (Two Rivers JV)**
Petrie Wessels RE (Two Rivers, OHMS)

**Atlatsa Bokoni PM**
Bertus van der Kevie Chief RE (Bokoni & Lebowa)

The authors would like to express their sincere appreciation for the disclosure by some of the collaborating mines of strata control training and seismic system related information, to the benefit of other mines exposed to rockburst hazard. The contributions by network suppliers ESG and IMS to the animation sequences are acknowledged with thanks.

The funding of this research project by the Mine Health and Safety Council is gratefully acknowledged.

# 5. EXECUTIVE SUMMARY

Founded on the analysis of the factors contributing to seismicity and rockbursts in platinum mines, the common geotechnical information gathering and the data analysis methods implemented on these mines, SIM100301 suggested several methods for improvement. These relate to mining practice, the effective gathering of rock mass related information, suitable seismic monitoring procedures and to training initiatives, which should focus on the conditions that generate seismicity inBushveld mines.

SIM140301 facilitated the implementation of these recommendations, enabling mines to train both their production and rock engineering personnel on how to manage seismic risk and how to avoid practices that are known to result in increased seismic hazard.

During the initiation phase, input was sought from a range of organisations and operations and the project team received expressions of interest from mines, the CoM, CGS, Wits, SANIRE, several geo-technical consultancies and seismic network suppliers, in addition to all major mine owners with underground operations in the Eastern and Western limb of the Bushveld. Twelve mines in the Bushveld Complex (BC) were visited by the project leader to develop a sound understanding of the need for seismicity related training and the conditions on site such as the training facilities and the nature of strata control training currently provided.

Responding to the needs and requests expressed by stakeholders, and giving consideration to the facilities available at mine training centres, a set of 10 to 12 animated, virtual reality training modules in basic technical English appeared to be the best option. The final product had to be modular and flexible to allow mines to only use those modules that would apply to their respective mining conditions and hazards.

The production of modules started end of January 2015 and ended in July 2015. The title of the set is “How platinum mining in the Bushveld Complex is changing – The future is not what it used to be.” (Output 2). The summary module acknowledges the participating mines, the contribution made by a number of authors of rock engineering publications, and the funding provided by the MHSC.

Subsequent to final review, the modules were presented at four training centres in the Western and Eastern BC during November 2015, and 45 USB flash drives containing the modules were distributed to mine training centres, senior rock engineering staff and selected external stakeholders (Output 3).

Output 4 comprised the collation of suitable training materials for rock engineering staff, revision of these and subsequent distribution to mines. In total, 300 copies (electronic and printed) were considered sufficient to supply all stakeholder mines with adequate stock. SANIRE (South African National Institute of Rock Engineering) indicated that is has approximately 120 members and associate members in its Bushveld branches at the current time. Mines received a proportional share based on their staff complement in the range Strata Control Officer and denominations above, on average three sets for every two employees in this field of expertise.

The project also drafted an audit protocol founded on the SIM100301 guidelines, designed to cater for a range of different seismic system setups (Output 5): From shafts monitored by a single surface site to those with more than twenty stations. The score card is subdivided into three main dimensions each of which is subdivided into a number of aspects:

1. Seismic network planning and operation (weighting 40%)
2. Seismic source quantification (30%)
3. Rockburst analysis and reporting (30%).

The total score achieved by a mine operating a seismic system is then determined from the performance within each aspect; the maximum score is 100%.

Nine mines in the BC accepted the invitation to join the audit initiative. All are located in the western BC, and they constitute all mines or shafts currently operating seismic networks. The final audit scores range from 60% to 100% with Impala Platinum’s networks and Anglo-Platinum’s Union mine being the best planned and operated networks amongst the BC mines. The average score is 87%.

The highest compliance levels are currently achieved in the needs-based planning of network layout; the procedures to maintain minimum quality standards for seismic source parameters; and the periodic reporting to management and production sections on seismicity trends and patterns.

# 6. PROJECT INTRODUCTION

## 6.1 Project Aims

The following objectives were formulated for this project:

- Innovative, state-of-the-art animated learning and awareness training material for production personnel on PGM mines to improve seismic risk management in the Eastern and Western Bushveld Complex.
- Facilitated roll-out of the production personnel training including train-the-trainer workshops on all mines with proven, expected or perceived seismic hazard.
- Sourcing and collation of revised seismicity related training materials for Rock Engineering professionals appropriate for all commodities.
- Audit protocol for seismic monitoring practice in line with SIM100301 guidelines.
- Once-off audits of seismic systems and reporting procedures of all business units.
- Reporting on audit findings by means of regional workshops.

The methodology detailed below was chosen to ensure that these objectives would be met.

The training materials were designed to explain the nature of seismic sources in Bushveld mines and point out the benefits of seismicity reducing practices. The materials provide simple rules on how to mitigate seismic hazard by motivating best practice to reduce conditions prone to seismic failure in PGM mines.

## 6.2 Project Hypothesis

After thorough analysis of geo-technical conditions and common mining methods in the Western Bushveld platinum mines, the authors of SIM100301 found that both mine layout and mining practice offer a range of opportunities to reduce the severity of seismic response and the likelihood of rock bursting.

This project made provision for, among others, the implementation of recommendations and best practice guidelines through the development of suitable training materials. The training of on-mine trainers ensured long-term teaching and instruction of mine production personnel on an ongoing basis.

The project also allowed for the compilation and distribution of training materials for rock engineering personnel on the subject of seismicity and rockbursts in PGM mines.

It further provided for seismic system and reporting procedure reviews covering the issues raised in item IV above and the reporting of these audit results to the relevant stakeholders. For further detail on the project see the following sections.

### 6.3 Project Methodology

To accommodate the project objectives and successfully facilitate rockburst risk mitigation in the Bushveld mines, the project defined six deliverables as detailed below, subsequent to an initial consultation phase to allow the deliverables to be customised and aligned with the needs of the Bushveld mining operations.

A. Learning materials for production personnel

The development of learning and awareness training material for mine production personnel (from Shift Supervisors to Production Managers) covering seismicity, mining and support practices, seismic risk monitoring, reporting and management required a flexible, modular approach on a high technical standard. The PGM operations in the Eastern and Western Bushveld face a wide range of seismic hazard levels from none (shallow operations such as Bathopele) to high (deeper than 2km such as Northam-Zondereinde).

The level of qualifications of the personnel to be trained ranges from Matric (NQF level 4) to mining engineer (level 8). Consultations with mines in the Western Bushveld during the planning phase for this proposal revealed that there are well in excess of one thousand employees considered in need of such training (Amplats: 581, Northam: 269, Lonmin: 140, Implats: similar to Amplats). The number of training centres on shafts with appreciable seismic hazard in the Western Bushveld (WBV) is 16. The Eastern Bushveld (EBV) has a smaller sized target audience in these occupations as their seismic hazard is significantly lower than in the WBV.

As a consequence, training materials should be visual, animated on a high technical standard and set at a level that is easily understood and related to by the audience. The materials must not rely on sophisticated IT equipment, but instead accommodate the typical and most common training facility setup at the mines. Not all trainers on mines can be expected to have specific rock engineering expertise. The materials also needed to be modular to allow each operation to choose only those sections that are relevant to their conditions.

Thus, the contents of the animated training materials required detailed planning and preparation with some consultation on mine level to ensure compatibility with existing on-mine training and the available facilities. The drafting of story lines; the selection of suitable input materials prior to the animation phase; the close collaboration between rock engineering experts and professional animators were all essential for a suitable end product: Computer generated, animated simulations of underground mining scenarios relevant to rockbursting in platinum mines.

B. Roll-out of the training for production personnel

For effective implementation at mine training centres, four regional workshops (two in Limpopo and two in the North West region) were conducted. The reason was that, based on past experience, due to work pressure and assigned responsibilities it is very difficult to attract all trainers in a region to a single date and location. The mines are unlikely to allow all of their trainers to be off-site at the same time.

C. Source and revise relevant seismic training material for Rock Engineering Professionals

For the strata control materials, a wide range of rock engineering hand and text books as well as other educational materials exist covering topics relevant to the conditions and processes resulting in seismicity and rockbursting, e.g. the MHSC funded handbook on rock engineering practice for hard-rock tabular mines (Jager & Ryder, 1999) and the recently released CoM Training Materials for the REC examinations, particularly for exam papers 2 and 3.1 The guidelines produced by Output 6 of project SIM100301 are concise and systematic and are suitable as training materials for rock mechanics personnel. SiM Mining Consultants also published a booklet specifically focusing on the outcomes in the REC syllabus pertaining to seismic sources and waves, seismic monitoring and seismic risk mitigation.

A total of 300 sets supplied all stakeholder mines with adequate stock, after stakeholder mines submitted their staff complements in the designation range of Strata Control Officer and above.

D. Development of an audit protocol for seismic monitoring and reporting.

Item IV of SIM100301 Output 6 contains detailed recommendations on how to establish sound seismic monitoring practice, ranging from seismic system planning to maintaining network health, optimal network configuration and data communications. A second set of guidelines relate to the analysis of seismic and rockburst incident data and how these can benefit the mine in terms of pro-active measures, implemented to reduce the frequency and severity of seismic hazard.

This project devised an audit protocol from above guidelines, which catered for a range of different seismic system setups: From shafts monitored by a single surface site to those with more than ten stations.

E. Once off audits on each PGM producer (per business unit).

In the WBV, stakeholders indicated that they would actively support an audit on nine of the mines. The situation in the EBV is different due to the generally lower seismic risk and the minimal extent of seismic monitoring practice. The project planning made provision for both time and travelling to both EBV and WBV.

The stakeholder interest in this initiative showed the relevance and necessity of practice reviews. Most operations do not include seismic system audits in their budgets and this project delivered a valuable service to a number of operations. Using the guidelines created during SIM100301, this ensured all networks and systems are held to the same benchmark.

F. Report on audit findings via regional workshops

Following the audit, individual audit reports were compiled per business unit as well as a summarising report reflecting all participating units. The summary contained statistics on equipment deployed, practices implemented, level of compliance and gaps evident between recommended and actual standard of seismic monitoring and reporting.

To present the findings to stakeholders, four workshops were planned: One each in Rustenberg, Northam, Polokwane and Burgersfort.

## 6.4 Project Milestones

**Table 1: Milestones defined for this project**

| MILESTONE | SUPPORTING INITIATIVES PER MILESTONE | DELIVERABLE PER INTIATIVE |
|---|---|---|
| **1.** Project initiation (start-up presentation and report) | Start-up presentations & report; inform stakeholders | Final proposal |
| **2.** Learning materials for production personnel | 2a.1 Concept and narrative Modules 1-6 | Outline, planned contents |
| | 2a.2 Scripting and production (1-6) | Draft animation 6 modules |
| | 2a.3 Consult RE experts & stakeholders, revise materials | Final modules 1-6 |
| | 2b.1 Concept and narrative Modules 7-14 | Outline, planned contents |
| | 2b.2 Scripting & production (7-14) | Draft animation 8 modules |
| | 2b.3 Consult RE experts & stakeholders, revise materials | Final modules 7-14 |
| **3.** Production personnel training roll-out | 3.1 Plan roll-out | Invitations, schedule, venues, RSVPs |
| | 3.2 Train-the-trainer | Workshops |
| **4.** Learning materials for RE personnel | 4.1 Contents and format | Concept |
| | 4.2 Select materials & compile | Draft materials |
| | 4.3 Present & release | Final materials |
| **5.** Seismic system audit protocol | 5.1 Compile protocol | Protocol |
| **6.** Audits | 6.1 Plan & conduct audits | Schedule, draft audit results |
| | 6.2 Analyse results, draft reports | Audit reports, summaries & conclusions |
| **7.** Audit results presentation | 7.1 Individual & summary reports, prepare presentation | Reports, Presentation |
| **8.** Draft final report (submission) | Compile draft project report | Draft project report |
| **9.** Final report (approval) | Compile final project report | Final project report |

## 6.5 Champion Mines

The following mines actively supported this project by motivating its proposal, providing input into the format and contents of training materials and by participating in the seismic system audits, where applicable:

> Dishaba, Khuseleka/Thembelani, Siphumelele, Tumela, Union, Impala Platinum 10#, 11# and 14#, Lonmin 1#, Northam-Zondereinde and -Booysendal, Marula, Modikwa, RBPM and Two Rivers.

Their participation is gratefully acknowledged.

# 7. MILESTONE DELIVERABLES

## 7.1 MILESTONE 1

**Project initiation and stakeholder consultation.**

SIM140301 is aimed at implementing the recommendations made by SIM100301 (“Minimising the increasing rockburst risk in the platinum mines”, Essrich et al., 2012), enabling mines to train both their production and rock engineering personnel on how to manage seismic risk and how to avoid practices that are known to result in increased seismic hazard.

### 7.1.1 Results per Milestone 1

This project was designed to produce in its first year a set of high-quality virtual reality training modules suitable for mine training centres. The scripting of modules (concept and contents) was the responsibility of the project’s mine seismology and rock engineering experts (SiM Mining Consultants and Middindi Consulting). Responsibility for the animation rested with Simulated Training Solutions (STS3D). The materials were meant to be incorporated into periodic or continual strata control training on mines, in most cases aimed at leave returnees and for the induction of new employees.

During the initiation phase, input was sought from a range of organisations and operations and the project team received expressions of interest from mines, the CoM, CGS, Wits, SANIRE, several geo-technical consultancies and seismic network suppliers, in addition to all major mine owners in the Eastern and Western limb of the Bushveld. The stakeholder list as of 25/2/2015 is included in Appendix I, the geographical location of the participating PGM mines are shown in Figure 1.

- Amplats – Siphumelele (School of Mines)
- Amplats – Tumela / Dishaba TC
- Lonmin – Academy
- Northam – Zondereinde TC
- Implats - 1# HR Development Centre
- Royal Bafokeng PM TC
- Northam – Booysendal TC
- Amplats – Twickenham TC
- Atlatsa/Amplats - Bokoni TC
- Implats/BEE - Marula TC
- ARM/Implats – Two Rivers TC
- ARM/Amplats - Modikwa TC

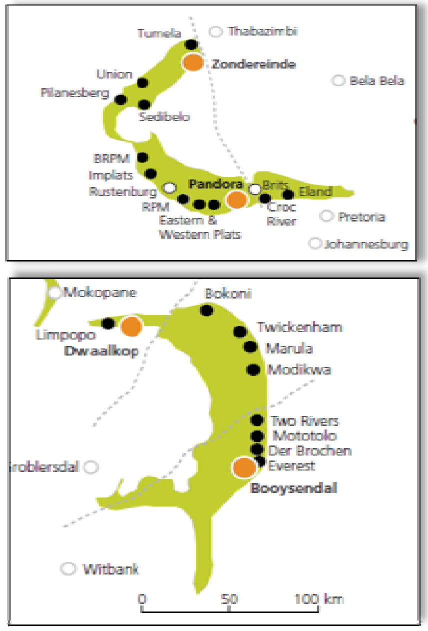



**Figure 1: Mines and Training Centres (TCs) visited in the Western limb of the Bushveld complex (top) and in the Eastern limb (bottom); map courtesy of Northam Platinum Mines.**

Twelve mines on the eastern and western Bushveld Complex were visited by the project leader to establish a sound understanding of the need for seismicity related training and the conditions on site such as the training facilities. To this end, rock engineering and training personnel were interviewed on the technical standard of current strata control training; to see the facilities and equipment for which SIM140301 will produce training modules; and to provide an opportunity for mine personnel involved in training to emphasise their needs and preferences.

Among others, it was important to establish how severe the rockburst risk is in the current operations and whether it may increase in coming years due to the strategic planning of the operations. The interviews also gave insight into the preferred language of instruction (English or basic English in all cases), and whether a combination of audio/visual materials could be presented to an audience whose size would exceed that of a standard classroom (>20). It was found that most training centres could accommodate larger groups of production personnel. The results of the consultation process are summarised in Table 2 below.

**Table 2: Summary of stakeholder consultation outcomes and technical and educational standards at mine training centres.**

| Mine | Seismic risk | SC training | Class rooms | Audi-torium | PC lab | Audio Video | Lang-uage | Trainer qualification |
|---|---|---|---|---|---|---|---|---|
| *Zondereinde* | ● | ● | 10x10 | 100 | - | ● | Engl | Mining |
| *Amandelbuilt* (2) | ● | ● | 20 | 80 | 15, STS | ● | Engl | Mining, MQA |
| *RPM* (3) | ● | ● | ? | 25 | 25, STS | ● | Engl-B | COMREC |
| Implats *Rbg.* (4) | ● | ● | 10 ? | 40 | 20, STS | ● | Engl | COMREC |
| *Lonmin (10)* | ● | ● | 5x40 | ? | old | ● | Engl-B | COMREC |
| *Royal Bafokeng PM* | - | ● | 6x20 | - | 35 | ● | Engl-B | SCO |
| *Booysendaal* | - | ● | 2x20 | 60 | 20 | ● | Engl | M/O |
| *Two Rivers* | - | ● | 2x20 | 200 | 10+20 | ● | Engl-B | Mining |
| *Twickenham* | - | ● | 8x20 | - | - | ● | Engl-B | Mining |
| *Bokoni* | - | ● | 15x20 | - | - | ● | Engl-B | Mining |
| *Marula* | - | ● | 10x20 | - | 20, STS | ● | Engl | Mining |
| *Modikwa* | - | ● | 3x35 | - | 35 | ● | Engl | - |

To illustrate the contents of Table 2, the information pertaining to Implats Rustenburg is explained in detail (4th mine visited in Table 2): Impala Platinum Rustenberg, four shafts with seismic risk, periodic strata control training, three classrooms seating 20 each, auditorium seating 40, PC lab for 15, uses animated training materials created by Simulated Training Solutions (Pty) Ltd., preference for a combination of audio and video based materials in English, trainer has a COMREC.

In line with the results of the consultation process, all modules were planned and scripted in basic English to address an audience consisting of members of production management teams, from shift supervisors to production managers. The animated modules are designed for presentation to groups using a projector and screen rather than for one-on-one study in a PC lab.

### 7.1.2 Conclusions from Milestone1

Responding to the needs and requests expressed by stakeholders, and giving consideration to the facilities available at mine training centres, a set of 10 to 12 animated training modules in basic technical English appeared to be the best option. The final product had to be modular and flexible to allow mines to only use those modules that would apply to their respective mining conditions and hazards.

The choice of module contents was informed by the recommendations issued by SIM100301 regarding the key factors determining rockburst hazard in PGM mines and how these were to be addressed.

Combining and optimally using the human and technical resources available at the three consultancies contributing to the project, a production schedule was agreed upon that would see one module being scripted approximately every two weeks. Allowing for a small contingency to accommodate minor delays, the production was scheduled to run from February to July 2015.

## 7.2 MILESTONE 2

**Innovative, state-of-the-art animated learning and awareness training material for production personnel on PGM mines to improve seismic risk management in the Eastern and Western Bushveld Complex.**

The module concepts and contents reflect Output 6 of SIM100301 (Essrich et al, 2012), which provides guidelines for the minimisation of rockburst risk in the platinum mining sector. The guidelines are grouped into four categories:

i. Analyse stress conditions and rock mass properties to enhance seismic risk assessments;
ii. Optimise mining practice to reduce seismic failure;
iii. Reduce rockburst damage once seismic failure occurs (exclude support issues);
iv. Improved seismic monitoring practice and rockburst risk quantification.

Each of the heading items contains a detailed explanation of topics that should be addressed by seismically active platinum mines, and by extension, the training materials. Thus, the guidelines formed the basis of the module planning, which resulted in 11 core modules, one introduction to the module set, and one summary module. These are the modules and their contents:

*0.* Introduction: *History of PGM mining, main topics, user interface for module selection.*
*1.* Geology: *Pulse episodes, rock types, strength, stiffness, brittleness, rock quality.*
*2.* Stress conditions: *Virgin and induced stresses, pillar and remnant shapes, confinement.*
*3.* Seismic sources: *Tectonic vs. mining induced tremors, seismic event, waves, basic source parameters, slips and bursts.*
*4.* Layout & sequence: *Panel sets, stress concentrations along boundaries, under- vs. overhand, down- and updip, problems: abutments, remnants, potholes, faults & dykes, tunnels.*

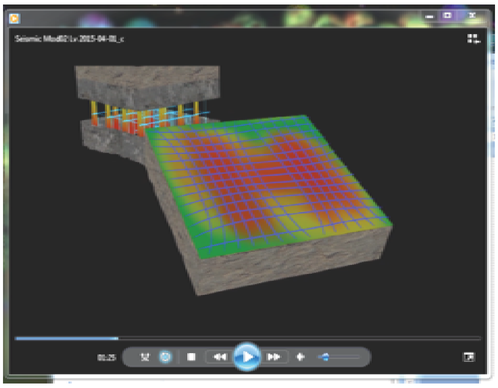
5. Mining practice (panel): *Safe access ways, corners & lead/lags, panel configuration, induced fracture zones.*
6. Gullies & sidings: *Fracture zones, lagging vs. advanced gullies, sidings and gully depth.*
7. Pillars: *Position, dimensions, spacing, shape, rock types, confinement.*
8. Seismic systems: *Seismic waves, recording and data analysis, network planning and main components, analysis & information release.*
9. Rockbursts: *Seismic event vs. rockburst, failure and damage mechanism, analysis, interpretation.*
10. Rules: *Societal, safety campaigns, compliance=safety & productivity.*
11. Seismic hazard & risk: *Hazard vs. risk, quantification, example: excavations in shaft pillar.*
12. Summary.

The scripting of the modules and the text for the accompanying audio recording were the responsibility of the rock engineering and mine seismology experts. The matching of the story line with visuals and audio content was an activity shared between animators and technical experts.

### 7.2.1 Results per Milestone 2

The production of modules commenced in late January 2015 and ended in July 2015. The title of the set is “How platinum mining in the Bushveld Complex is changing – *The future is not what it used to be*.” The first six modules were produced by the end of May 2015:

Module 1: Geology

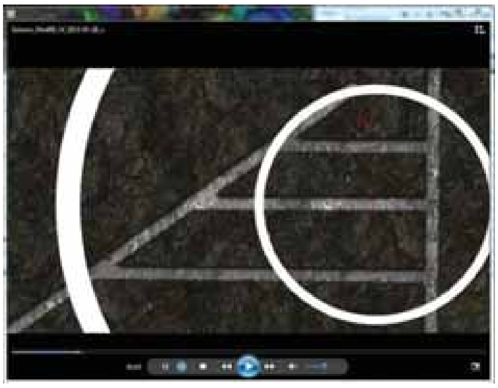


Module 2: Stress conditions

Module 3: Seismic sources

Module 4: Layout and sequence

Module 5: Mining practice

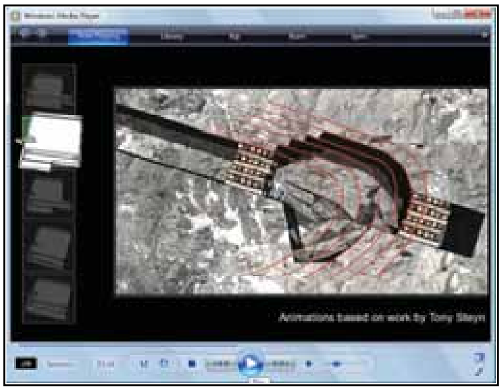


Module 8: Seismic systems

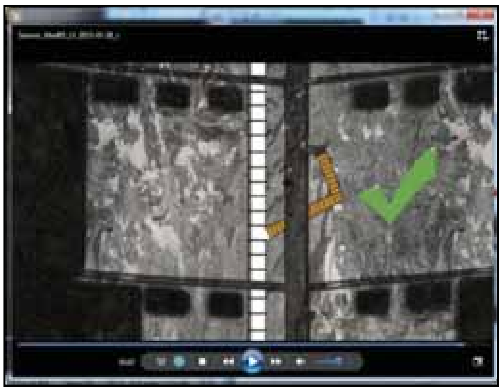
The comments received from the reviewer on the first six modules were constructive and positive, similar to the response by the CoM’s RETC committee when consulted in mid May.

In mid July 2015, a further RETC consultation workshop took place, prior to the completion of the second set of modules. The Summary module acknowledges the participating mines, the contribution made by a number of authors of rock engineering publication, and the funding provided by the MHSC.


Module 0: Introduction



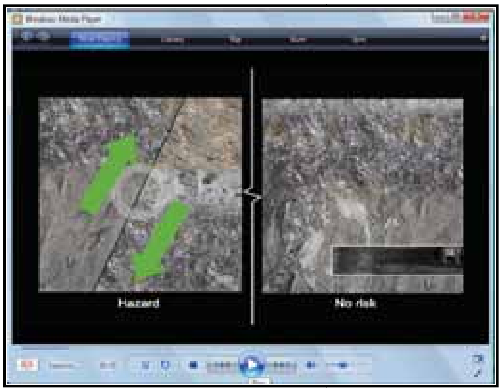
Module 6: Gullies & sidings



Module 7: Pillars

Module 9: Rockbursts


Module 10: Rules




Module 11: Seismic hazard & risk

The RETC’s comments were integrated into the modules wherever possible, together with the comments obtained from the official reviewer. A request by Impala Platinum to be granted access and permission to use the first six modules can be seen as an indication of the quality of the draft modules. The request was granted by SIMRAC and the audience’s response obtained during an initial workshop comprising mostly strata control and rock engineering personnel were shared with the project team.

### 7.2.2 Conclusions from Milestone 2

After completion of the modules, the second set was submitted to the MHSC project manager at the end of July 2015. The feedback from mines received after the completion of this milestone was positive throughout. The requests by a Witwatersrand gold mine to also be granted access to the modules further illustrates the value of the materials.

## 7.3 MILESTONE 3

**Facilitated roll-out of the production personnel training including train-the-trainer workshops on all mines with proven, expected or perceived seismic hazard.**

Compilation of the virtual-reality modules was successfully concluded in August 2015 after receiving positive feedback from the Chamber of Mine’s RETC committee, the SIMRAC reviewer and from external stakeholders.

The modules were planned for presentation at four training centres in the Western and Eastern Bushveld during November 2015, together with the distribution to mine training centres, senior rock engineering staff and selected external stakeholders of USB flash drives containing the modules.

### 7.3.1 Results per Milestone 3

In preparation of the roll-out, suitable dates and venues were selected to reach as wide an audience as possible. After consultations with mines, the workshops were scheduled as follows:

- 5 November 2015, Tumela Mine (Amandelbuilt Training Centre)
- 6 November 2015, Impala Platinum (Visitor Centre)
- 23 November 2015, Two Rivers Platinum Mine (Farmhouse)
- 24 November 2015, Bokoni Platinum Mine (Main Office).

The workshops attracted between one and twenty attendees each, with much lower participation in the Eastern Bushveld compared to the Western Bushveld (see Figure 2 for photos from the events at Impala and Bokoni). The feedback received during the workshops was positive throughout. It was evident that the training modules raised, in an effective manner, all the relevant issues and underlying causes relating to seismicity and rockbursting in the Bushveld platinum industry, without infringing on the local, mine specific standards and recommendations.

It was generally agreed that mine rock engineering personnel would utilize the modules to illustrate and explain the pertinent technical issues, and then use their own observations, photos and other training materials to motivate compliance with recommendations. The audience also made the suggestion that tests should be created with a small number of questions covering the module contents in order to effectively examine training participants with respect to their understanding of the subject.

**Figure 2: Impressions from the workshop at Impala’s Visitor Centre (top, 6/11/2015) and at Bokoni mine (24/11/2015).**

The modules were distributed by means of memory sticks, which contained an installer suitable for WIN7, 8 and 10 operating systems (32-bit installation). Figure 3 shows the root folder with installer and a simple codec pack with media player. Figure 4 shows the installation instructions (incl. MHSC copyright agreement); and Figure 5 the user interface, which allows the selection of modules, sequencing of the modules, and the saving of the selection for future use.

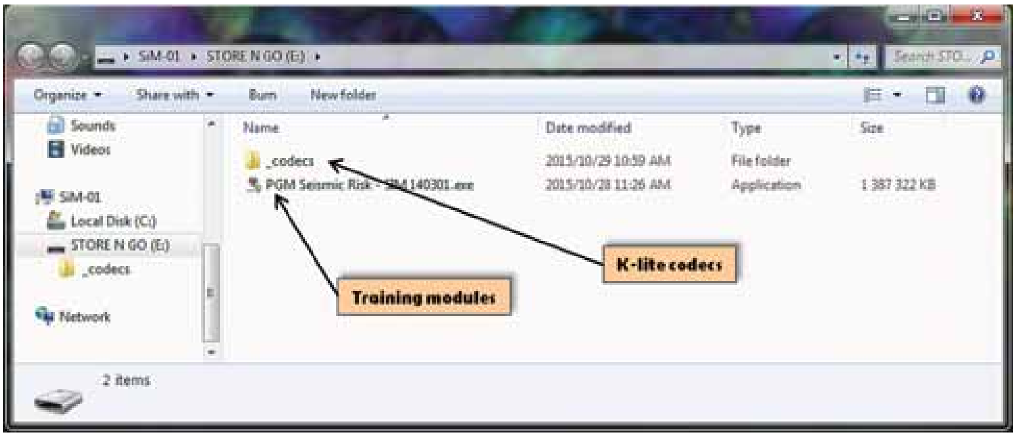



**Figure 3: USB drive with installer and media player (codecs).**

In total, 45 USB drives were configured for distribution to mine training centres and other, external stakeholders such as the RETC (CoM), Council for Geoscience, Wits University, University of Pretoria, large consultancies and two network suppliers who had made material contributions to the modules.

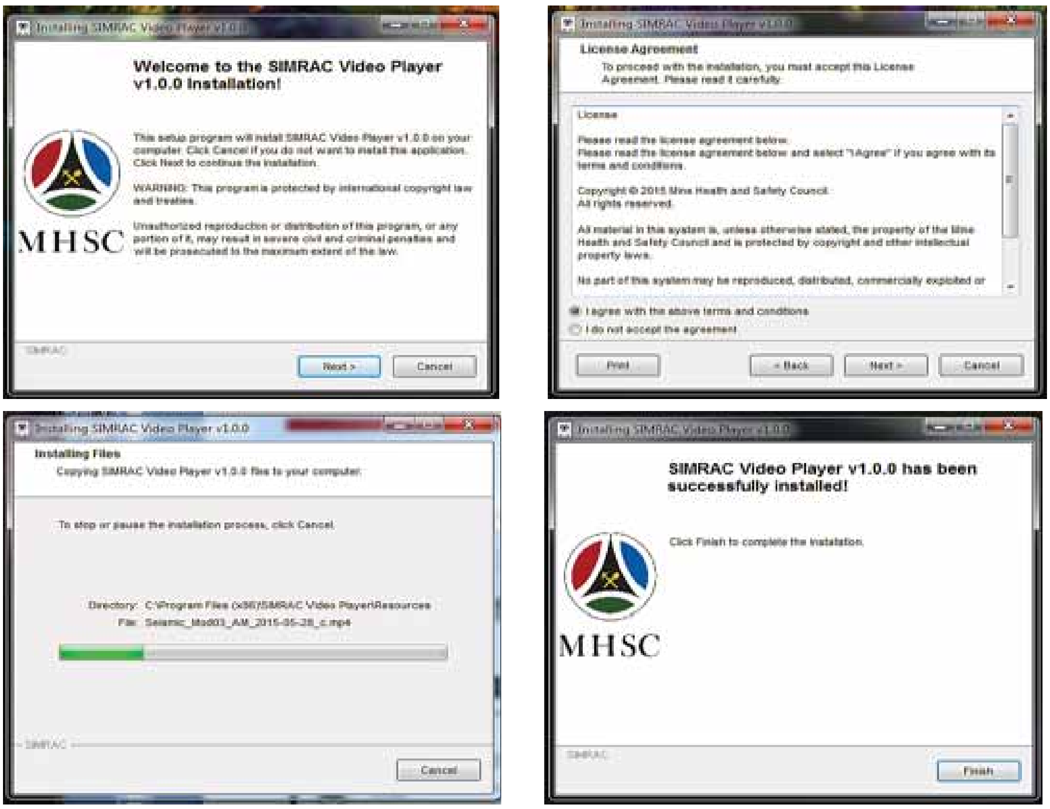



**Figure 4: Installation procedure**

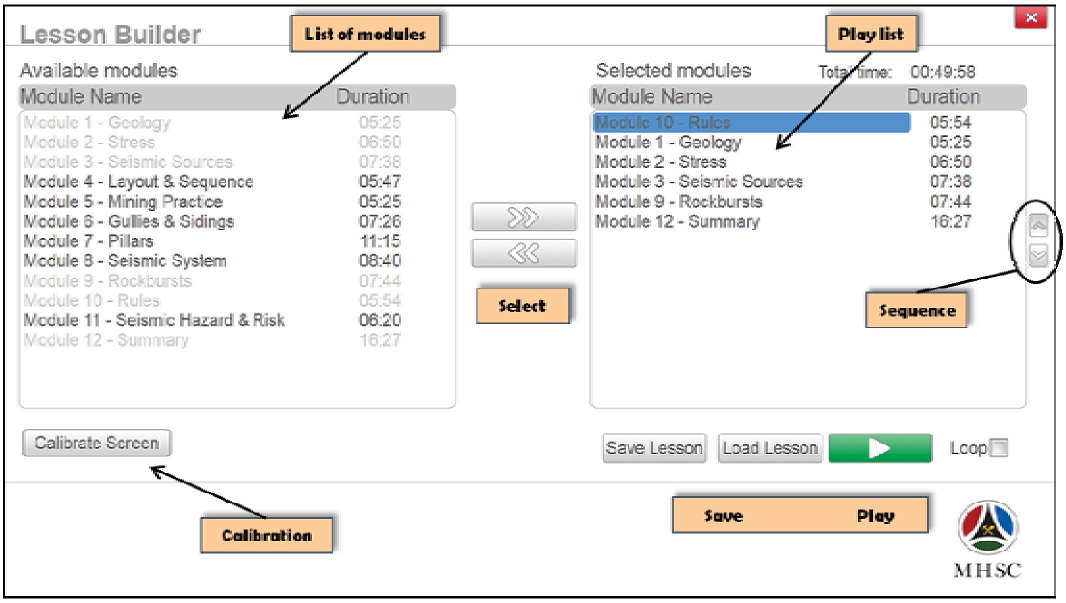



**Figure 5: User interface**

The interface also allows the calibration of the data projector for optimum colour and brightness (bottom left in Figure 5).

### 7.3.2 Conclusions from Milestone 3

The modules were produced and rolled out to mine training centres within the planned timelines of the project. Judging from the response received since the roll-out, they appear to be used on at least some of the mines identified as stakeholder in the milestone 1 stage of the project.

## 7.4 MILESTONE 4

**Sourcing and collation of revised seismicity related training materials for Rock Engineering professionals appropriate for all commodities.**

This project milestone made provision for the collation of suitable materials for rock engineering personnel which were to be sourced and collated from existing handbooks, textbooks, the internet and from the two consulting companies involved in this project (SiM and Middindi), both of which generate their own, copyrighted materials. The materials were to be formatted and distributed in printed and digital format.

### 7.4.1 Results per Milestone 4

A wide range of rock engineering hand and text books as well as other educational materials exist covering topics relevant to the conditions and processes resulting in seismicity and rockbursting in tabular, hard-rock mines. Many, such as the MHSC funded handbook on rock engineering practice for hard-rock tabular mines (Jager & Ryder, 1999) and the recently released CoM Training Materials for the REC examinations, particularly for exam papers 2 and 3.1, offer sufficient coverage of the relevant topics.

The guidelines produced by Output 6 of project SIM100301 are concise and systematic and are suitable as training materials for rock mechanics personnel. SiM published a manual specifically focusing on the outcomes in the REC syllabus pertaining to seismic sources and waves, seismic monitoring and seismic risk mitigation.

The collation of suitable materials, revision of these and subsequent distribution was based on the following approach: The guidelines determined the topics covered in the manual. The main headings are:

- ❖ Analysis of rock types and their properties; stress conditions and rock mass properties to enhance seismic hazard and rockburst risk assessments.

- ❖ Optimal mining practice to reduce seismic failure (avoidance of sources of seismic energy emissions).
- ❖ Precautions to reduce rockburst damage where seismic failure occurs (control of damage severity).
- ❖ Improved seismic monitoring practice and rockburst risk quantification.

The guidelines then specify a number of topics that need to be explained and understood in order to be able to comply with the recommendation. Grouping of these topics results in the following headings and sub-headings, which reflect the structure of the printed manual:

Chapter 1 - Geotechnical environment

- Rocks and minerals
- Stress field
- Rock mass quality.

Chapter 2 - Potential for geotechnical environment to affect seismic failure

- Rock type, strength, quality and stiffness
- Stress distribution and fracturing
- Geological structures
- Rock mass behaviour.

Chapter 3 - Mining practice to reduce seismic failure potential

- Mining directions and sequencing
- Multi-reef mining
- Confinement
- Pillars.

Chapter 4 - Mining practice to reduce the potential of seismic damage

- Stable ground conditions
- Support practice
- Safe off-reef areas.

Chapter 5 - Seismic monitoring - Planning

- Monitoring objectives
- Sensor configuration
- Location accuracy
- Velocity model
- Local vs. regional coverage
- Capacity
- In-house expertise.

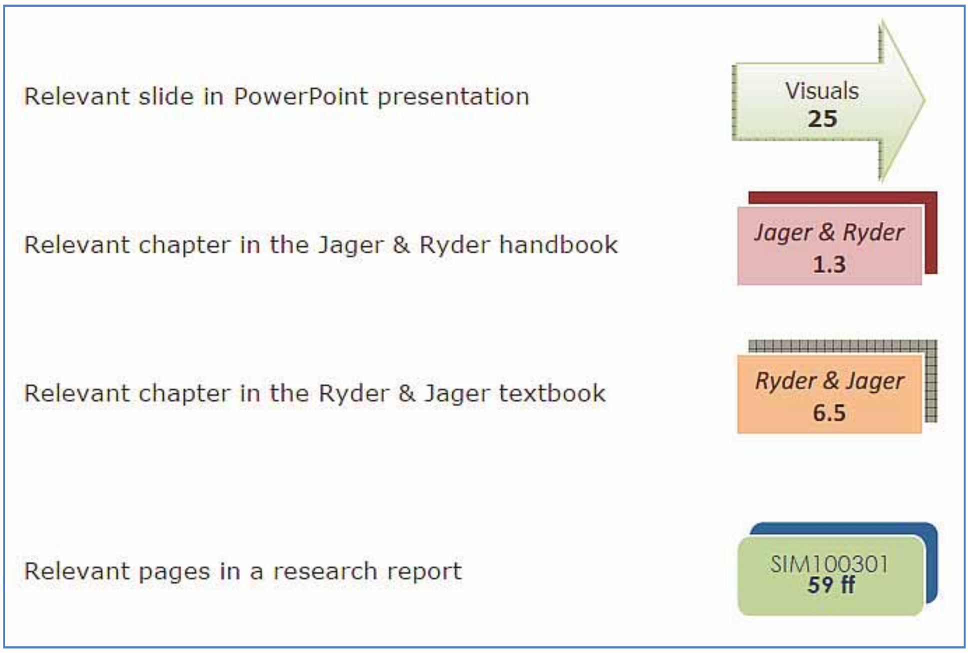
Chapter 6 - Seismic system operation

- Source parameters
- System timing
- Sensor and station health
- Status reporting
- Principal sites
- Data back-up
- System optimisation
- Quality control
- Practice reviews.

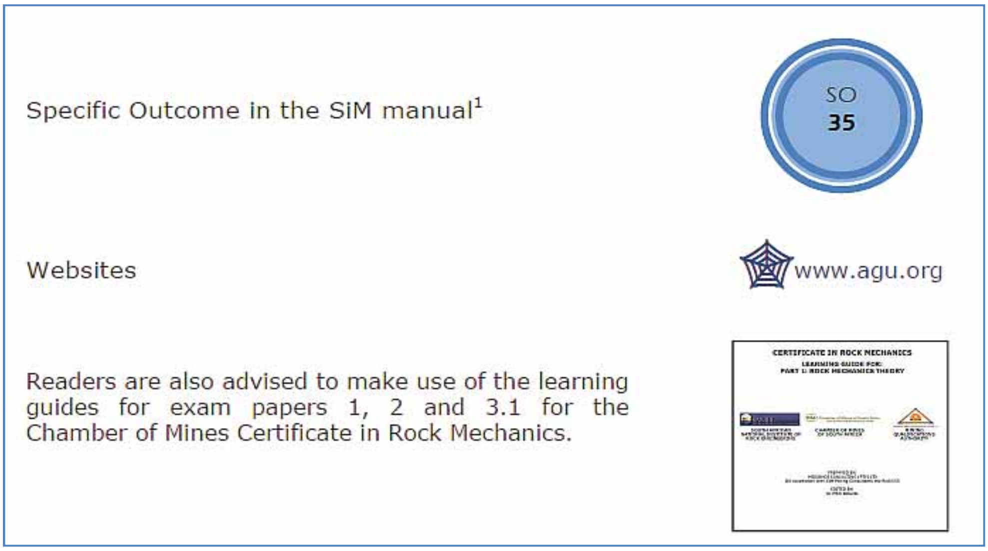
Chapter 7 - Seismic monitoring – Value-add

- Incident data base
- Rock burst analysis
- Rock burst risk ratings
- Risk reduction.

In order to access external references such as animations and textbooks, the readers of the manual are referred to the slides in the visual materials, to text books and to research reports. In the manual, the first four icons below refer to sources that are included on the CD attached to the back page of the manual:




Other symbols refer to specific outcomes in the manual published by SiM and provided as a hardcopy to the stakeholder, to web sites or to the learning guides for the Rock Engineering Certificate, which are available in PDF from the MQA:




Conceptually, the text-based manual (WORD format, printed in grey-scale, 43 pages) is designed to provide information and to explain the relevance of certain principles. It also motivates the recommendations contained in the guidelines. Each of the bulleted items in the list above is the heading of a small chapter, which ends with the relevant guideline to this topic.

Each of the seven main chapters ends with a list of pertinent questions that allow the reader to test her knowledge and understanding of the subject. The manual ends with a list of useful references to handbooks and textbooks mentioned in the manual, and a short glossary of acronyms used throughout the manual. Some examples are given here:

| | |
|---|---|
| ASG | Advanced strike gully |
| BC | Bushveld Igneous Complex |
| CGS | Council for Geoscience |
| GPS | Global Positioning System |
| IRUP | Iron Rich Ultramafic Pegmatite |
| MER | Merensky reef horizon |
| $M_{max}$ | Magnitude of the largest event |
| NoT | Number of Triggers |
| ... | |

A much more comprehensive glossary of terms is provided in the SiM published manual on the Specific Outcomes related to mining induced seismicity in the COMREC syllabus. The SiM manual, the fourth edition of which was recently published, accompanies the manual and the visuals. Together they make up the set of training materials distributed to mines. This latest edition includes additional materials pertaining to seismic risk in PGM mines and includes specific examples from platinum mines. Below are the front covers of the two manuals in the set (Figure 6).

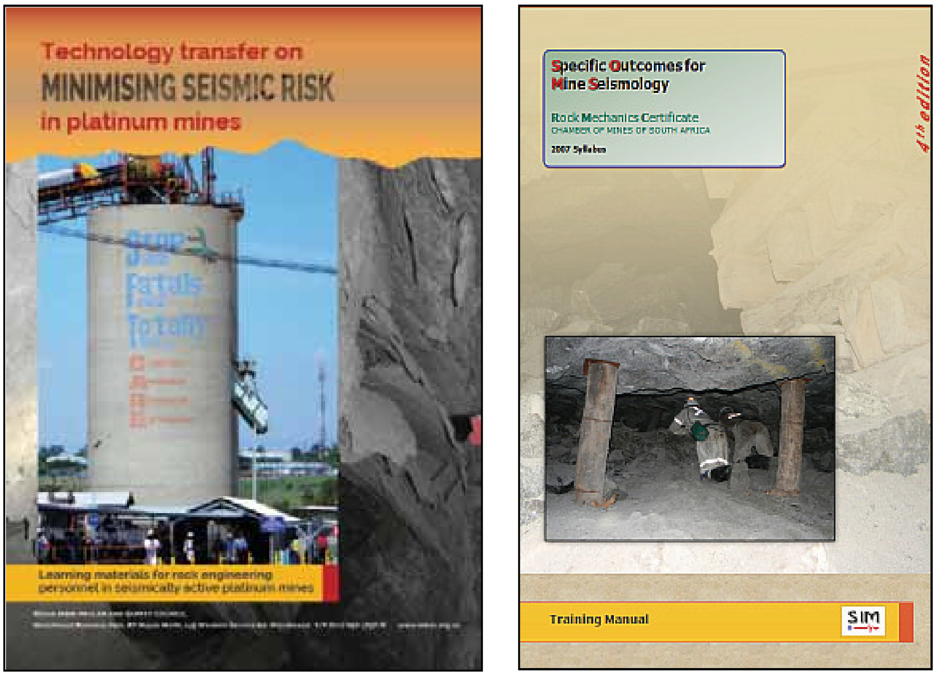



**Figure 6: Front covers of the two manuals distributed to mines (CD included).**

The slides in the visuals (PowerPoint format) are designed to add photos, charts, diagrams and links to animations. The visuals are meant to illustrate the points raised in the manual, which can be done more effectively in a slide show than in manual printed in grey-scale. This mode of presentation also allows active hyperlinks to animations and to project reports such as SIM050302 and SIM100301, which are mentioned on a number of occasions in the manual. A typical slide from the visual materials and the final slide with acknowledgments are shown in Figure 7.

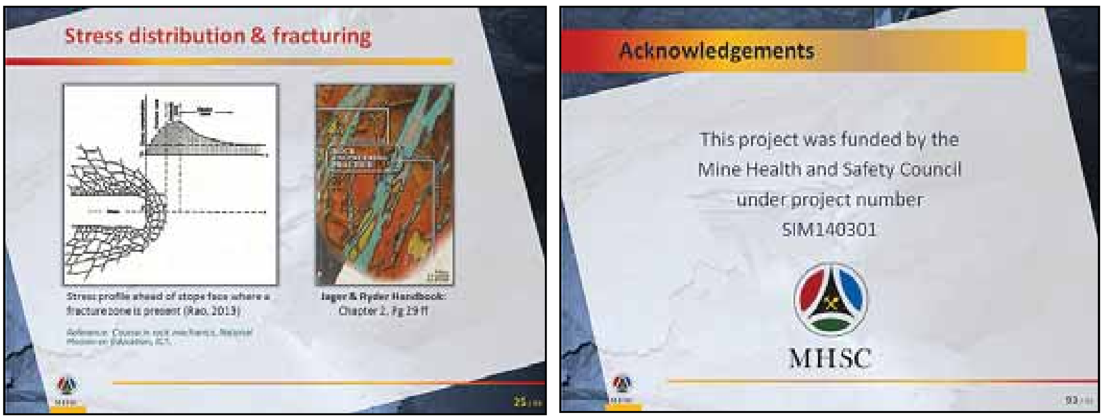



**Figure 7: Two slides from the visual materials accompanying the manuals.**

### 7.4.2 Conclusions from Milestone 4

A total of 300 copies (electronic and/or printed) was considered sufficient to supply all stakeholder mines with adequate stock. SANIRE (South African National Institute of Rock Engineering) indicated that is has approximately 120 members and associate members in its Eastern and Western Bushveld branches at current.

Mines submitted their complement in the designation range of Strata Control Officers and above and were supplied with, on average, three sets for every two employees in this range. The allocation of sets to mines is summarised in Appendix V.

## 7.5 MILESTONE 5

**Audit protocol for seismic monitoring practice in line with SIM100301 guidelines.**

During Phase 2 of SIM050302 (Durrheim et al, 2006), a “seismic scorecard” was developed with the intention to assist rockburst-prone mines to continuously improve their systems to manage rockburst risk.

The overall score should be a reflection of a mine’s efforts to optimise the design and operation of its seismic network. In combination, a high score should reflect the considerable effort a mine will have made to accurately quantify the seismic hazard level in various parts of its operation, thereby reducing the exposure of its employees and ore reserves and complying with legal requirements.

In 2011, Output 6 of SIM100301 made recommendations on best practice with respect to seismic system operation, data collection and analysis (see Appendix II for details). The current Output 5 of SIM140301 is based on these recommendations and guidelines, which broadly relate to the following topics:

- seismic network planning,
- system settings and configuration,
- maintenance and upgrades,
- seismic source quantification,
- data analysis and interpretation,
- rockburst analysis,
- seismic hazard quantification.

The resulting audit protocol has the format of a score card, similar to what was produced by SIM050301, which aimed at defining best monitoring practice in seismically active mines. The scope of this current score card for platinum mines is reduced and more general in order to match the overall lower seismic risk levels compared to deep gold mines.

### 7.5.1 Results per Milestone 5

For Output 5, an audit protocol was created based on outcomes of SIM050302 and SIM100301, ensuring that it would cater for a range of different seismic system setups: From shafts monitored by a single surface site to those with more than ten stations. The complexity of seismic monitoring technology deployed in mines of the Bushveld Complex reflects the levels of severity of seismic hazard: From zero on virtually all mines in the Eastern Bushveld, to severe risk on two of the Western Bushveld mines.

This score card is subdivided into three main themes each of which is subdivided into a number of aspects:

- Seismic network planning and operation
- Seismic source quantification
- Rockburst analysis and reporting.

The purpose of each aspect within each theme is explained and annotated in a way to assist the auditor in arriving at a fair evaluation score. The total score achieved by a mine operating a seismic system is then determined from the performance within each aspects.

A bonus point was allocated where mines use calibration blasts or confirmed rockburst sites to verify source parameters, e.g. location an source radius.

### 7.5.2 Conclusions from Milestone 5

Comments were sought and received from mine seismologists deployed in some of the Bushveld mines and their advice was incorporated into this document prior to submission to SIMRAC.

While the maximum score is 100%, few mines were expected to achieve the maximum as planning related issues and financial and operational constraints may interfere with optimal system operation.

**Table 3: Seismic system score card**

| Section No. | Criteria | Comment | Score |
|---|---|---|---|
| | | | 40% |
| 1. Seismic network planning, system settings & configuration, | Monitoring objectives defined for different areas of the mine. | | |
| | Network station configuration planned according to monitoring objectives. | | |
| | Shallow or deep sites added to reduce location error in depth. | | |
| | Principal[1] sites defined to ensure minimum coverage at all times. | | |
| | Capacity for speedy sensor installation (<3 months). | | |
| | Filter settings and sampling rate match relevant Magnitude range. | | |
| | At least 80% of stations operational at all times. | | |
| | Sensor health checked and reported on, and always above 80%. | | |
| | Sensor orientation and polarity checked (not required for smart sensors). | | |
| | Synchronisation of system clocks for regional events. | | |
| | | | 30% |
| 2. Seismic source quantification | At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | | |
| | Hypo-centre location from at least 3 sensors. | | |
| | Standardisation of Magnitude relation with neighbouring mines. | | |
| | Minimum quality standards for events before data analysis. | | |
| | Back-up procedures for seismic event data base. | | |
| | Access to SANSN data for larger events. | | |
| | | | 30% |
| 3. Event and rockburst analysis and reporting | Data analysis by mine seismologist. | | |
| | Seismic hazard and risk quantification. | | |
| | Periodic reporting to management and production sections. | | |
| | Rockburst data gathering and analysis, including mine plans. | | |
| | Rockburst data base complete, accurate and consistent. | | |
| | Regular practice review and quality management procedures for data collection. | | |
| **Total** | | | **100%** |

[1] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

## 7.6 MILESTONE 6

**Once-off audits of seismic systems and reporting procedures of all business units.**

Output 6 applied an audit protocol to each mine actively involved in seismic monitoring. This score card is subdivided into three main dimensions each of which is subdivided into a number of aspects.

An additional 5% bonus was allocated where mines used calibration blasts or rockbursts to confirm the seismic event parameters calculated by the network, such as hypo-centre location and source dimensions. The introduction to the score cards is found in Appendix III. In the score card, the purpose of each aspect within each theme is explained and annotated in a way to assist the auditor in arriving at a fair evaluation score. The maximum achievable score is 100%, but few mines were expected to achieve the maximum as planning related issues and financial and operational constraints may interfere with optimal system operation.

### 7.6.1 Results per Milestone 6

Nine mines in the BC accepted the invitation to join the audit initiative. All are located in the western Bushveld, and they constitute all mines or shafts currently operating seismic networks. The only seismic network operated in the eastern BC is installed at Everest Mine, which was closed after a hangingwall collapse and has yet to return to normal operations.

Audits took place in March and April 2016, mostly by means of site visits. Where meetings could not be arranged in time, interviews were conducted over the phone and by e-mail. In all cases where IMS is a service provider (six out of nine networks) an IMS network engineer participated in the exchange of information and provided technical details, reports and seismic data. Following mines participated:

- Implats 10#, 11# and 14#,
- Siphumelele,
- Thembelani/Khuseleka,
- Northam-Zondereinde.
- Tumela,
- Dishaba,
- Union,

The completed protocols in Appendix IV reflect the facts established during the audit interviews. Also included is information on sensor health and system status over time from reports; and the accuracy of event locations and other source parameters based on the seismic data provided. The final score as determined in the score card represents the compliance with each of the aspects in the assessment.

Draft audit forms were submitted for comment to all mines and all disagreements or misunderstandings were remedied. Presented below, and in the following project Output 7, which comprises the full audit results, are the outcomes as agreed between the audit team and the mine’s representatives.

For the purpose of result presentation, names of mines which asked for confidentiality were changed and encoded to prevent identification of the mine. They are referred to as Mines A to E as shown in the table below, which presents the overall score achieved by the nine seismic systems.

The final scores range from 60% to 100% with Impala Platinum’s networks and Anglo-Platinum’s Union mine being the best planned and operated networks amongst the BC mines. Incidentally, these two also did not request confidentiality. The average score is 87%.

### 7.6.2 Conclusions from Milestone 6

It is possible that the rockburst risk severity partly influences the resources assigned to managing a seismic system, which impacts on its performance: The two mines with the highest seismic risk score 90% and 95% respectively; the two with negligible risk score 60% and 71% respectively.

The single assessment criterion that is least complied with is the speedy replacement of faulty sensors: only three out of nine mines are able to complete this task within six months. The highest compliance levels are achieved in the needs-based planning of network layout; the procedures to maintain minimum quality standards for seismic source parameters; and the periodic reporting to management and production sections.

The project team would like to thank the participating mines for taking the time and making the effort to allow access to this information, which is internal to a mine’s operation and is sensitive due to its direct link to workers’ safety. Five of the nine participating mines expressed their wish to have the audit results disassociated from their operation; their audit forms are sterilised accordingly.

Output 7 presents the detailed analysis to stakeholders and provides for meetings and/or workshops with mines and the public.

## 7.7 MILESTONE 7

**Results of seismic system audits and reporting procedures.**

Appendix III contains the scores achieved by all nine participating mines per assessment criterion. The figures included in Appendix IV further support the facts established during the audit interviews. Information on sensor health and system status over time from mine reports are detailed in the individual audit reports in Output 6, as are event location accuracy and other source parameters based on the seismic data provided. The final score as determined in the score card represents the compliance with each of the aspects in the assessment.

### 7.7.1 Results per Milestone 7

For the purpose of result presentation to the public, mines which asked for confidentiality are referred to as Mines A to E as shown in Figure 8 and the Table 4 below, which presents the total score achieved by the nine seismic systems. The bonus point is awarded where a mine uses rockburst incidents or calibration blasts to confirm source parameters calculated by the network, e.g. 3D-locations or source dimensions.

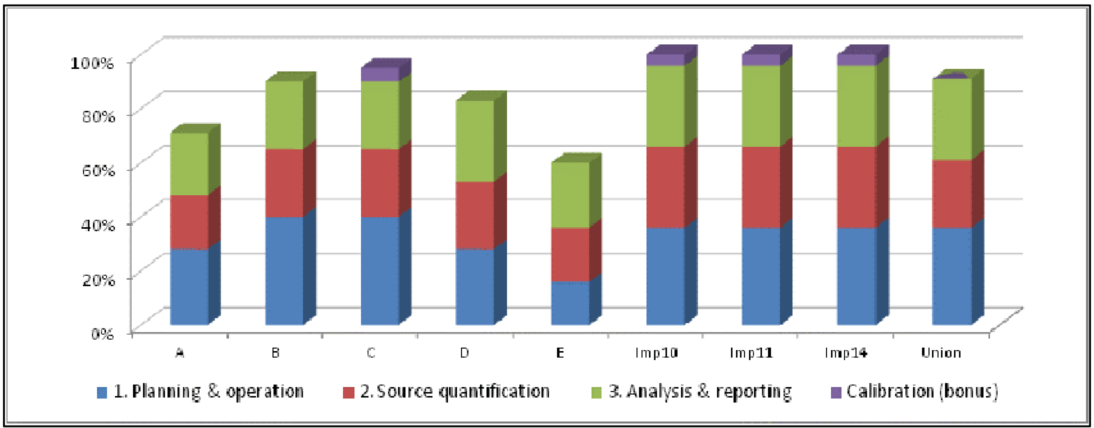



**Figure 8: Scores achieved by each of the participating mines.**

The cumulative scores range from 60% to 100% with Impala Platinum’s networks and Mine C being the best planned and operated networks amongst the BC mines. The average score is 88%.

The single assessment criterion that is least complied with is the speedy replacement of faulty sensors: only three out of nine mines are able to complete this task within three months. The highest compliance levels are achieved in the needs-based planning of network layout; the procedures to maintain minimum quality standards for seismic source parameters; and the periodic reporting to management and production sections.

**Table 4: Summary of seismic hazard level, audit score and stations**

| Mine | Events per day | $M_{max}$ | Seismic stations | Compliance |
|---|---|---|---|---|
| A | 3 | 3 | 9 | 71% |
| B | 54 | 2.9 | 28 | 90% |
| C | 9 | 3.2 | 14 | 95% |
| D | 4 | 2 | 7 | 83% |
| E | 5 | 2.8 | 18 | 60% |
| Impala 10#, 11#, 14# | 10 | 2.5 | 21 | 100% |
| Union | 2 | 1.7 | 6 | 91% |

It is possible that the rockburst risk severity partly influences the resources assigned to managing a seismic system, which impacts on its performance: The two mines with the highest seismic risk have audit scores of 90% and 95% respectively; the ones with non-existent to negligible risk score 60% and 71% respectively.

The nine mines participating in the audits are exposed to a wide range of seismic hazard level. The largest events recorded range from $M_{max}$=1.7 to $M_{max}$=3.2 (Table 15 and Figure 15 in Appendix III); the depth range where seismic response is observed varies from approximately 900m below surface to 2 200m below surface. Not unexpectedly, daily rates of processed and accepted events range from two to 54 based on the data catalogues of recent months made available by the mines. There is no reporting of significant seismic response from the UG2 reef horizon (see SIM100301 project report for possible reasons).

The frequency of recorded events depends on production volumes, number of operational stations and network sensitivity, but also on mining practice and geo-technical conditions such as brittleness of the rock and the presence of faults, dykes and joint sets. Mines operate between six and 28 sensor sites; the standard sensor set is a tri-axial 4.5Hz geophone set, suitable for the small to medium magnitude range of events. With the exception of Mine A, all mines have at least one surface site to improve vertical location accuracy (Appendix III, Figure 13).

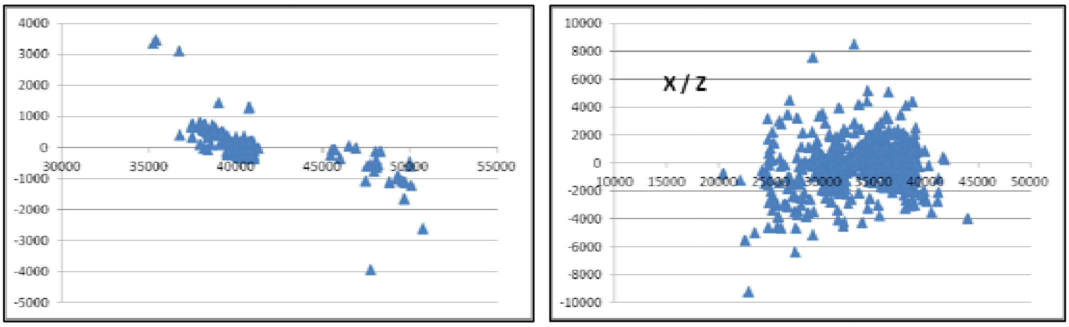



**Figure 9: Location accuracy in vertical section view at Mine A (left) and Mine D (right).**

The number of sites, which is small in most cases when compared to gold mines in the Wits basin, places constraints on the achievable data quality, especially where some of the sensors are impaired or not functional at all. Where the station configuration is well planned, most events are located within ±1 000m of the reef horizon (Figure 9, left). Where the network layout is planar or arrival times picked from seismograms are scarce, the majority of events can be within ±4 000m of the reef (Figure 9, right). According to the audit results, all systems use at least three stations to calculate event locations.

Contributing to location errors is the fact that some of the sensors may not be fully aligned to the mine's survey grid: Five of the networks have assessed their sensor alignments after installation and made corrections where necessary (56% compliance).

Similar constraints apply to the accuracy of source parameters. The number of accepted, low-noise seismograms with valid velocity and displacements spectra impacts on the reliability of the event information supplied by the network, such as seismic energy and moment release, dominant frequency (used to determine the source radius) and stress drop. The audit protocol prescribes at least four P- and four S-waves for calculation of source parameters, which is achieved by 67% of the mines.

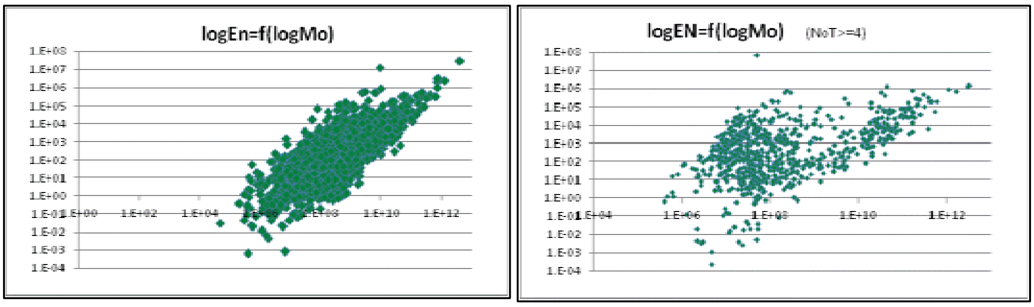



**Figure 10: Energy-Moment correlation of seismic events from Mine B (left) and Mine C.**

In some cases, the data sets provided for the audit reflect limited alignment with basic physical principles (Figure 10). Even when the NoT≥4 filter is applied, the Energy-Moment correlation is poor as in the case of Mine C’s data. The percentage of events satisfying the original SIM100301 recommendation of at least five stations triggered by each recorded event ranges from 5% at Union to 70% at Mine B (see Figure 14 in Appendix III). At the centre of this issue is the balance between data quality and quantity: in order to record sufficient data for daily data analysis and reporting, the NoT threshold is lowered leading to more information being gathered for evaluation and interpretation. But this can impact negatively on the accuracy of the data, as is seen in some of the data sets, which in turn put the analysis outcomes at risk.

A different type of impairment is seen in the source parameters that are artificially restrained to avoid outliers, for instance corner frequency $f_c$. Corner (or dominant) frequency should be inversely related to seismic moment: The larger the physical source size and the greater the forces acting at the source, the lower should be the frequency of the radiated waves. But corner frequency is less stable than for example seismic moment and its values are often subject to an upper cut-off to avoid spurious data.

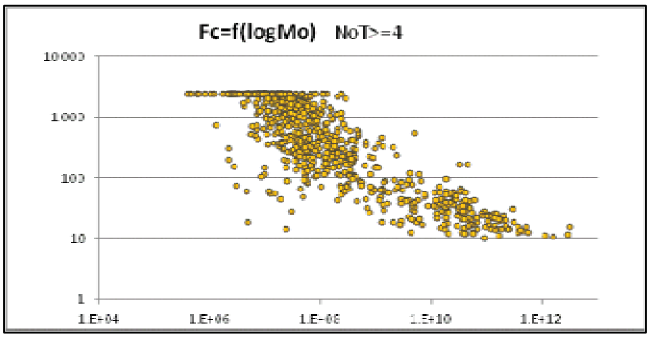



**Figure 11: Correlation between corner frequency fc and seismic moment (Mo).**

The data set in Figure 11 originates from a mine with an IMS processing service which applies quality control standards during event processing. The artificial upper cut-off of 2 500Hz is visible in the data set (minimum of four triggers per event).

Full credit is due to the system operators and network suppliers for proper planning of the monitoring needs prior to network design (100% compliance), the selection of specific monitoring objectives (100%). Also, the dedication to maintain the system after commissioning, evident from the 89% compliance with a minimum of 80% station health and 80% operational status, is clear. Significant resources both in technical expertise and financial resources are allocated to most of the networks and incidents of the entire network being off-line or otherwise severely affected are the exception amongst the monitoring mines.

Equally in line with guidelines is the standardisation of the magnitude scale and the common GPS based time standard that allows synchronisation of system clocks and the exchange not only of event information but of individual seismograms. Thus, where system technology allows this, event parameters can be calculated using seismograms from several systems in a region thereby increasing the accuracy and reliability of source parameters. Data exchange between mines may be the only method to derive meaningful event details for regional tremors seeing that less than half of the mines have formal or informal agreements with the CGS to share in SANSN collected data.

All mines have data back-up procedures in place to safely store recorded and accepted events. Seismograms, due to their large data volumes especially where event frequency is high, are permanently stored by Impala mines and are kept for at least three months on IMS systems at the remaining mines. The lack of historic data bases of all recorded seismograms prevents the recalculation of event parameters when system software changes or the algorithms embedded in the software.

Periodic reporting in the form of daily, weekly and monthly status reports are common practice on all mines. The main topics reported on are:

1) Station status and system health
2) Recent large events
3) Changes in seismicity trends and patterns
4) Rockburst Incidents.

Seismic activity levels can be as low as two to three events per day, which does not allow for daily trend analysis. But where event frequency is sufficiently high, data are analysed by an in-house mine seismologist (Impala mines) or a mine seismologist associated with an external service provider (IMS in case of all other mines). There is no indication that in the case of an external service, which includes event processing, services are delayed or reports not delivered on time due to unreliable data communication or other technical faults.

Subsequent chapters elaborate in detail on the findings pertaining to individual mines and the relevant recommendations, where applicable. For detailed information on each audit refer to the Milestone 6 chapter in this report.

#### 7.7.1.1 Mine A: Results and recommendations

Mine A achieved a total score of 71%, comprising 28% for network planning and operation, 20% for accurate seismic source quantification, and 23% for analysis and reporting on seismic hazard (Table 5). The mine does not make use of calibration blasts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 5: Mine A’s score achieved in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| A | 0.28 | 0.20 | 0.23 | - | 71% |

Mine A has no principal sites to provide basic coverage in case of power outages in the shaft, and takes more than two years on average to replace a faulty sensor set. However, the network was systematically planned to achieve certain, pre-defined objectives and is well maintained when measured in terms of station status and sensor health. The medium-term trend is slightly downward, but status and health are still above 80%, the recommended benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately 2.6 events per day, and this includes events with only three triggers. All events in the sample data base have source parameters and there is a reasonably close correlation between seismic energy and seismic moment. In case of large, possibly regional events or those associated with geological features, the mine has no co-ordinated, formalised access to the national seismic system (SANSN) to exchange information.

The fact that rockburst incidents are not recorded and analysed in a formalised manner cannot be held against the mine as it has to date not experienced a sufficient number of seismic failures with subsequent damage that would warrant a systematic recording.

The reviewer agrees that the minimum number of triggers should be kept at three to allow for a basic flow of information to monitor dynamic rockmass failure, should it take place. This requirement should be maintained unless data quality deteriorates or seismic response levels increase and the number of events with NoT≥4 become sufficiently frequent to quantify seismic hazard at Mine A.

To ensure acceptable quality standards, the downward trend in system health should be reversed and not be allowed to drop below 80%. Major impairments were experienced in late November 2015 (all stations down) and during the Christmas holiday break (50% operational, see xxx_REP-MNTH-201601-IMSv0.pdf). It is also recommended that at least three principal sites be chosen to provide basic coverage for the mine and to allocate resources for the replacement of sensors should one fail.

The January 2016 monthly IMS report indicates that three of the nine operational stations have two impaired or faulty components, which should be addressed to ensure accurate and reliable information being retrieved by the mine’s seismic system.

Mine A’s seismic system is managed by an experienced mine seismologist and its maintenance and technical support is outsourced to IMS. The system has never been subjected to a detailed, external practice review, a fact that could perhaps be addressed in the future.

#### 7.7.1.2 Mine B: Results and recommendations

Mine B achieved a total score of 90%, comprising a full 40% for network planning and operation, 25% for accurate seismic source quantification and 25% for analysis and reporting on seismic hazard (Table 6). The mine does not make use of calibration blasts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 6: Mine B’s score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| B | 0.40 | 0.25 | 0.25 | - | 90% |

Mine B has declared principal sites to provide basic coverage in case of power outages in the shaft, and takes less than three months on average to replace a faulty sensor set. The network was systematically planned to achieve certain, pre-defined objectives and is well maintained when measured in terms of station status and sensor health. The medium-term trend is flat and stable, and is well above the 80% benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately 54 events per day, the highest of all seismically active mines in the BC. The data base comprises events with only three triggers, but very few events are without source parameters apart from location. Overall there is a good correlation between seismic energy and seismic moment and moment and corner frequency.

Hypo-centre locations are well clustered and the vertical spread of event locations is limited due to the sites on surface and on shallow levels two to six. In case of large, regional events or those associated with geological features, the mine has no access to the national seismic system (SANSN) to exchange information and no formal agreement with the CGS for this purpose.

Likely due to the mining depth beyond 2 000m b.s. and the narrow middling between MER and UG2 reef horizons, Mine B is the mine with the highest seismic activity level in the Bushveld Complex. It underwent changes to mining practice in order to mitigate this risk. Rockburst incidents are recorded and analysed in a formalised manner, in some cases outsourced to consulting specialists, and recommendations were effectively implemented in the past.

The reviewer suggests that the minimum number of triggers should be raised to four to improve the data accuracy and to allow for a steady flow of reliable information to monitor dynamic rockmass failure. The focus should shift from quantity to quality, as it is evident from the data catalogue that not all source parameters are meaningful and accurate.

The generally high level of sensor health and station status is commendable and is likely among the highest and most consistent of the nine participating mines.

The weekly IMS report for mid April 2016 suggests that five of the 28 operational stations were impaired, which should be addressed to ensure accurate and reliable information being retrieved by the mine’s seismic system.

Considering the occurrence of damaging events at Mine B, the mine should engage with the CGS to gain access to the SANSN for the exchange of information on large events (M>=3), which are recorded more accurately by a regional network equipped for low frequency ground motion.

Mine B’s seismic system is managed by a qualified and experienced mine seismologist and its maintenance and technical support are outsourced to IMS. The system has been subjected to a detailed, external practice review in 2006, which should perhaps be repeated in the future.

#### 7.7.1.3 Mine C: Results and recommendations

Mine C achieved a total score of 95%, comprising a full 40% for network planning and operation, 25% for accurate seismic source quantification and 25% for analysis and reporting on seismic hazard (Table 7). In addition, it earned a 5% bonus for making use of rockbursts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 7: Mine C's score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| C | 0.40 | 0.25 | 0.25 | 0.05 | 95% |

Mine C has declared principal sites to provide basic coverage in case of power outages in the shaft, and takes less than three months on average to replace a faulty sensor set. The network was systematically planned to achieve certain, pre-defined objectives and is mostly well maintained when measured in terms of station status and sensor health. The medium-term trend is upward and well above the 80% benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately nine events per day, which includes some events with only three triggers. The three-trigger events are responsible for the 1.3% of events in the data base that have no source parameters apart from location and there is a poor correlation between seismic energy and seismic moment unless these events are excluded (see Figure 10 above).

Hypo-centre locations are clustered and the vertical spread of event locations is limited. In case of large, regional events or those associated with geological features, the mine has no access to the national seismic system (SANSN) to exchange information and no formal agreement with the CGS for this purpose.

Mine C is the mine with the highest seismic hazard level in the Bushveld Complex and had to undergo significant changes to support and mining practice in order to mitigate this risk. Rockburst incidents are recorded and analysed in a formalised manner and recommendations were effectively communicated and implemented in the past.

The reviewer suggests that the minimum number of triggers should be raised to four to improve the data accuracy and to allow for a steady flow of reliable information to monitor dynamic rockmass failure. The focus should shift from quantity to quality, as it is evident from the NoT=3 data that source parameters are not necessarily meaningful and may violate basic physical principles such as a close correlation between source size and energy release.

The high level of sensor health and station status is commendable and is likely the highest and most consistent among the nine participating mines.

The weekly IMS report for mid March 2016 suggests that five of the 14 operational stations were impaired or faulty, which should be addressed to ensure accurate and reliable information being retrieved by the mine’s seismic system.

Considering the size of damaging events, Mine C should engage with the CGS to gain access to the SANSN for the exchange of information on large events (M>=3), which are recorded more accurately by a regional network equipped for low frequency ground motion.

The mine’s seismic system maintenance and technical support are outsourced to IMS. The system has never been subjected to a detailed, external practice review, a fact that could perhaps be addressed in the future.

#### 7.7.1.4 Mine D: Results and recommendations

Mine D achieved a total score of 83%, comprising 28% for network planning and operation, 25% for accurate seismic source quantification, and 30% for analysis and reporting on seismic hazard (Table 8). The mine does not make use of calibration blasts to confirm and quantify the accuracy of event locations and other source parameters. Its overall score is roughly equal to the average score obtained by all the participating mines.

**Table 8: Mine D's score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| D | 0.28 | 0.25 | 0.30 | - | 83% |

Despite Mine D experiencing several rockbursts each year, its network comprises only five stations, three underground and two on surface. It records roughly the same number of events per day as Mine E (four to five per day), which is equipped with 18 sites. Despite its appreciable seismic risk level, Mine D has no principal sites to provide basic coverage in case of power outages in the shaft. It takes several years to install equipment: One set of monitoring instruments purchased in 2012 has yet to be commissioned.

The network was systematically planned to achieve certain, pre-defined objectives and system configuration parameters are set to accurately record the events in the small to medium magnitude range expected at the mine. According to the January 2016 IMS monthly report, several of the sensor sets are severely impaired by intermittent power supply, timing or data communication (see Milestone 6).

The system is poorly maintained in terms of station status and sensor health. Prior to a recent improvement in May 2016, the medium-term trend was downward with status and health levels below 50%, well below the recommended 80% benchmark for good system maintenance. The alignment of sensors installed in boreholes has not been verified and, where required, corrected.

The seismic network records less than five events per day, which includes events with only three triggers. All events in the sample data base have source parameters and there is a reasonably close correlation between seismic energy and seismic moment. In case of large, possibly regional events or those associated with geological features, the mine has no co-ordinated, formalised access to the national seismic system (SANSN) to exchange information.

Rockburst incidents are recorded and analysed in a formalised manner. Seismicity trends are analysed and results reported to mine management.

The reviewer agrees that the minimum number of triggers should be kept at three to allow for a basic flow of information to monitor dynamic rockmass failure. This requirement should be maintained unless data quality deteriorates or seismic response levels increase and the number of events with NoT>3 become sufficiently frequent to quantify seismic hazard at the mine.

To ensure acceptable quality standards, the low system health standards should be raised with urgency and not be allowed to drop below 80%, an issue that has already been addressed according to recent information provided by the mine. Stations without functional sensors (at least two components working) should be upgraded or decommissioned to save on maintenance and channel licensing costs. Subject to a detailed review, the network size should be increased, possibly beyond the yet to be commissioned sites planned since 2012.

The February 2016 monthly IMS report indicates that sites 62, 64 and 65 are impaired or have faulty components, which should be addressed to ensure accurate and reliable information being retrieved by the mine’s seismic system. It appears that additional sensors were recently brought on-line and are now maintained in working order.

It is also recommended to declare at least three principal sites to provide basic coverage of the mine and to allocate resources for the replacement of sensors should one fail.

Mine D’s seismic system maintenance and technical support are outsourced to IMS. The system was reviewed by the network supplier two years ago, but has never been subjected to a detailed, external practice review, a fact that could perhaps be addressed in the future.

#### 7.7.1.5 Mine E: Results and recommendations

Mine E achieved a total score of 60%, comprising 16% for network planning and operation, 20% for accurate seismic source quantification, and 24% for analysis and reporting on seismic hazard (Table 9). The mine does not make use of calibration blasts to confirm and quantify the accuracy of event locations and other source parameters. It received the lowest score amongst the nine participating systems.

**Table 9: Mine E's score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| E | 0.16 | 0.20 | 0.24 | - | 60% |

Despite its surprisingly large number of stations (18) when considering its low seismic risk level, Mine E has no principal sites to provide basic coverage in case of power outages in the shaft. On average, it takes more than two years to replace a faulty sensor set which may explain why up to seven of its sensor sets are severely impaired, according to the January 2016 IMS monthly report (see Milestone 6). However, the network was systematically planned to achieve pre-defined objectives and system configuration parameters are set to accurately record the events in the small to medium magnitude range expected at Mine E.

The system is not well maintained in terms of station status and sensor health. The medium-term trend is slightly upward, but status and health are around 60%, well below the recommended 80% benchmark for good system maintenance. The alignment of sensors installed in boreholes has not been verified and, where required, corrected.

The seismic network records approximately four to five events per day, and this includes events with only three triggers. All events in the sample data base have source parameters and there is a reasonably close correlation between seismic energy and seismic moment. In case of large, possibly regional events or those associated with geological features, the mine has no co-ordinated, formalised access to the national seismic system (SANSN) to exchange information.

The fact that rockburst incidents are not recorded and analysed in a formalised manner cannot be held against the mine as it has to date not experienced a sufficient number of seismic failures with subsequent damage that would warrant a systematic recording (one rockburst incident in 2005 resulting in two fatalities).

The reviewer agrees that the minimum number of triggers should be kept at three to allow for a basic flow of information to monitor dynamic rockmass failure, should it occur. This requirement should be maintained unless data quality deteriorates or seismic response levels increase and the number of events with NoT>3 become sufficiently frequent to quantify seismic hazard at Mine E.

To ensure acceptable quality standards, the low system health standards should be raised and not be allowed to drop below 80%. Stations without functional sensors (at least two components working) should be upgraded or decommissioned to save on maintenance and channel licensing costs. Subject to a detailed review, the stations density could probably be reduced.

The January 2016 monthly IMS report indicates that five of the 18 stations have two impaired or faulty components, which should be remedied to ensure accurate and reliable information being retrieved by the mine’s seismic system.

It is also recommended to declare at least four principal sites to provide basic coverage of the mine and to allocate resources for the replacement of sensors should one fail.

Mine E’s seismic system is managed by an experienced mine seismologist and its maintenance and technical support are outsourced to IMS. The system has never been subjected to a detailed, external practice review, a fact that could perhaps be addressed in the future.

#### 7.7.1.6 Impala 10#: Results and recommendations

Impala 10# achieved a total score of 100%, comprising 36% for network planning and operation, a full 30% for accurate seismic source quantification and full 30% for analysis and reporting on seismic hazard (Table 10). In addition, it earned a 4% bonus for making use of rockbursts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 10: Impala 10# score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| Implats 10# | 0.36 | 0.30 | 0.30 | 0.04 | 100% |

Implats 10# operates seven underground and one surface site (all tri-axial, three more sites planned). It has equipped all stations with batteries to provide coverage in case of power outages in the shaft, but takes more than three months on average to replace a faulty sensor set. The network was systematically planned to achieve certain, pre-defined objectives and is well maintained when measured in terms of station status. The percentage of days when stations are down is less than 10% on average, below the benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately three events per day, which includes a large proportion of events with only two triggers. These events are partly responsible for the 7% of events in the data base that have no source parameters apart from location. There is a poor correlation between seismic energy and seismic moment unless these events are excluded. The missing source parameters relate mostly to seismic energy and moment of the P-wave, less to the S-wave.

Hypo-centre locations are clustered and the vertical spread of event locations is limited to approximately 1 000m above and below the reef horizon. In case of large, possibly regional events or those associated with geological features, the mine has signed a MoU with the CGS to exchange data from the national seismic system (SANSN).

In the past, Implats 10# has experienced high seismic hazard levels. It has undergone changes to support and mining practice in order to mitigate this risk. Rockburst incidents are recorded and analysed in a formalised manner and recommendations were effectively communicated and implemented in the past. All events M>1 are investigated including underground visits, provided the site is accessible.

The high level of sensor health and station status is commendable and is likely one of the highest and most consistent among the nine participating mines.

The reviewer suggests that the minimum number of triggers should be raised to three to improve the data accuracy and to allow for a steady flow of reliable information to monitor dynamic rockmass failure. The focus should shift from quantity to quality, as it is evident from the NoT=2 data that source parameters are often not meaningful and contradict basic physical principles such as a close correlation between source size and energy release or moment and dominant period.

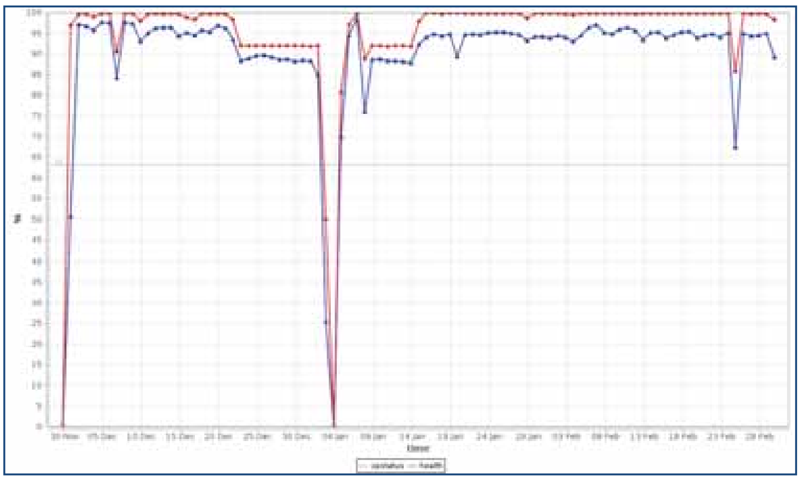


**Figure 12: Station health and system status as percentage over time (sample IMS report).**

The system administrator does not produce a time-based station health report as is common practice with IMS networks. Such reports reflect the sensor health, continuity of communication, accuracy of station’s internal time base, the contribution in terms of triggers made by a station to the data base of accepted events and other detail. These reports are valuable as they allow the quantification of operational functionality, as seen in the example in Figure 12.

Impala’s seismic systems are managed by a qualified and experienced mine seismologist and their maintenance and technical support are provided by in-house technicians. The system has last been subjected to a detailed, external practice review in 2008, a fact that could perhaps be addressed in the future.

#### 7.7.1.7 Impala 11#: Results and recommendations

Impala 11# achieved a total score of 100%, comprising 36% for network planning and operation, a full 30% for accurate seismic source quantification and full 30% for analysis and reporting on seismic hazard (Table 11). In addition, it earned a 4% bonus for making use of rockbursts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 11: Impala 11# score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| Implats 11# | 0.36 | 0.30 | 0.30 | 0.04 | 100% |

Implats 11# operates six underground and one surface site (all tri-axial 4.5Hz, three more sites planned). It has equipped all stations with batteries to provide coverage in case of power outages in the shaft, but takes more than three months on average to replace a faulty sensor set.

The network was systematically planned to achieve certain, pre-defined objectives and is well maintained when measured in terms of station status. The percentage of days when stations are down is less than 10% on average, below the benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately three events per day, which includes a large proportion of events with only two triggers. These events are partly responsible for the 7% of events in the data base that have no source parameters apart from location. There is a poor correlation between seismic energy and seismic moment unless these events are excluded. The missing source parameters relate mostly to seismic energy and moment of the P-wave, less so to the S-wave.

Hypo-centre locations are clustered and the vertical spread of event locations is limited to approximately 1 000m above and below the reef horizon. In case of large, possibly regional events or those associated with geological features, the mine has signed a MoU with the CGS to exchange data from the national seismic system (SANSN).

Implats 11# is a mine with moderate seismic hazard level. The few rockburst incidents, when they occurred, were recorded and analysed in a formalised manner and recommendations were communicated and implemented. All events M>1 are routinely investigated including underground visits, provided the site is accessible.

The high level of sensor health and station status is commendable and is likely one of the highest and most consistent among the nine participating mines.

The reviewer suggests that the minimum number of triggers should be raised to three to improve the data accuracy and to allow for a steady flow of reliable information to monitor dynamic rockmass failure. The focus should shift from quantity to quality, as it is evident from the NoT=2 data that source parameters are often not meaningful and contradict basic physical principles such as a close correlation between source size and energy release or moment and dominant period.

The system administrator does not produce a time-based station health report as is common practice with IMS networks. Such reports reflect the sensor health, continuity of communication, accuracy of station’s internal time base, the contribution in terms of triggers made by a station to the data base of accepted events and other detail. These reports are valuable as they allow the quantification of operational functionality, as seen in Figure 5.

Impala’s seismic systems are managed by a qualified and experienced mine seismologist and their maintenance and technical support are provided by in-house technicians. The system has last been subjected to a detailed, external practice review in 2008, a fact that could perhaps be addressed in the future.

#### 7.7.1.8 Impala 14#: Results and recommendations

Impala 14# achieved a total score of 100%, comprising 36% for network planning and operation, a full 30% for accurate seismic source quantification and full 30% for analysis and reporting on seismic hazard (Table 12). In addition, it earned a 4% bonus for making use of rockbursts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 12: Impala 14# score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| Implats 14# | 0.36 | 0.30 | 0.30 | 0.04 | 100% |

Implats 14# operates five underground and one surface site (all tri-axial 4.5Hz, three more sites planned). It has equipped all stations with batteries to provide coverage in case of power outages in the shaft, but takes more than three months on average to replace a faulty sensor set.

The network was systematically planned to achieve certain, pre-defined objectives and is well maintained when measured in terms of station status. The percentage of days when stations are down is less than 10% on average, below the benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately three events per day, which includes a large proportion of events with only two triggers. These events are partly responsible for the 7% of events in the data base that have no source parameters apart from location. There is a poor correlation between seismic energy and seismic moment unless these events are excluded. The missing source parameters relate mostly to seismic energy and moment of the P-wave, less to the S-wave.

Hypo-centre locations are clustered and the vertical spread of event locations is limited to approximately 1 000m above and below the reef horizon. In case of large, possibly regional events or those associated with geological features, the mine has signed a MoU with the CGS to exchange data from the national seismic system (SANSN).

Implats 14# is a mine with high seismic hazard level. Rockburst incidents are recorded and analysed in a formalised manner and recommendations are communicated and implemented. All events M>1 are also routinely investigated including underground visits, provided the site is accessible.

The high level of sensor health and station status is commendable and is likely one of the highest and most consistent among the nine participating mines.

The reviewer suggests that the minimum number of triggers should be raised to three to improve the data accuracy and to allow for a steady flow of reliable information to monitor dynamic rockmass failure. The focus should shift from quantity to quality, as it is evident from the NoT=2 data that source parameters are often not meaningful and contradict basic physical principles such as a close correlation between source size and energy release or moment and dominant period.

The system administrator does not produce a time-based station health report as is common practice with IMS networks. Such reports reflect the sensor health, continuity of communication, accuracy of station’s internal time base, the contribution in terms of triggers made by a station to the data base of accepted events and other detail. These reports are valuable as they allow the quantification of operational functionality, as seen in Figure 5.

Impala’s seismic systems are managed by a qualified and experienced mine seismologist and their maintenance and technical support are provided by in-house technicians. The system has last been subjected to a detailed, external practice review in 2008, a fact that could perhaps be addressed in the future.

#### 7.7.1.9 Union Mine: Results and recommendations

Union mine achieved a total score of 91%, comprising 36% for network planning and operation, 25% for accurate seismic source quantification, and 30% for analysis and reporting on seismic hazard (Table 13). The mine does not make use of calibration blasts to confirm and quantify the accuracy of event locations and other source parameters.

**Table 13: Union mine's score in each of the main dimensions.**

| Mine/Shaft | 1. Planning & operation | 2.Source quantification | 3. Analysis & reporting | Calibration (bonus) | Total |
|---|---|---|---|---|---|
| Union | 0.36 | 0.25 | 0.30 | - | 91% |

Union has equipped all stations with UPS, but has not formally declared principal sites to provide basic coverage in case of power outages in the shaft. It takes less than three months on average to replace a faulty sensor set. The network was systematically planned to achieve certain, pre-defined objectives and is mostly well maintained when measured in terms of station status and sensor health. The medium-term trend is slightly upward, but status and health also experience major impairments, recently also below the recommended 80%, the benchmark for good system maintenance (see Milestone 6).

The seismic network records approximately two events per day, which includes some events with only three triggers. All events in the sample data base have source parameters and there is a reasonably close correlation between seismic energy and seismic moment (see Milestone 6). Hypo-centre locations are clustered and the vertical spread of event locations is limited. In case of large, possibly regional events or those associated with geological features, the mine has no formalised access to the national seismic system (SANSN) to exchange information, but has previously exchanged data informally.

The fact that rockburst incidents are not recorded and analysed in a formalised manner cannot be held against the mine as it has to date not experienced a sufficient number of seismic failures with subsequent damage that would warrant a systematic recording.

The reviewer agrees that the minimum number of triggers should be kept at three to allow for a steady flow of information to monitor dynamic rockmass failure, should it take place. This minimum requirement should be maintained unless data quality deteriorates or seismic response levels increase and the number of events with NoT>3 become sufficiently frequent to quantify seismic hazard at Union.

To ensure acceptable quality standards, the level of system health should be raised and stabilised and not be allowed to drop below 80%. Major impairments were experienced in late 2015 and early 2016 when most stations were temporarily off-line. It is also recommended to choose at least three principal sites to provide basic coverage of the mine and to allocate resources for the replacement of sensors should one fail.

The weekly IMS report for 21-27 April 2016 suggests that three of the five operational stations were impaired or faulty, which should be addressed to ensure accurate and reliable information being retrieved by the mine’s seismic system.

Union's seismic system is not managed by a qualified and experienced mine seismologist and its maintenance and technical support are outsourced to IMS. The system has never been subjected to a detailed, external practice review, a fact that could perhaps be addressed in the future.

### 7.7.2 Conclusions from Milestone 7

It should always be kept in mind that seismic systems are not a means to themselves. Rather, they should serve as sources of raw data and, after analysis, accurate, reliable and relevant information to mitigate the risk of rockbursting. Thus, these systems are to be maintained at high levels of functionality or else they become obsolete, possibly a waste of resources.

In this context, seismic data linked to rockburst incidents are the most valuable for a mine, which should strive to derive from this information the causes of rockbursts, especially the underlying mechanisms of dynamic rock mass failure.

Of the participating mines, 89% systematically record and analyse rockburst incidents and two thirds maintain a formal rockburst data base. Considering the low level of seismic hazard severity on most operations, this is a reasonably high compliance level. As transpired during the audit interviews, rockbursts are taken seriously by rock engineers and mine management and receive the level of attention and resource allocation they deserve. Mine A, for example, has a complete set of rock related incident analysis and evaluation procedures prescribed in a Technical Support Document, but has so far only experienced one rockburst in 2012. The mines with significant rockburst risk, Mine B, C and the Impala shafts, all score 90% or above in the audit.

## 7.8 GENERAL CONCLUSIONS

With the nature of this project being on implementation rather than on fundamental or applied research, the achieved outcomes need to be judged by their potential to leave a lasting impression in the mining industry in the Bushveld region.

The project team went out of their way to establish, at an early stage, what the needs of the industry are as far as training and education around the issue of seismic hazard and risk are concerned. The previous project SIM100301, laid a strong foundation for meaningful interaction with mines and their training, production and rock engineering staff. Throughout the project, feedback was sought and obtained from mines, the CoM, seismic system suppliers, the SIMRAC reviewer and several individuals who all contributed meaningfully to the outcomes.

The continued input received from the various parties leads to the conclusion that the project was well embedded with main role players, delivered meaningful materials for the training of mine personnel, conducted important first-level audits of seismic systems and produced audit reports that identified positive and negative aspects of seismic network operation as it is currently practiced. These audit results could serve to harmonise the monitoring practice and ensure that similar quality standards are accepted and adhered to throughout the Bushveld mines exposed to mining induced seismic risk.

# 8. RECOMMENDATIONS FOR FURTHER RESEARCH

On a number of occasions when interaction took place with project stakeholders, especially after the completion of the milestones that produced training materials, suggestions were made that a similar project should be conducted for the gold mines in the Witwatersrand Basin.

There is significant synergy between the two mining sectors: Both operate along tabular reefs with hard, mostly brittle rock mass. The mining layouts are similar, at least in terms of their fundamentals, and both experience specific forms of seismic response that are founded on the same principles of dynamic rock mass failure at high stress levels.

The materials produced for platinum mines explain many of these fundamental, but the specifics would have to be developed for the gold mines. A vast collection of research reports detail the mechanism of rockbursts in deep and ultra-deep gold mines. The research results could be used to design and produce training materials for production personnel and for rock engineering staff similar to those produced by this project.

In addition to the target audience of SIM140301, one should consider expanding the audience to include mine safety inspectors, as they represent the third element involved in successful risk management, apart from production and rock engineering targeted by SIM140301..

# 9. RECOMMENDATIONS FOR IMPLEMENTATION FOR THE SECTOR

Since SIM140301 is a knowledge and technology transfer project by its nature, no such recommendations could be made, apart from the following: The project team encourages SIMRAC to allow the use of the materials produced by this project by as many interested parties as possible. The wider the distribution the wider the benefit seeing that the funding has already been secured. The only limit to utilisation should be drawn by intellectual property rights and the prevention of infringements on copyrights.

# 10. TECHNOLOGY TRANSFER OPTIONS

To enhance the impact that the SIM140301 training materials may have, the facilitation of workshops and short courses should be considered. A suitable format could be chosen based on the technical background of the audience and their familiarity with the concepts and principles applicable to dynamic rock mass failure induced by mining.

Based on the lecturing experience of the authors, courses should last between two and five days and should include underground visits to areas affected by seismicity.

# 11. CONCLUSIONS

The interest expressed in the animated materials by rock engineering consultancies, universities, technical specialists in the rock engineering sector and a seismic system supplier is encouraging and serves as confirmation that valuable outputs were delivered by this project.

# 12. REFERENCES

RJ Durrheim, Cichowicz, A., Ebrahim-Trollope, R. Essrich, F., Goldbach, O., Linzer, L., Spottiswoode, S.M., Stankiewicz, T. & van Aswegen, G. (2007). “Minimising the Rockburst Risk (Phase 2) Output 3: Guidelines, Standards and best Practice for Seismic Hazard Assessment and Rockburst Risk Management.”

F Essrich, Hanekom, J.W.L., Stankiewicz, T. (2012): “Minimising the increasing seismic risk in the platinum sector, Guidelines for best practice in seismically active and rockburst prone platinum mines of the Western Bushveld, Outcome 6 of SIMRAC project SIM100301.

# 13. LIST OF APPENDICES

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| APPENDIX II | SIM100301 OP6 Guidelines |
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| APPENDIX IV | Table 16: Seismic system score card Mine A |
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# 14. FINANCIAL SUMMARY

**Name of project: SIM140301 'TechTransfer on minimising seismic risk in the platinum mines'**

**Project expenses (excl VAT) as at 31 July 2016**

| | Project staff costs | Operating costs | Capital costs | Subcontractor costs | Other costs | Total |
|---|---|---|---|---|---|---|
| Planned | 904000 | 168180 | 0 | 1531216 | 60000 | 2663396 |
| Actual | 904000 | 168180 | 0 | 1531216 | 60000 | 2663396 |

**Income received**

| Date | Submission | Planned % Income | Amount [R] | Actual % Income | Amount [R] | Balance [R] |
|---|---|---|---|---|---|---|
| 30-Nov-14 | start-up | 10% | 266339.60 | 10% | 266339.60 | 0.00 |
| 28-Feb-15 | Audit protocol | 1% | 24015.00 | 1% | 24015.00 | 0.00 |
| 31-May-15 | Modules 1-6 | 22% | 573352.80 | 22% | 570175.44 | -3177.36 |
| 31-Jul-15 | Modules 7-14 | 32% | 860029.20 | 32% | 863206.56 | 3177.36 |
| 30-Nov-15 | Roll-out | 3% | 89070.00 | 3% | 89070.00 | 0.00 |
| 30-Jun-16 | RE learning matei | 7% | 175425.00 | 7% | 175425.00 | 0.00 |
| 30-May-16 | System audits | 6% | 159787.00 | 6% | 159787.00 | 0.00 |
| 30-Jun-16 | Audit results | 4% | 115867.00 | 0% | 0.00 | -115867.00 |
| 31-Jul-16 | Draft final report | 0% | 0.00 | 0% | 0.00 | 0.00 |
| 31-Aug-16 | Final report | 0% | 0.00 | 0% | 0.00 | 0.00 |
| | | | 2263885.60 | | | -115867.00 |

**Detailed costing**

| **Enabling output** | Milestone Date | Days planned | Planned costs | % progress | Actual costs |
|---|---|---|---|---|---|
| 1 Project initiation | 31-Dec-14 | 6 | 266339 | 100% | 266339 |
| 2.A Learning modules 1-6 for production personnel | 31-May-15 | 67 | 1433382 | 100% | 1433382 |
| 2.B Learning modules 7-14 for prod. pers. | 31-Jul-15 | | | | |
| 3. Production personnel training roll-out | 30-Nov-15 | 10 | 89070 | 100% | 89070 |
| 4. Learning materials for RE personnel | 30-Jun-16 | 16 | 175425 | 100% | 175425 |
| 5. S. system audit protocol | 28-Feb-15 | 3 | 24015 | 100% | 24015 |
| 6. Audits | 31-May-16 | 22 | 159788 | 100% | 159788 |
| 7. Audit results present. | 30-Jun-16 | 15 | 115868 | 100% | 115868 |
| 8. Draft final report | 31-Jul-16 | 26 | 133170 | 100% | 133170 |
| 9. Final report | 31-Aug-16 | 3 | 266339 | 0% | 0 |
| Total | | | 2663396 | | 2397057 |

| **HR costs** | | Total planned | | Actual | | Costs for quarter | | Costs for project | |
|---|---|---|---|---|---|---|---|---|---|
| Name | Charge-out rate | For quarter | For project | For quarter | For project | Planned | Actual | Planned | Actual |
| F Essrich | 9200 | 11.9 | 95 | 11.9 | 83.1 | 109250 | 109250 | 874000 | 764750 |
| J van der Merwe | 1500 | 2.5 | 20 | 2.5 | 17.5 | 3750 | 3750 | 30000 | 26250 |
| total | | 14.375 | 115 | 14.375 | 100.625 | 113000 | 113000 | 904000 | 791000 |

| **Operating costs** | Total planned | | Actual | |
|---|---|---|---|---|
| Expense | For quarter | For project | For quarter | For project |
| Travel | 16673 | 133380 | 16673 | 116707.5 |
| Accommodation | 2700 | 21600 | 2700 | 18900 |
| Venues & catering | 1650 | 13200 | 1650 | 11550 |
| total | 21023 | 168180 | 21023 | 147157.5 |

| **Capital costs** | Total planned | | Actual | |
|---|---|---|---|---|
| Expense | For quarter | For project | For quarter | For project |
| N/A | 0 | 0 | 0 | 0 |
| total | 0 | 0 | 0 | 0 |

| **Subcontractor costs** | Total planned | | Actual | |
|---|---|---|---|---|
| Expense | For quarter | For project | For quarter | For project |
| STS | 0 | 970016 | 0 | 970016 |
| Middindi | 78550 | 543200 | 78550 | 543200 |
| Editing | 18000 | 18000 | 18000 | 18000 |
| total | 78550 | 1513216 | 78550 | 1513216 |

# 15. APPENDIX I Table 14: Project stakeholders

| | Name | Shaft/Mine/Responsibility | Telephone | Cellular Ph | e-mail |
|---|---|---|---|---|---|
| MHSC | Fleckson Magweregwede | SIMRAC | 011 656 1797 | 061 202 8644 | fmagweregwede@mhsc.org.za |
| | Alec Gumbie | SIMRAC | 011 656 1797 | 0794828938 | agumbie@mhsc.org.za |
| Labour | Dr. WK Rymon-Lipinski | NUM | 011 673 0394 | 082 468 5066 | rymon@telkomsa.net |
| DMR Inspectorate | | Chief Inspector of Mines | 012 444 3972 | | Ane.Pieterse@dmr.gov.za |
| **Western Bushveld** | | | | | |
| Impala Platinum | Lesiba Ledwaba | Group Seismologist | 014 569 6635 | 072 804 9831 | Lesiba.Ledwaba@implats.co.za |
| | Thabo Molikeng | RE Training | 014 569 0308 | 082 351 5707 | Thabo.Molikeng@implats.co.za |
| Northam – Zondereinde | Sanjay Singh | Chief RE, Zondereinde | 014 784 3134 | 083 254 2329 | Sanjay.Singh@norplats.co.za |
| | Maryke Willemse | Sen. Seismologist | 014 784 3269 | 084 909 4091 | Maryke.Willemse@norplats.co.za |
| | Abrie van Rhyn | SC Training | 014 784 3072 | | Abrie.vanRhyn@norplats.co.za |
| AngloPlatinum | Riaan Carstens | Manager RE | 011 373 6708 | 073 466 6523 | Riaan.Carstens@angloamerican .com |
| | Ephraim Mkhize | Principal RE | | 083 554 7784 | Ephraim.Mkhize@angloamerican.com |
| | Alan Olivier | RE School of Mines | 014 598 2807 | 073 332 1252 | Alan.Olivier@angloamerican.com |
| | Rudi Rudolph | GM School of Mines | 014 598 2925 | 083 455 1609 | Rudi.Rudolph@angloamerican.com |
| | Willie Snyman | Chief RE, Thembe/Khuseleka | | 082 444 5569 | Willie.Snyman2@angloamerican.com |
| | Christo Haasbroek | Chief RE, Siphumelele | | 083 262 7255 | Christo.Haasbroek@angloamerican.com |
| | Linden Skorpen | Chief RE, Union | | 083 678 8220 | Linden.Skorpen@angloamerican.com |

| | | | | | |
|---|---|---|---|---|---|
| | Wynand Bester | Chief RE, Tumela | 014 784 1008 | 083 253 8165 | Wynand.Bester@angloamerican.com |
| | Sampie van Buuren | Chief RE, Dishaba | 014 784 1191 | 083 272 7927 | JSvBuuren@angloplat.com |
| Bafokeng Rasimone PM | Theresa van Aardt | RE, North # | 014 573 2263 | 072 900 2555 | tvaard@bafokengplatinum.co.za |
| Lonmin | Michael du Plessis | Group RE | 014 571 4990 | 083 661 1736 | Michael.duPlessis@lonmin.com |
| | Otto van der Merwe | REM Karee Section | 014 571 2542 | 083 377 9874 | Otto.vanderMerwe@lonmin.com |
| | Willie Liebenberg | REM Training | 014 571 3360 | 071 882 4825 | willie.liebenberg@lonmin.com |
| Aquarius | Hein van Rooyen | REM (Nostrada) | 011 465 6127 | 072 234 8194 | info@nostrada.co.za |
| Glencore (Chrome) | | Kroondal | | | |
| Wesizwe | 500-600m, sinking | | | | |
| Pandora | AP-LnMin JV | | | | |
| | | | | | |
| **Eastern Bushveld** | | | | | |
| Northam - Booysendal | Paul Couto | Chief RME, Booysendal | 013 235 6730 | 060 795 1295 | Paul.Couto@norplats.co.za |
| AmPlats Twickenham | Lebogang Baloyi | Jun. RE | | 073 3051 964 | Lebogang.Baloyi@angloamerican.com |
| Atlatsa Bokoni PM | Bertus van der Kevie | Chief RE, Bokoni & Lebowa PM | 015 620 0063 | 084 589 4848 | bertusv@atlatsa.com |
| Impala Plat. Marula (JV) | Louis Bronkhorst | REM, | 013 214 6296 | 083 520 1448 | Louis.bronkhorst@implats.co.za |
| ARM & Implats: Two Rivers Plat. | Petrie Wessels | RE (OHMS) | 013 230 2674 | 082 339 0918 | Petrie.Wessels@trp.co.za |
| AmPlats Modikwa (JV) | Godwin Hungwe | Chief RE | | 083 606 2094 | Godwin.Hungwe@angloamerican.com |

| | | | | | |
|---|---|---|---|---|---|
| Samancor (Chromitite) | Jimmy Kidd | REM (soon to retire), Easavani Pillay | | | Jimmy.Kidd@SamancorCr.com |
| IvanPlats | Adam Cooper | Sen. Geotechn. Eng. | | 082 664 2763 | adamco@ivanplats.com |
| Everest and Mandagshoek | ⇨ closed operations | | | | |
| Potgietersrus Platinum Ltd. | Open cast | | | | |
| | | | | | |
| **Orgs & Agents** | | | | | |
| CGS | Artur Cichowicz | CGS /Senior Specialist Scientist | 012 841 1457 | 073 165 6400 | artur@geoscience.org.za |
| IMS | Olaf Goldbach | Consultant | 021 809 2075 | 084 236 0341 | olaf.goldbach@imseismology.org |
| Open House | Gerrit Kotze | Geotechnical Modelling Consultant | 018 293 1944 | 082 903 7944 | gerrit.kotze@ohms.co.za |
| SRK | William Joughin | Consultant | 011 441 1214 | 083 601 9527 | wjoughin@srk.co.za |
| Wits | Ray Durrheim | Professor | 011 358 0082 | 083 677 8778 | Raymond.durrheim@wits.ac.za |

25/2/2015

# 16. APPENDIX II

**SIM100301 OP6 - Part IV. *Improved seismic monitoring practice and rockburst risk quantification***

The following originate from the review of currently implemented monitoring practice. The full range of issues to achieve optimum seismic monitoring practice is detailed in Enabling Output 3. Those with high priority and high potential impact should be addressed first:

a. Plan network sensitivity and location accuracy according to monitoring objectives;

b. At least 80% of all seismic stations to be operational at any given time, equipped with healthy sensors;

c. Periodic reporting on sensor health to network owners;

d. Identify ‘principal sites’ required for basic coverage;

e. Capacity created for prompt sensor installation, delays reduced to three months maximum;

f. 3D velocity model preferred over homogenic half space;

g. Locations of seismic events in 3D determined from at least three triggers, better four;

h. Additional shallow and deep sensor sites to reduce location error in depth;

i. Filter settings and sampling rate to be aligned with event magnitude range of interest;

j. All valid events used for data analysis provided they meet the minimum quality standards (excluding blasts);

k. Quantification of source parameters from at least four P- and four S-picks using tri-axial sensor sets;

l. Standardisation of reported magnitude and other basic source parameters across the region and in line with CGS standard;

m. Mix of mine network coverage and SANSN operated sensors;

n. Release of SANSN data into public domain;

o. Synchronisation of system clocks (regional events).

The following refer to the capacity to analyse and interpret relevant information:

p. Reliable seismic database back-up procedures including data migration across software versions;
q. Mine seismology expertise to be created in-house (where appropriate);
r. Regular practice reviews and quality management procedures implemented;
s. Rockburst risk ratings based on factors contributing to potentially damaging seismicity and to rock conditions that increase damage probability;
t. Rockburst analysis to specify source, failure and damage mechanisms, location and the mining and rock conditions under which failure occurred;
u. Rockburst data bases to be consistent, complete and accurate for a given reporting period and in a format that allows statistical analysis, e.g. spreadsheets or relational data base;
v. Periodic analysis of rockburst data bases to extract guidelines for improved mining methodology.

In combination, these measures will result in seismic data which are more likely to be complete, accurate and relevant and which contribute more meaningfully to the management of seismic hazard and rockburst risk.

# 17. APPENDIX III Audit protocol aligned with project SIM100301 outputs.

1. Score card

This score card is subdivided into three main themes each of which is subdivided into a number of aspects:

- Seismic network planning and operation
- Seismic source quantification
- Rockburst analysis and reporting.

The purpose of each aspect within each theme is explained and annotated in such a way as to assist the auditor in arriving at a fair evaluation score (see criteria). The total score achieved by a mine operating a seismic system is then determined from the performance within each aspect.

The maximum score is 100%, but few mines are expected to achieve the maximum as planning related issues and financial and operational constraints may interfere with optimal system operation.

2. Evaluation

The score is determined from facts established during interviews with mine personnel responsible for seismic system operation and management. Possible sources of input include documents relating to the issues raised in the score card such as CoPs to manage rock related hazards, Technical Support Documents, strategic documents such as practice reviews, budget proposals and motivations submitted by seismic system manufacturers and service providers.

The established facts are summarised in a draft fact file and finalised once the mine was provided with an opportunity to review and comment on the fact file. After finalisation of the fact file, members of the project team evaluate the established and agreed facts and determine the final score.

Abbreviations:
CGS=Council for Geosciences; CoP=Code of Practice to combat rockfall and rockburst accidents; En=seismic energy; f/wall=footwall; Fres=resonance frequency; GPS=global positioning system; IMS=Institute of Mine Seismology; lvl=level; mbs=metres below surface; M=magnitude; Mmin=minimum magnitude (sensitivity); Mmax=maximum expected magnitude; Mo=seismic moment; MonObs=monitoring objectives; MoU=memorandum of understanding; NoT=number of triggers; poly=event selection polygon; SANSN=SA National Seismic Network; sgram=seismogram; u/g=underground; TSD=Technical Support Document; UPS=uninterrupted power supply.

**Table 15: Compliance with individual assessment criteria** (Mines A to E requested confidentiality, N/A: too few incidents, red if below 60%)

| Mine | A | B | C | D | E | Imp 10# | Imp 11# | Imp 14# | Union | Assessment criterion | Compl |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.1** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | MonObs defined during planning | 100% |
| **2** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Station configuration accord. to MonObs | 100% |
| **3** | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | Shallow & deep sites | 89% |
| **4** | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | Principal sites declared | 67% |
| **5** | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | Speedy replacement of sensors | 33% |
| **6** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Filters and sampling rate set | 100% |
| **7** | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | Min. 80% of stations operational | 89% |
| **8** | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | Sensor health >= 80% | 89% |
| **9** | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | Orientation and polarity checked | 56% |
| **10** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Clocks synchronised | 100% |
| **2.1** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Minimum quality standards | 100% |
| **2** | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | Min 4P plus 4S for s. parameters | 67% |
| **3** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Min NoT=3 for location | 100% |
| **4** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Periodic back-up of data base | 100% |
| **5** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Mag standard | 100% |
| **6** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | Access to SANSN data | 44% |
| **3.1** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Data analysis by seismologist | 100% |
| **2** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | N/A | Seismic hazard and risk quantification | 89% |
| **3** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | Periodic reporting | 100% |
| **4** | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | RB data gathering | 89% |
| **5** | N/A | 1 | 1 | 1 | N/A | 1 | 1 | 1 | N/A | RB data base complete & accurate | 67% |
| **6** | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | Practice reviews | 56% |
| Bonus | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | Calibration of source parameters | 44% |
| Total | **71** | **90** | **95** | **83** | **60** | **100** | **100** | **100** | **91** | | |

## Result summary

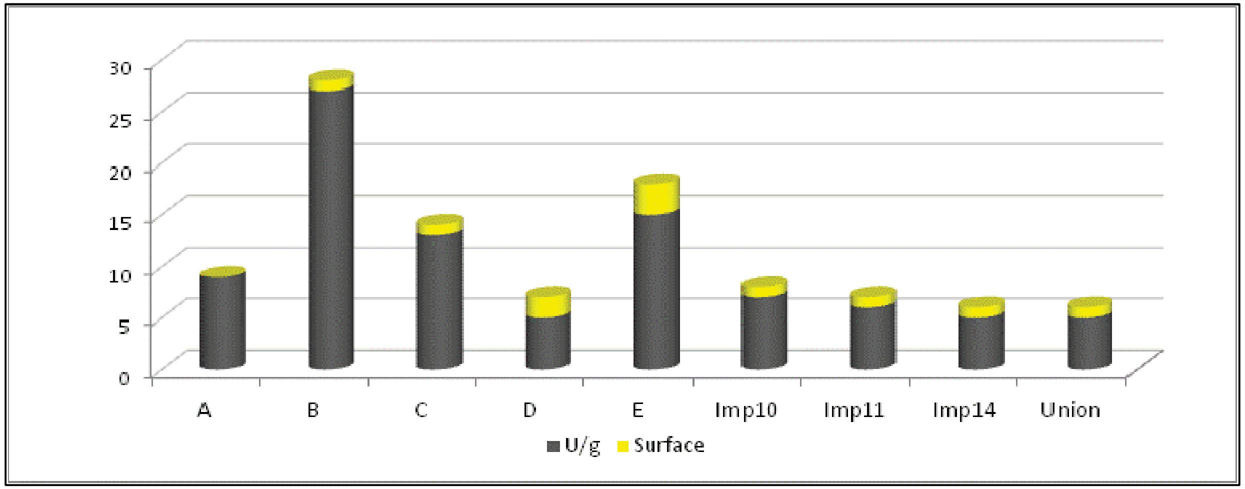



**Figure 13: Number of underground and surface stations per mine**

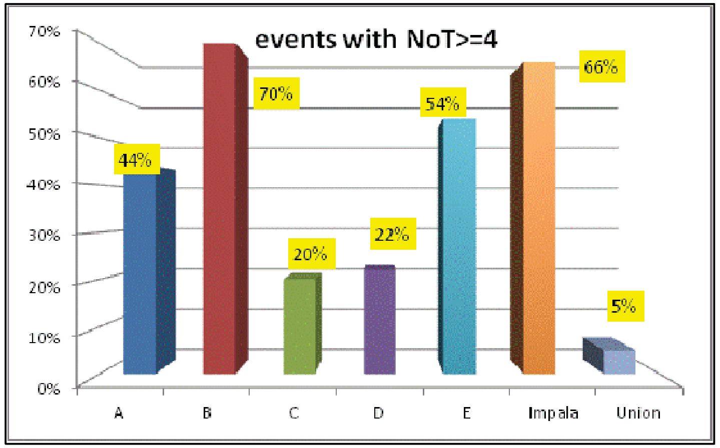



**Figure 14: Percentage of events with at least four triggers.**

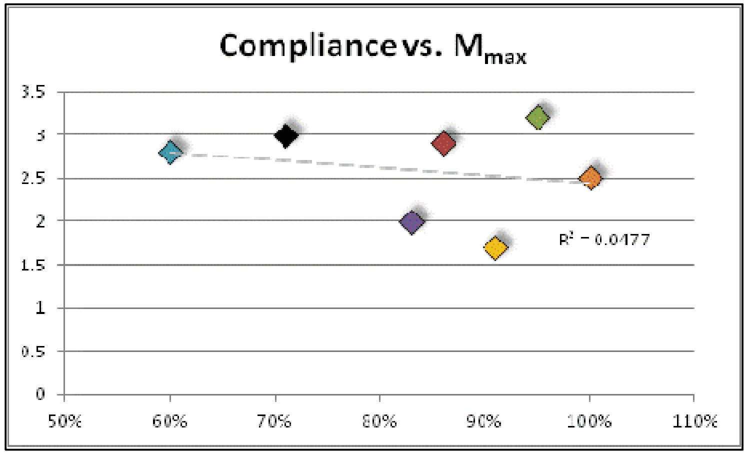



**Figure 15: Correlation compliance level / Mmax**

# 18. APPENDIX IV Table 16: Seismic system score card Mine A

**Assessed by WB and FE, 15/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 7/10*40% = 28% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | According to TSD, 5 standard MonObs declared (Jager & Ryder, 1999). Some cannot be met due to low seismic activity levels (<3 events p.day). | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Originally installed for MER mining. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | 1 shallow site; data show high z-error (see below). | ✓ |
| | 4. Principal[2] sites defined to ensure minimum coverage at all times. | No. | × |
| | 5. Capacity for speedy sensor installation (<3 months). | Average 2-4 years; low priority due to low risk level. | × |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Yes (1.65 to 3.3kHz) | ✓ |
| | 7. At least 80% of stations operational at all times. | 80-90%, but slowly decreasing (see below); major faults with short repair times. | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Checked and reported: usually above 80% (see below). | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Not done for shaft A and C. | × |

[2] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | 10. Synchronisation of system clocks for regional events. | GPS time base; suitable for exchange with neighbouring networks. | ✓ |
| | | | 4/6*30% = 20% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | In accordance with IMS quality assurance procedures; good En-Mo correlation (see below). | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Min NoT=3, i.e. 3P + 3S (see below). | × |
| | 3. Hypo-centre location from at least 3 sensors. | Yes, sufficiently accurate in plan. | ✓ |
| | 4. Back-up procedures for seismic event data base. | 3 months of sgrams plus all historic events with IMS. | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Anglo standard (Stankiewicz Mag). | ✓ |
| | 6. Access to SANSN data for larger events. | No access to SANSN, no exchange with neighbours. | × |
| | | | ¾*30% = 23% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes (IMS service). | ✓ |
| | 2. Seismic hazard and risk quantification. | Too few events for assessments, attempt medium & long-term hazard estimate. | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily and quarterly reports by IMS, incl. NS report; monthly activity report to GM; occasional back analysis of larger events. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | Procedures are described in TSD, but very few incidents (e.g. M>1 in 2012). | N/A |
| | 5. Rockburst data base complete, accurate and consistent. | N/A (too few incidents). | N/A |
| | 6. Regular practice review and quality management procedures for data collection. | None. | × |
| **Total** | | | **71%** |

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? __No__

**Notes:**

- MER mining on-going at low extraction due to large potholes;
- new shallow UG2 mining 45m below mined out MER;
- deepest MER mining on 19lvl (1 200 m.b.s);
- 8 u/g sites plus 1 shallow, none on surface.
- Geophones are tri-axial sets of $F_{res}$=4.5Hz.
- Confidentiality: refer to as Mine A.

**Additional data, information and documents made available by the mine:**

Sample day shift report (IMS: aaa-REP-DS-20160315-IMSv0.pdf)

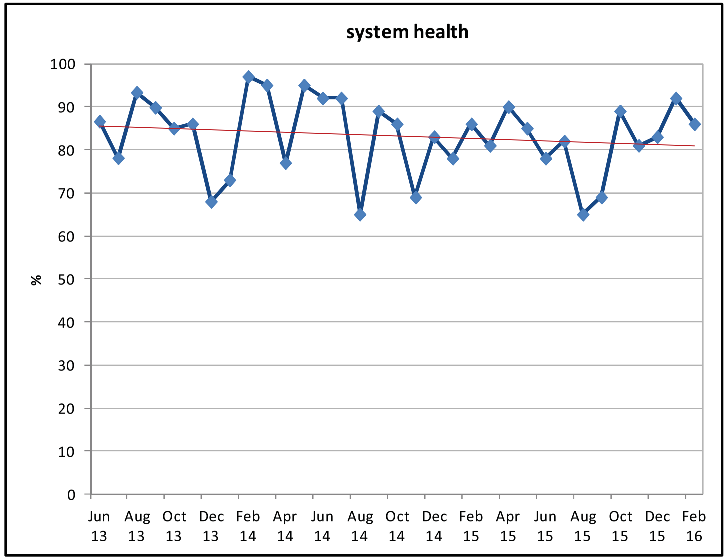
Sample night shift report (IMS: aaa-REP-ns-20160315-IMSv0.pdf)

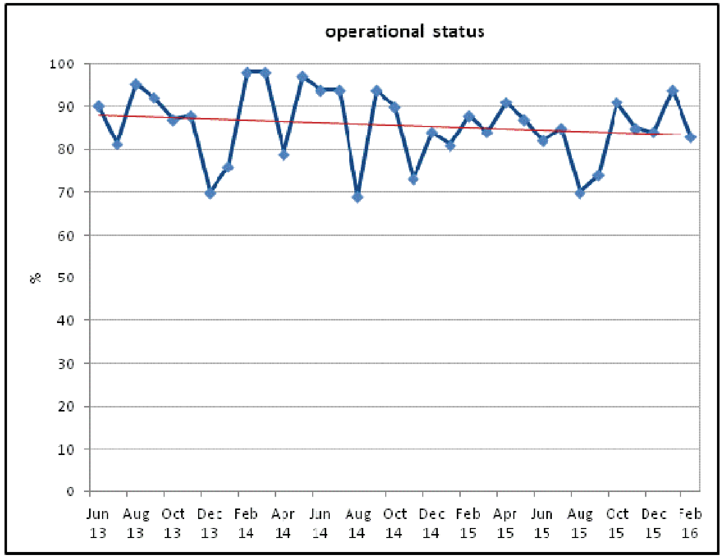
Sample monthly report (IMS: aaa-REP-MNTH-201601-IMSv0.pdf)

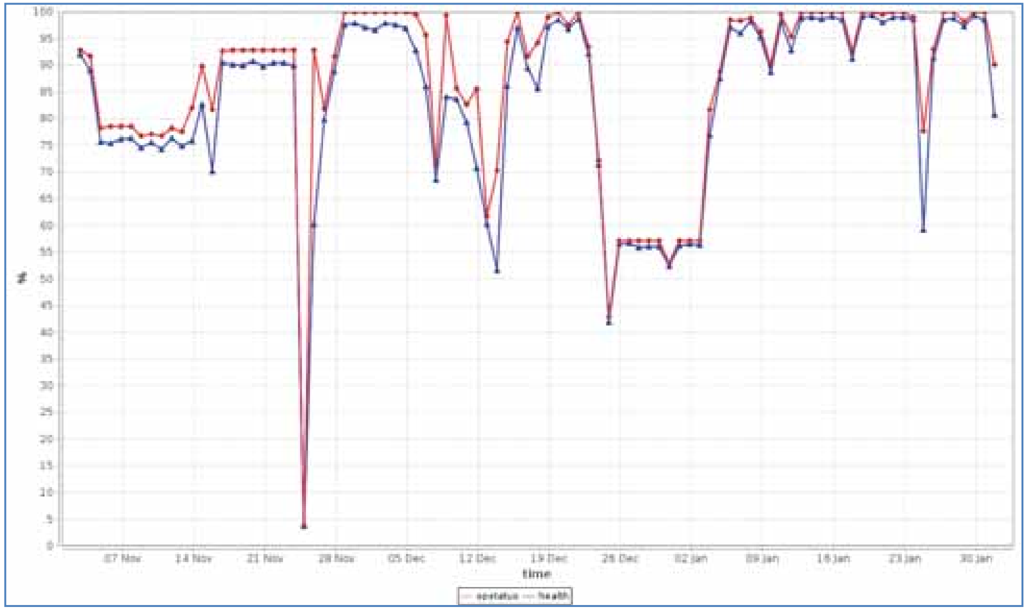
3-months system health and status report

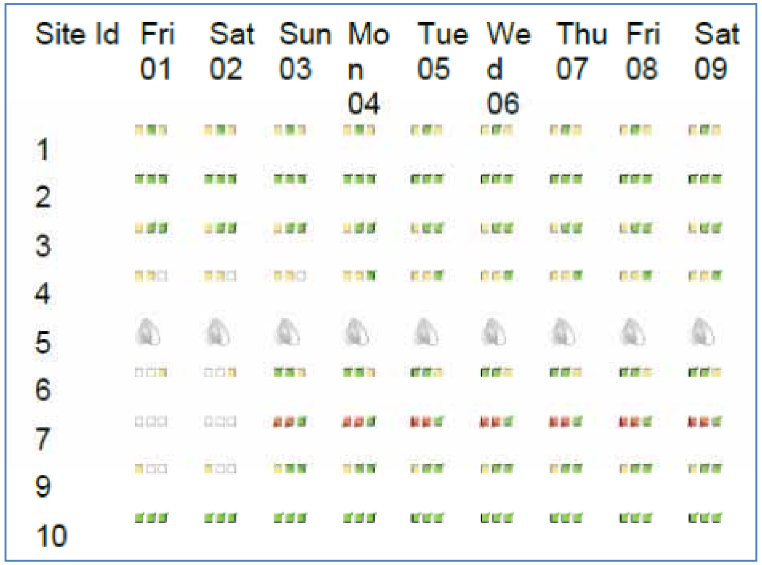
3 months of seismic data (accepted events).

System status and station health (monthly average):

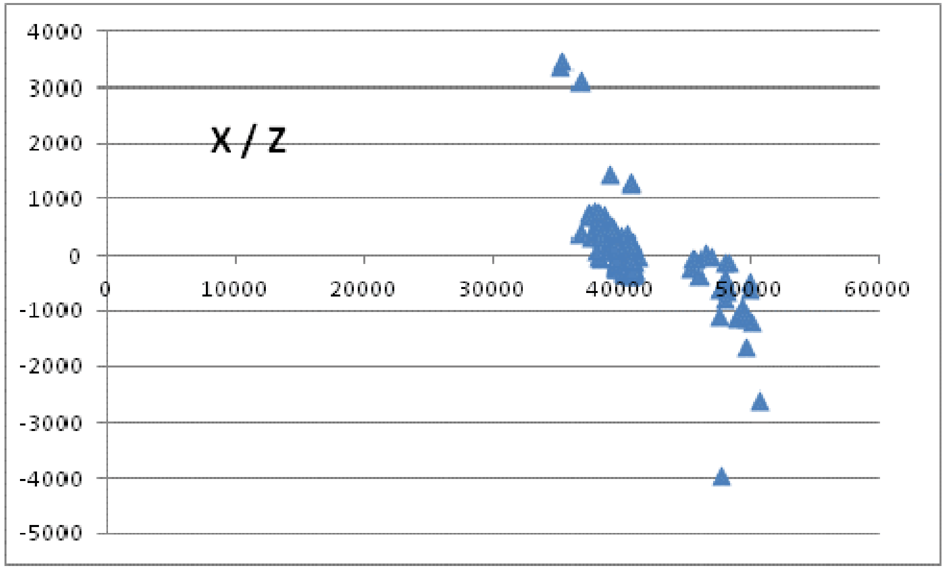


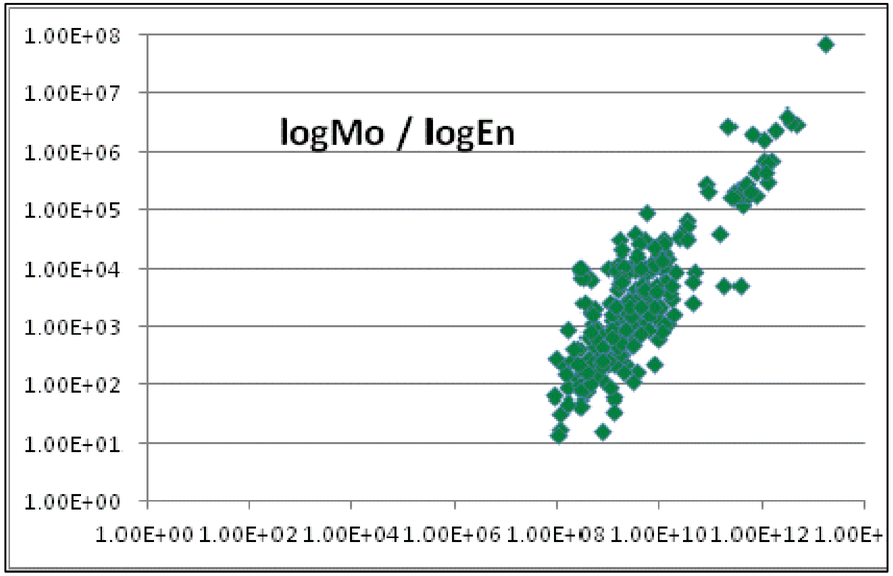



Location accuracy (vertical section):




EnMo correlation:




Number of triggers associated:

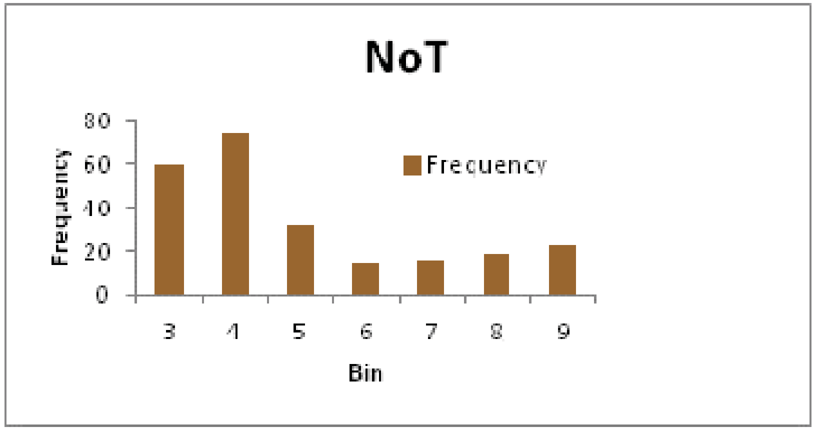


**Table 17**: **Mine/shaft:** Mine B **Assessed by: MW and FE** **Date: 26/4/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 10/10*40%=40% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Division into Class I (deep MER) and Class II (back area, some UG2); based on recommendation after external audit in 2007. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Yes, incl. sites ahead of mining (see MonObs and zoning in CoP). | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | One surface site, shallow sites, and deep site on 42lvl (shaft bottom). | ✓ |
| | 4. Principal[3] sites defined to ensure minimum coverage at all times. | All stations equipped with UPS. | ✓ |
| | 5. Capacity for speedy sensor installation (<3 months). | Can be done in 3 months when required. | ✓ |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Sampled at 3.3kHz at sensor. | ✓ |
| | 7. At least 80% of stations operational at all times. | 90% and above over past 6 months (see below); occasional faults are quickly repaired. | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Above 90%, few tri-axial sets with faulty components. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Tested and corrected for where applicable (by IMS) | ✓ |
| | 10. Synchronisation of system clocks for regional events. | All on satellite time (GPS). | ✓ |

[3] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | | | 5/6*30%=25% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | According to IMS processing procedures and quality control systems. | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Yes (min NoT=4); note poor correlation between Energy and Moment and corner frequency and Moment (see below); 10% of events have NoT=3 (see below). | ✓ |
| | 3. Hypo-centre location from at least 3 sensors. | Yes (min NoT=4); locations are not closely clustered around reef horizons (below). | ✓ |
| | 4. Back-up procedures for seismic event data base. | RTS located at mine's IT department, back-up to IT server (events and sgrams). | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Stankiewicz relation, as neighbouring mines. | ✓ |
| | 6. Access to SANSN data for larger events. | No access, no exchange. | × |
| | | | 5/6*30%=25% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Periodic day and night shift reports (IMS), monthly report intermittent. | ✓ |
| | 2. Seismic hazard and risk quantification. | Daily and when required (by seismologist); UG2 and MER event polys for analysis. | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily (when required) and monthly RE report with seismic content. Special reports on large event or rockburst when required. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | RB investigation where site is accessible, reporting and report roster. Previous rockburst analysis by SiM. | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | No specific RB data base, but FOG incident records. | ✓ |
| | 6. Regular practice review and quality management procedures for data collection. | Last in 2006, need to review again. | × |
| **Total** | | | **91%** |

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? _No_

**Notes:**

- Equipped with 28 stations (27 u/g incl shaft bottom, 1s ), commissioned in 2001, audited in 2006 by SiM;
- MER mining at deeper levels (down to 15), UG2 at shallower levels (9-12);
- Occasional RBs on remnants, rare face ejection on UG2, $M_{max}$=2.9;
- UPSs on all sites, all routine services outsourced to IMS, but also in-house technicians;
- Confidentiality requested: Refer to as Mine B.

**Additional data, information and documents made available by the mine:**

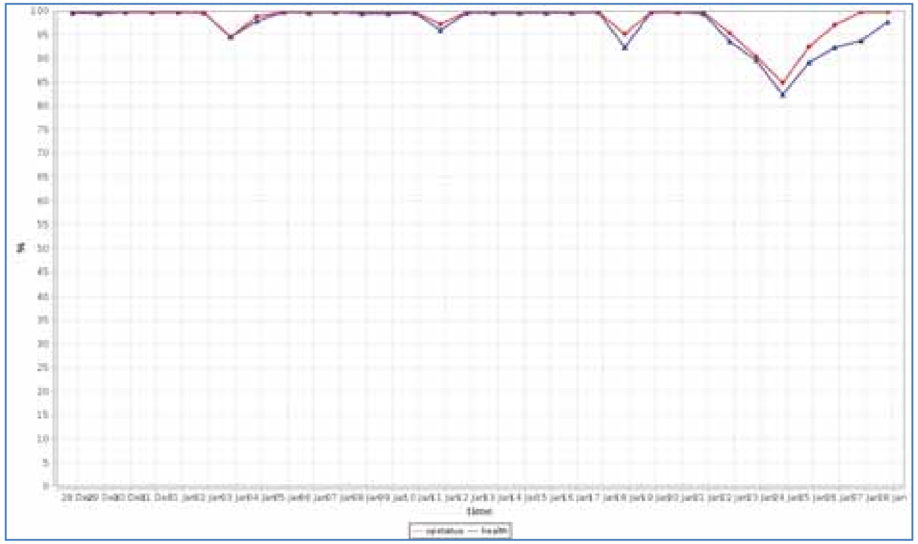
Seismic section of CoP (bbb-TS-MRD-COP-CH8.pdf, bbb-TS-MRD-COP-CH18.pdf)

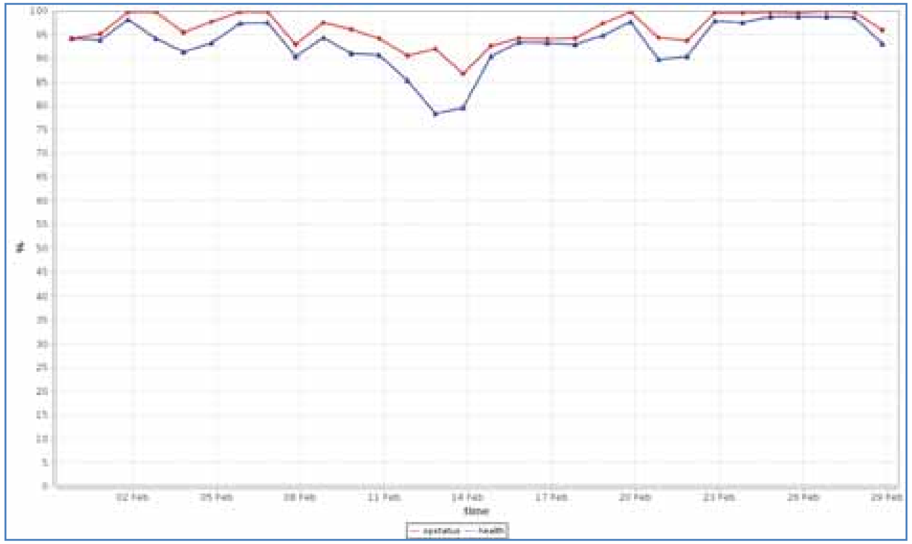
Daily reports from IMS (bbb-REP-DS-20160229-IMSv0.pdf, bbb-REP-DS-20160324-IMSv0.pdf, bbb-REP-DS-20160426-IMSv0.pdf)

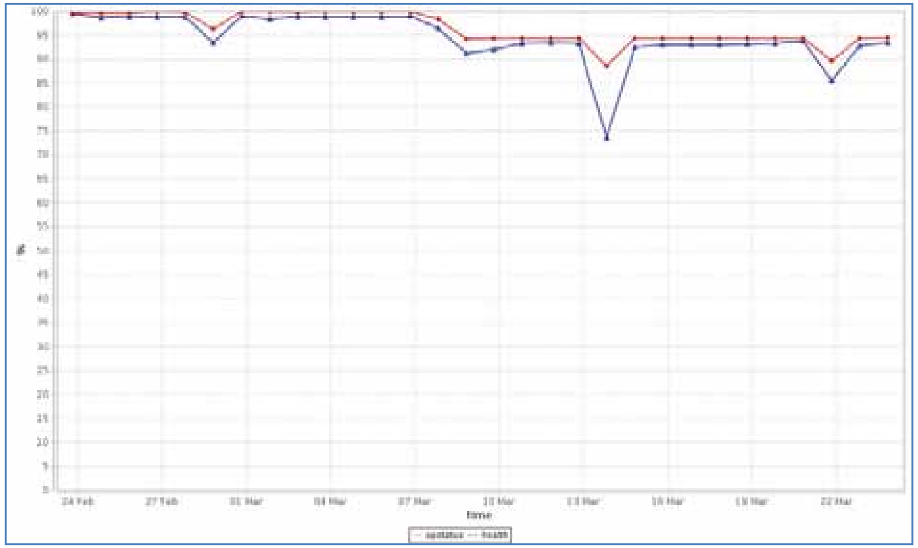
Monthly reports (IMS, bbb-REP-MNTH-20151128-RCv0.pdf, bbb-REP-MNTH-20160128-RCv0.pdf, bbb-REP-MNTH-20160328-RCv0.pdf)

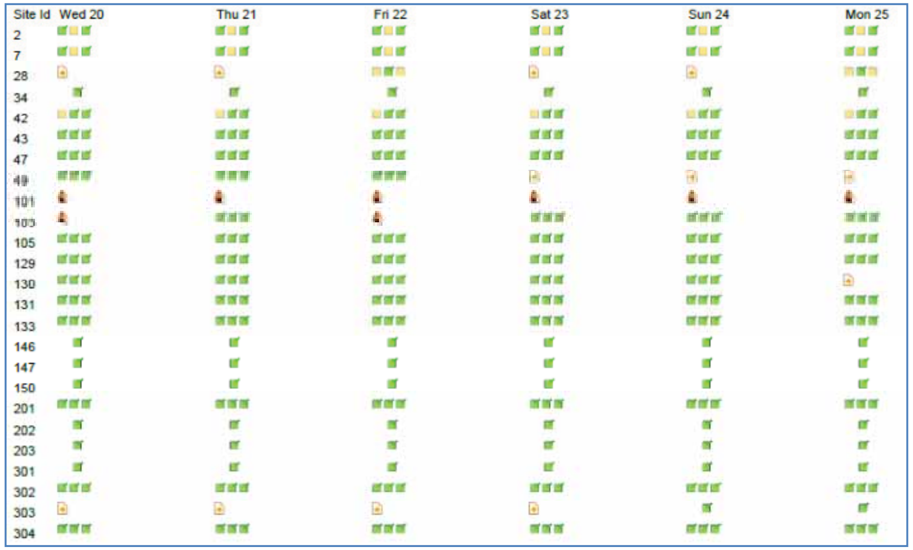
3 months of seismic data (Feb-Apr-2016, accepted events).

System status and station health (Dec-2015 to Apr-2016):

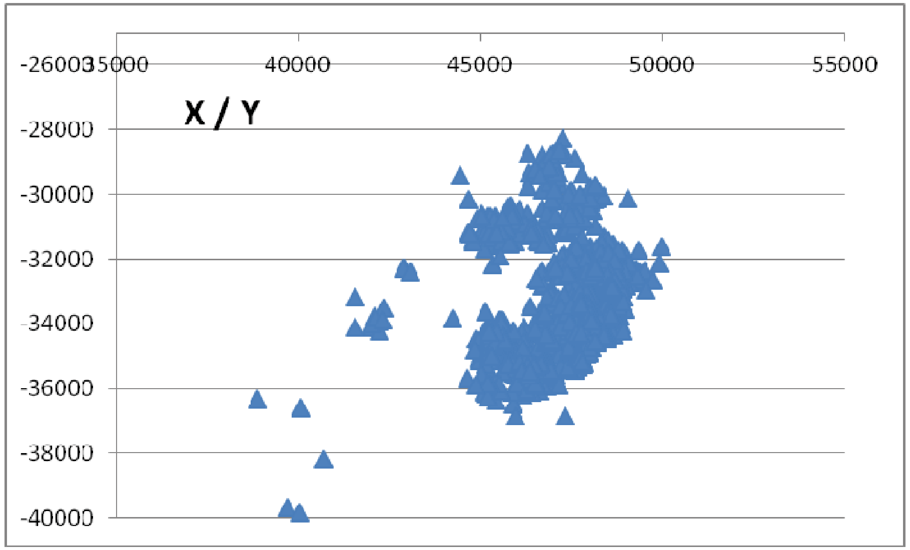


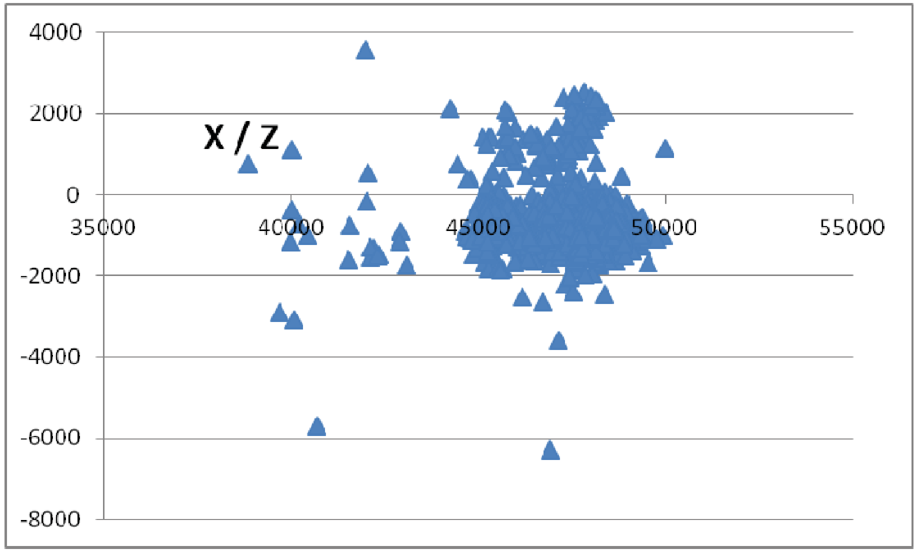



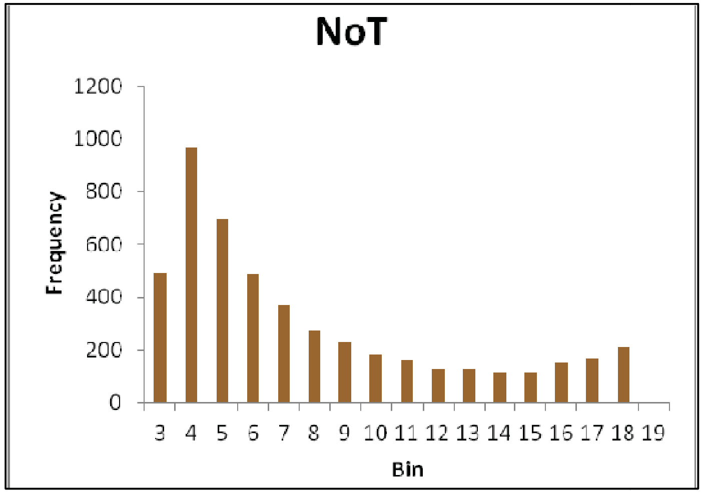
Location accuracy in plan:



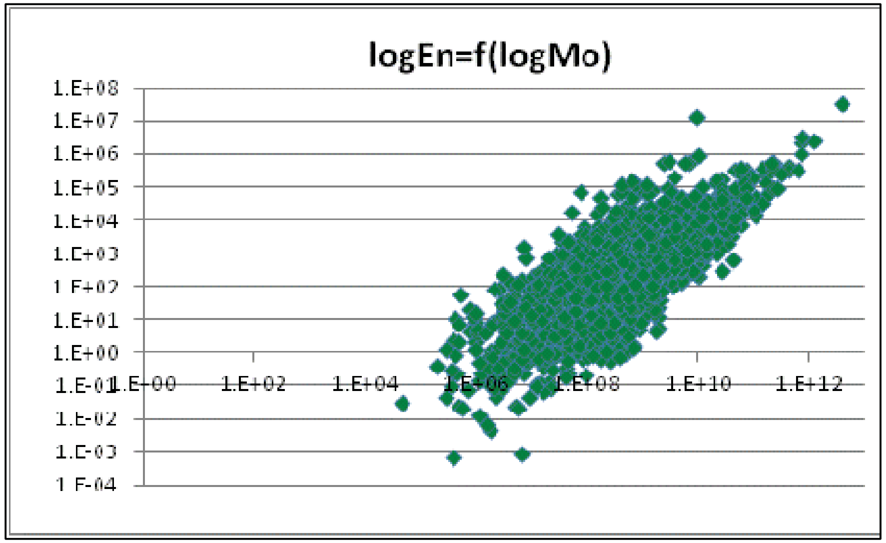

Location accuracy in section:




Number of triggers associated:



Energy-Moment correlation:




Corner frequency – Moment correlation:

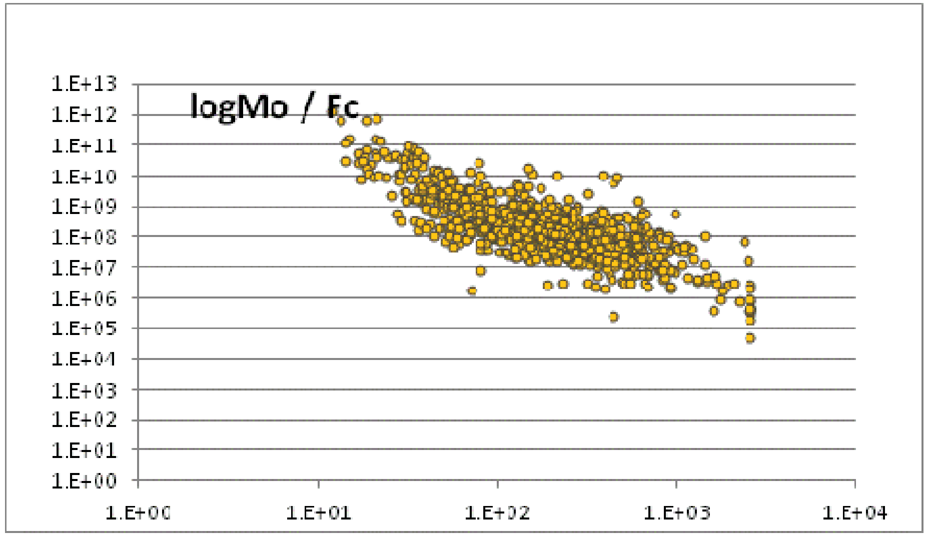


**Table 18**: **Mine/shaft:** Mine C **Assessed by: EM, RC and FE** **Date: 14/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 10/10=40% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | No formal delineation, but 5 standard MonObs for production areas; $M_{min}$=-0.5 in active areas, 0.0 for central shaft area with a min NoT=5. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Yes, modelled to provide for above; including coverage of deep L-shaft section, to be accessed and mined in future; strategy detailed in CoP. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | 13 u/g plus 1 surface site; reasonably dense clustering along reef, few outliers (see below). | ✓ |
| | 4. Principal[4] sites defined to ensure minimum coverage at all times. | No principal sites, but all with UPS, set up in steel containers; surge protection installed on surface site; quick response to faults (see daily status report). | ✓ |
| | 5. Capacity for speedy sensor installation (<3 months). | 6 months to install 3 sensors; but not without challenges. | ✓ |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Sampled at 3.3kHz per channel; most sensors are 4.5Hz tri-axial geophone sets. | ✓ |
| | 7. At least 80% of stations operational at all times. | Above 90% and improving (see below); occasional dip, but quick repair due to dedicated rock eng. staff (see below). | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Reported daily and monthly; quick response by technical team. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Deviations determined by RB incidents with known location; system settings allow correction for non-alignment. | ✓ |
| | 10. Synchronisation of system clocks for regional events. | All on GPS with internal delays below 1 μ-sec; below 100ms when on internal battery. | ✓ |

[4] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | | | 5/6*30%=25% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | Yes, processing benchmarks defined (refer to IMS' Quality Control document); approx. 9 events NoT>3 per day. | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | 3 station events recorded but not used for trend analysis; NoT>3 data show reasonably close En/Mo correlation; 2 500Hz upper cut-off in Fc / Mo distribution and should be investigated (see below). | ✓ |
| | 3. Hypo-centre location from at least 3 sensors. | Min NoT=3; locations in XY and XZ seem accurate (see below). | ✓ |
| | 4. Back-up procedures for seismic event data base. | Sgrams up to 3 months, events since 2001 in various copies. | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Anglo standard (Stankiewicz Mag). | ✓ |
| | 6. Access to SANSN data for larger events. | No MoU, no exchange. | × |
| | | | 5/6*30%=25% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes (IMS); all unusual auto-ratings checked, all events M>=1.5 analysed in detail. | ✓ |
| | 2. Seismic hazard and risk quantification. | DS report checked by seismologist prior to release, monthly report by seismologist; CoP specifies hazard quantification procedures. | ✓ |
| | 3. Periodic reporting to management and production sections. | DS and monthly report; NS report on request; sufficient data for analysis: avg. 86 events per day. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | RE team visits damage sites and creates report; IMS contributes source analysis. | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | Yes (EXCEL). | ✓ |
| | 6. Regular practice review and quality management procedures for data collection. | None yet. | × |
| **Total** | **plus bonus for calibration using rockburst sites ➔final score:** | | **95%** |

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? __Investigated & confirmed RB sites were used_

**Notes:**

- $M_{max}$≈3, severe rockbursting experienced on oversized, odd-shaped pillars.
- Currently 13u/g + 1 surface site; planned: 8u + 1s, incl. two on UG2.
- Homogenous velocity model, but with individual velocity settings per site; stratified velocity model does not seem to work.
- System upgraded to SYNAPSE, most of the others in the region still on RTS.
- Confidentiality: Refer to mine as Mine C.

**Additional data, information and documents made available by the mine:**

Mine’s CoP to combat rock fall and rockburst accidents (2015, cc-MRM-REN-MCOP-0018 SEISMIC MON & ANALYS.pdf)

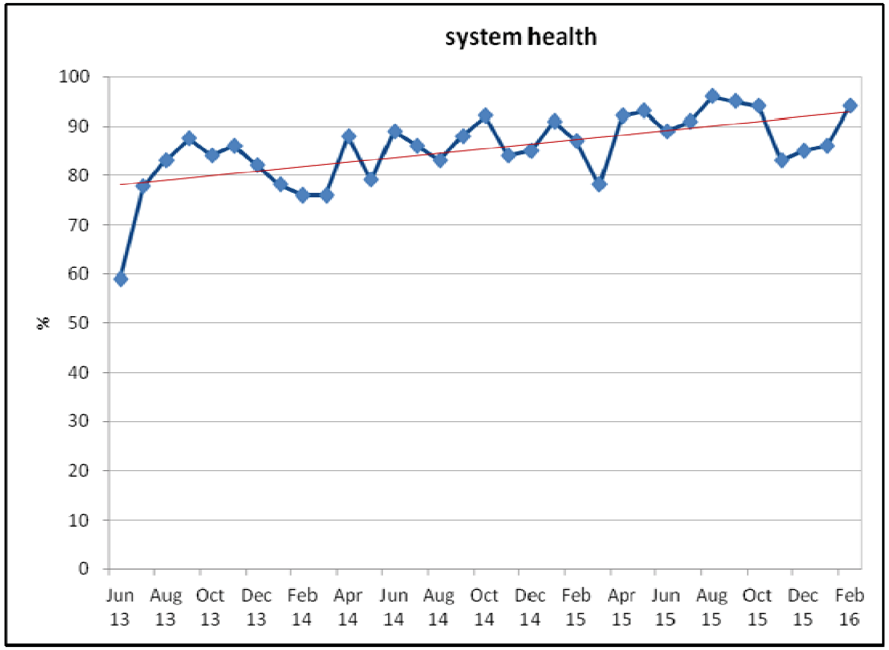
Sample day shift report (IMS, cc-REP-DS-20160314-IMSv0.pdf)

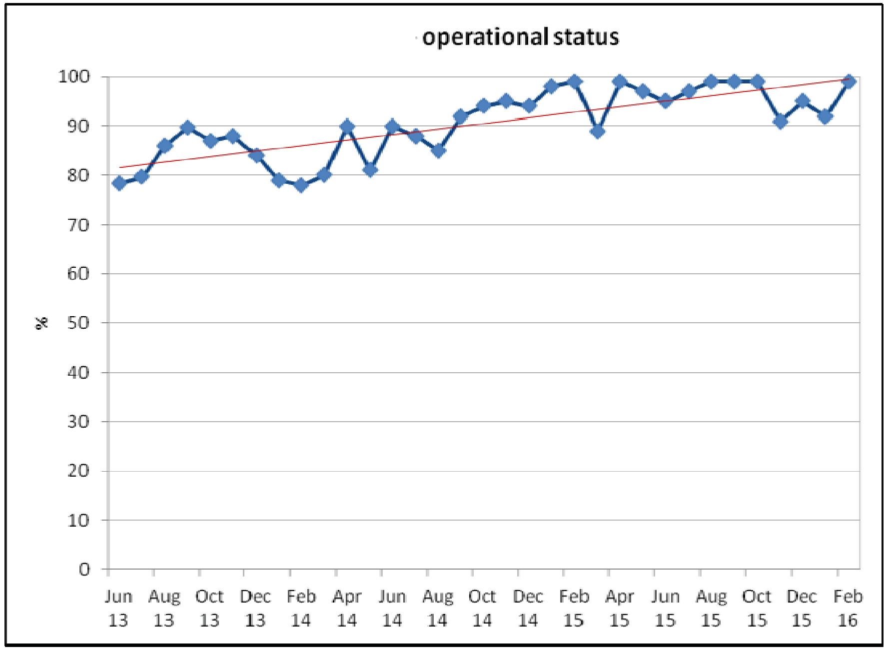
Sample monthly report (IMS, cc-REP-MNTH-20160228-RCv0.pdf)

Sample large event back analysis report (cc-REP-LRG-20150914-RCv0.pdf)

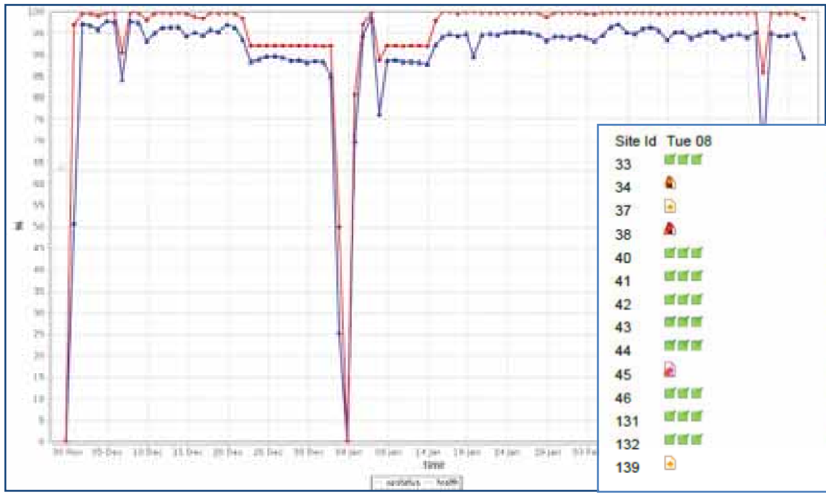
March 2016 accepted events.

Seismic system status and station health (monthly average):

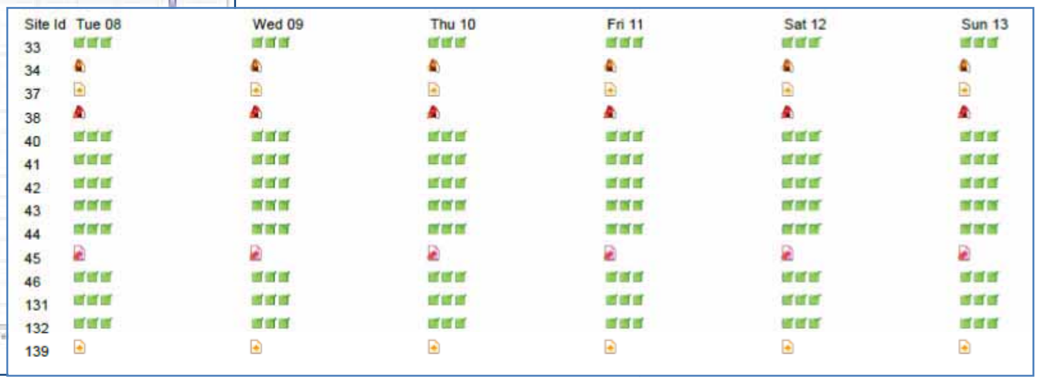


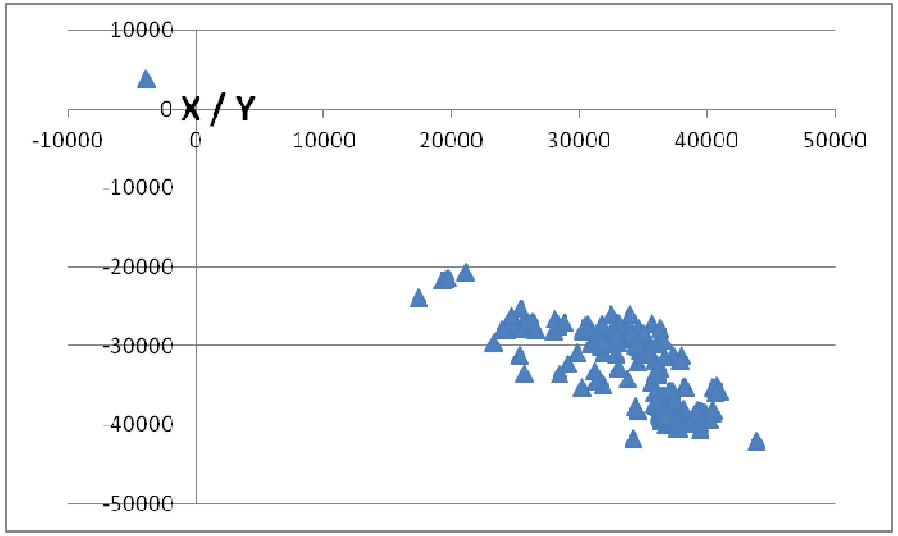

Daily system 2016): health and station status Dec-2015 to Feb-2016



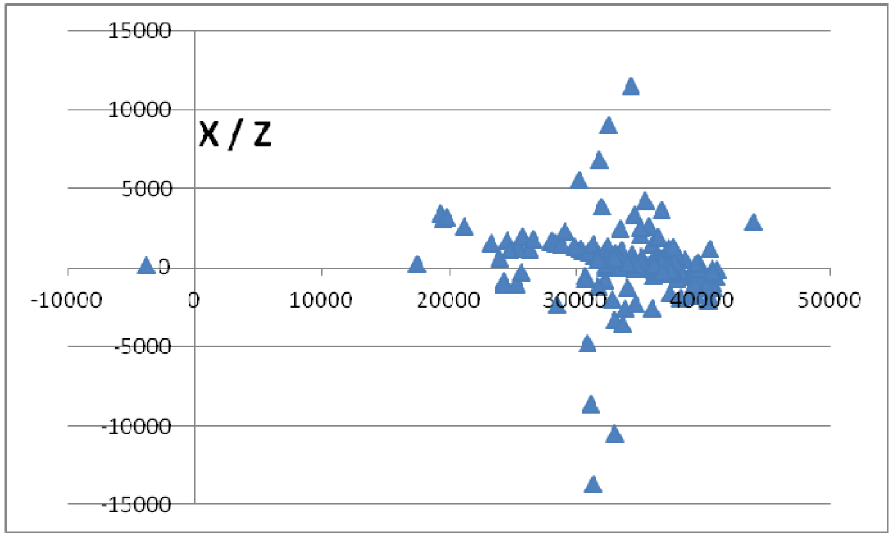
System health and station status (8-13 March



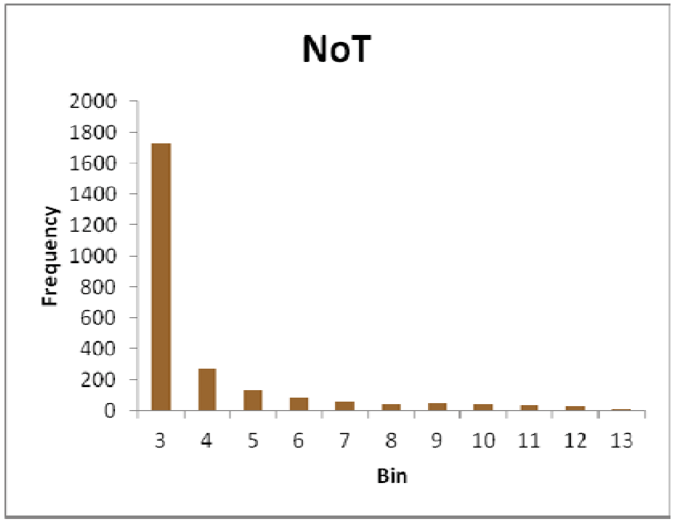
Location accuracy in plan:

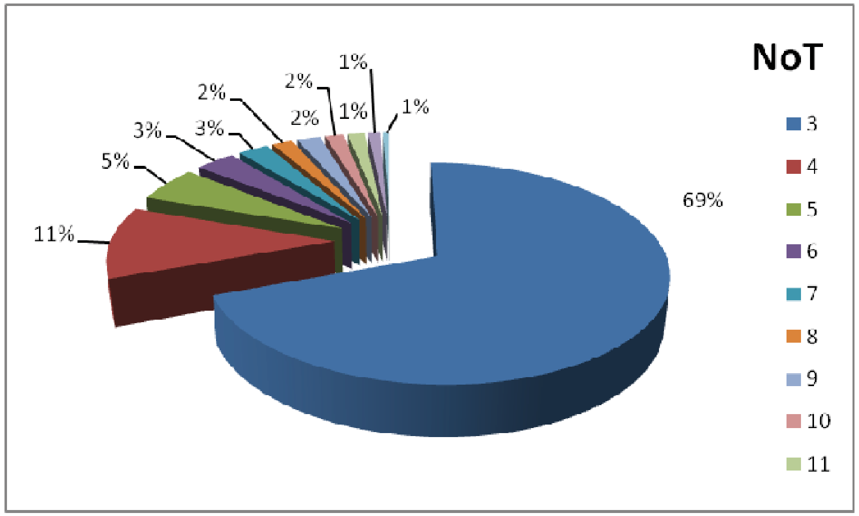



Location accuracy in section:

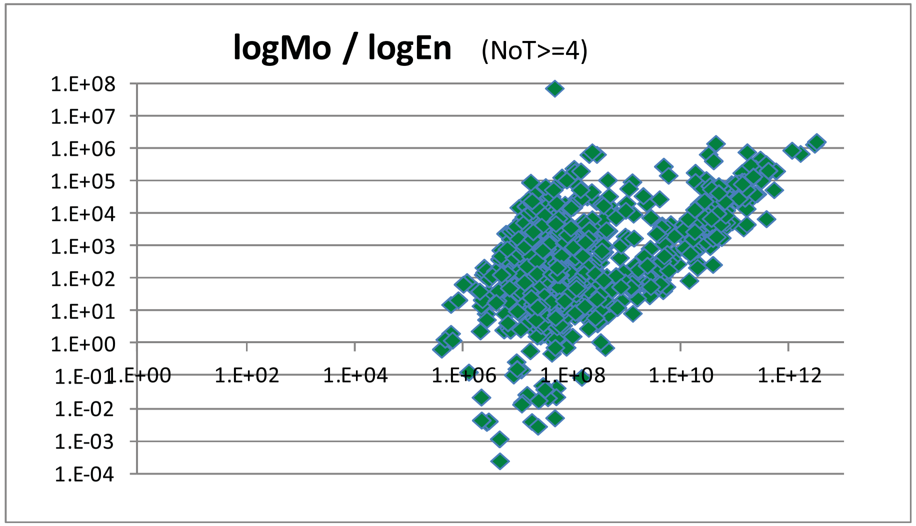



Number of triggers associated:



Energy-Moment correlation (4 triggers and more):




Moment- corner frequency correlation (4 triggers and more):

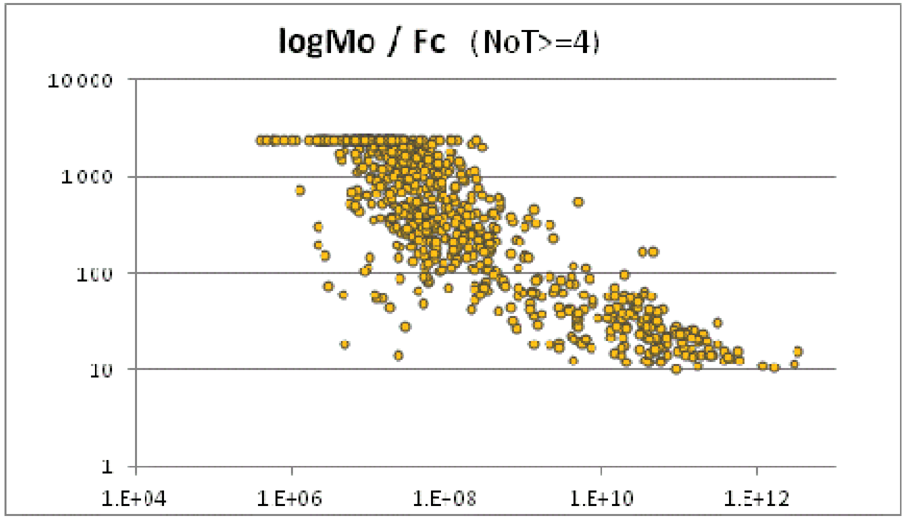


**Table 19**: **Mine/shaft:** Mine D **Assessed by: WS and FE** **Date: 16/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 7/10*40%=28% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Main n/work of 4 sites at D1-shaft plus 1 surface site at D2- shaft; aimed at $M_{min}$=0.5 across deep MER and shallow UG2; no delineation. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Plans to add sites, but not yet in operation. No differentiation w.r.t. areas. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | Yes: Surface, shallow and deep sites (25lvl). | ✓ |
| | 4. Principal[5] sites defined to ensure minimum coverage at all times. | No principal sites; UPSs on GS equipped sites only (GS sites not operational). | × |
| | 5. Capacity for speedy sensor installation (<3 months). | No; equipment purchased in 2012; sensors installed but not connected. | × |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Yes: 6kHz per channel. | ✓ |
| | 7. At least 80% of stations operational at all times. | Long-term trend downward (40-60%, see below), recently improved to 80%. | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Seems not effective: usually around 30-50% (see below); recently improved. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Not checked or corrected. | × |
| | 10. Synchronisation of system clocks for regional events. | GPS time base; suitable for exchange with neighbouring networks. | ✓ |

[5] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | | | 5/6*30%=25% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | 4P and 4S, detailed Quality Control protocols applied by IMS. | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | 3P and 3S, but 80% of events have NoT>=4; close En-Mo correlation (see below). | ✓ |
| | 3. Hypo-centre location from at least 3 sensors. | Yes, but only planar location is trusted due to high z-error (see below). | ✓ |
| | 4. Back-up procedures for seismic event data base. | 3 months of sgrams with IMS; event data base since mid 1998 (former PRISM system). | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Anglo standard (Stankiewicz Mag). | ✓ |
| | 6. Access to SANSN data for larger events. | No access to SANSN, no exchange with neighbours. | ✗ |
| | | | 6/6*30%=30% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes (IMS service for all reporting). | ✓ |
| | 2. Seismic hazard and risk quantification. | Only medium and long-term hazard assessments due to lack of activity (approx. 4 events per day). Attempt medium-/long-term hazard assessments. | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily and quarterly report by IMS (several polygons); monthly report to planning and GM; occasional back analysis of larger events. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | All rockbursts are investigated and documented (approx. 5 per year). | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | Events and damage loaded onto 3D viewing s/ware, details captured. | ✓ |
| | 6. Regular practice review and quality management procedures for data collection. | Not external, but IMS reviewed network setup 2 years ago. | ✓ |
| **Total** | | | **83%** |

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? ___None__________

**Notes:**

- Deep MER mining at D2-shaft’s West side and at D1-shaft; shallow UG2 mining at around 140m middling.
- $M_{max}$=2, damage from around M=1.2.
- 4 stations on D1# (1s plus 3u), 1s on D2# (2 more to be added). Additional site at D1 and 2#, but not operational (no power).
- Still on RTS, Mine C and Union network were upgraded to SYNAPSE.
- Confidentiality: Refer to as Mine D.

**Additional data, information and documents made available by the mine:**

Sample rockburst report (CS_ll1_275_20160314_ddd27-26_RSE_Seismic_Event_Report.pdf)

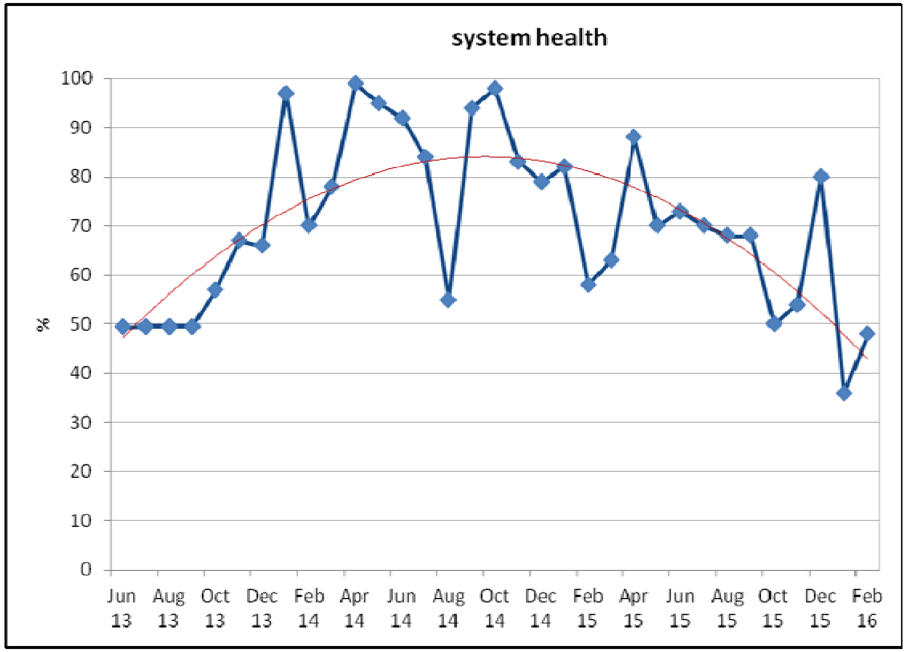
Sample daily report (IMS, ddd-REP-DS-20160311-IMSv0.pdf, ddd-REP-DS-20160316-IMSv0.pdf, ddd-REP-DS-20160524-IMSv0)

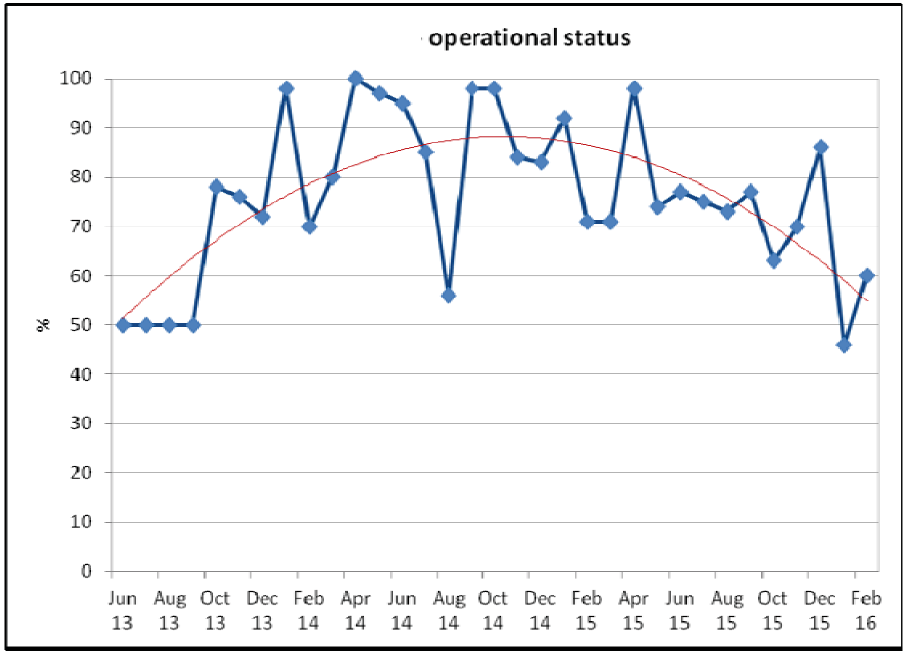
Sample monthly report (IMS, ddd-REP-MNTH-20160228-RCv0.pdf)

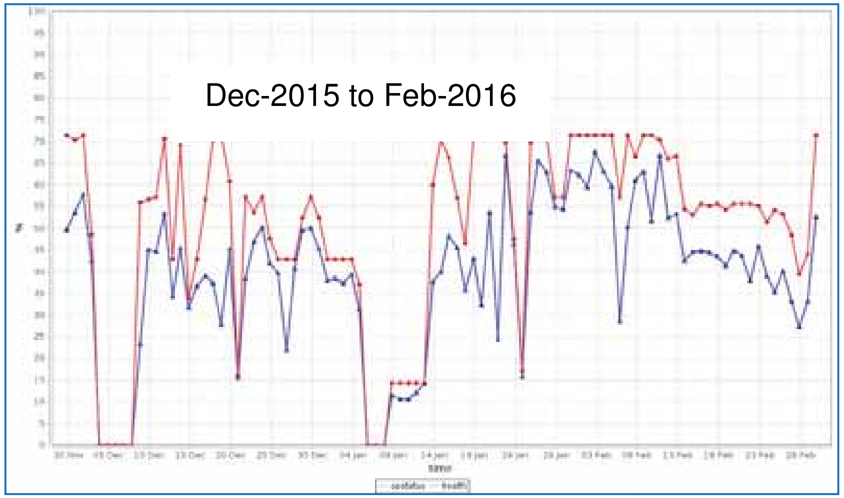
Site preparation notes (IMS, lll-SPN-EXPANSION-201402v1ep.pdf)

Jan-2015 to Mar-2016 accepted events.

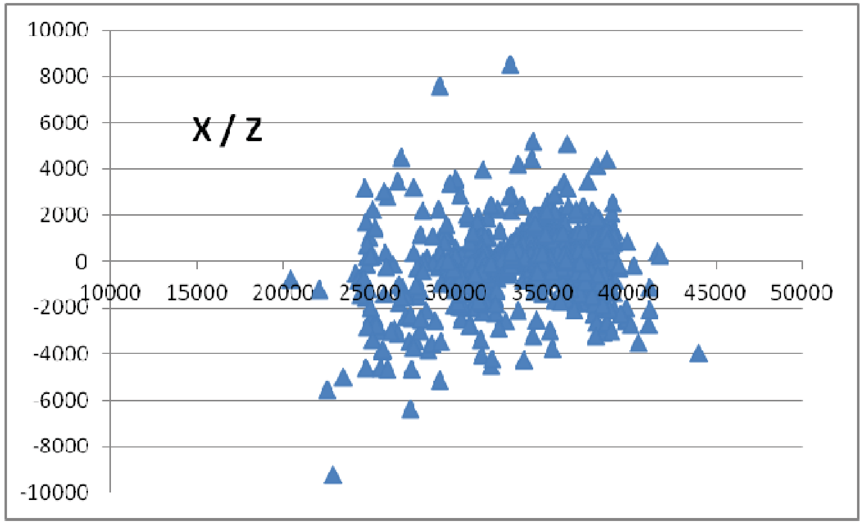
Seismic system status and station health report (monthly averages):



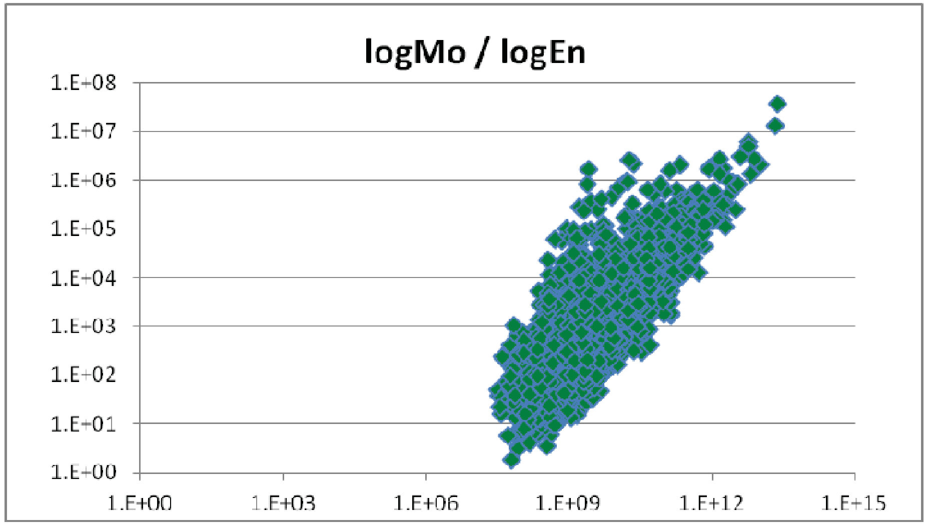



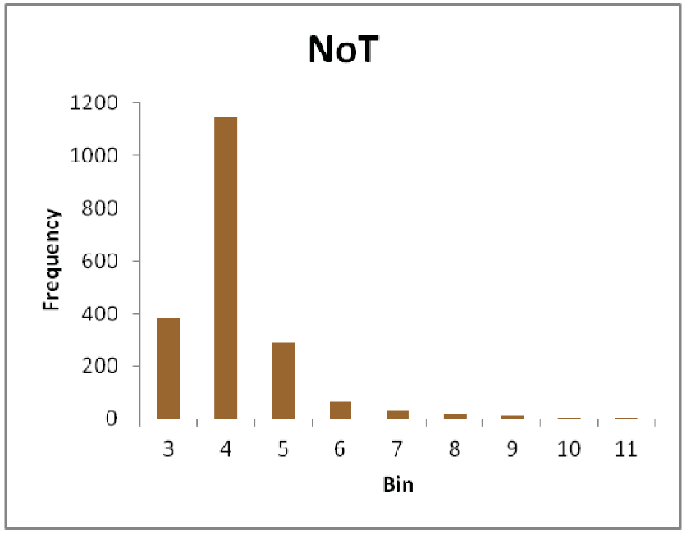

Location accuracy (vertical section):




EnMo correlation:




Number of triggers associated:




Improvement in system health after the audit

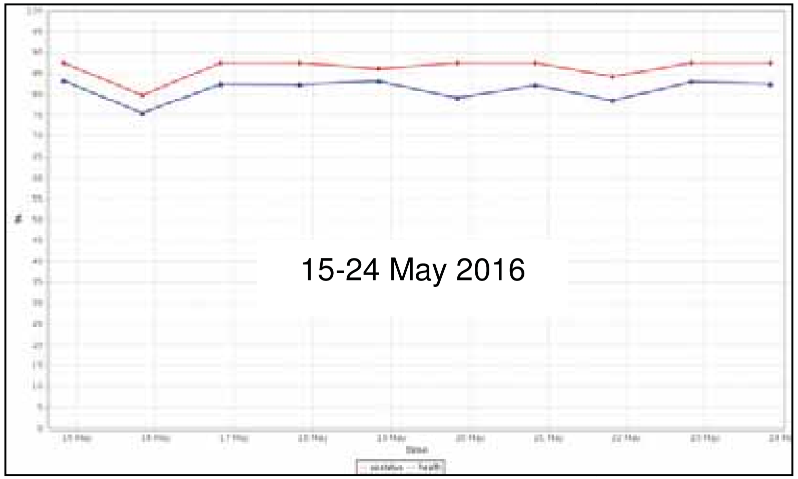


**Table 20**: **Mine/shaft:** Mine E **Assessed by:** **WB and FE** **Date: 15/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 4/10*40%=16% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Divided into back area for large events ($M \approx 2$) and active mining on the UG2: $M_{min}=0$, loc error in plan approx. 200x200m. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Originally planned and installed for MER mining in the MER f/wall, now covers UG2 mining approx. 45 below MER. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | 3 surface sites, deepest on 15lvl; large z-error in data (see below). | × |
| | 4. Principal[6] sites defined to ensure minimum coverage at all times. | No; UPSs only at surface sites. | × |
| | 5. Capacity for speedy sensor installation (<3 months). | Average 2-4 years; low priority due to low risk level. | × |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Adequate for $M \geq 0$. | ✓ |
| | 7. At least 80% of stations operational at all times. | Usually around 60-70% (see below). | × |
| | 8. Sensor health checked and reported on, and always above 80%. | Checked and reported: usually around 60% (see below). | × |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | No. | × |
| | 10. Synchronisation of system clocks for regional events. | GPS time base; suitable for exchange with neighbouring networks. | ✓ |

[6] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | | | 4/6*30%=20% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | Quality check by IMS after auto-processing; 10% of all accepted are manually re-processed; good E-M correlation (see below). | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Min. NoT is 3P + 3S. | × |
| | 3. Hypo-centre location from at least 3 sensors. | Planar location considered accurate, vertical needs improvement (see below). | ✓ |
| | 4. Back-up procedures for seismic event data base. | 3 months of sgrams with IMS; event data base since mid 1998 (former PRISM system). | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Anglo standard (Stankiewicz Mag). | ✓ |
| | 6. Access to SANSN data for larger events. | No access to SANSN, no exchange with neighbours. | × |
| | | | 4/5*30%=24% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes (IMS service). | ✓ |
| | 2. Seismic hazard and risk quantification. | Only medium and long-term hazard assessments due to lack of activity (less than 5 events per day). | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily and quarterly report by IMS; 2 B-polys; monthly report to GM; occasional back analysis of isolated, rare large events. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | Procedures are in place, but very few incidents (a pillar burst in 2005, 2 fatalities). | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | N/A (only one incident). | N/A |
| | 6. Regular practice review and quality management procedures for data collection. | Not done. | × |

**Total** **60%**

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? ____No______________________

**Notes:**

- MER mining complete, currently only shallow UG2 mining (middling 45m);
- 3 surface and 15 u/g sites, incl. 2 faulty;
- previously Prism system installed for MER extraction, upgraded to IMS system in 2005 after oversized crush-pillar burst caused 2 fatalities;
- sites were installed in haulages below MER, are now covering the UG2 mining below the MER;
- network expansion and upgrade planned in 2001, commissioned in 2015;
- occasional pillar bursts reported from UG2 (!), but no effect on operations.
- deepest MER mining was at 16lvl (≈1 000 m.b.s.).
- geophones are $F_{res}$=4.5Hz, the surface sites may be 30Hz.
- Confidentiality: Refer to as Mine E.

**Additional data, information and documents made available by the mine:**

Sample monthly report (IMS, e-REP-MNTH-201601-IMSv0.pdf)

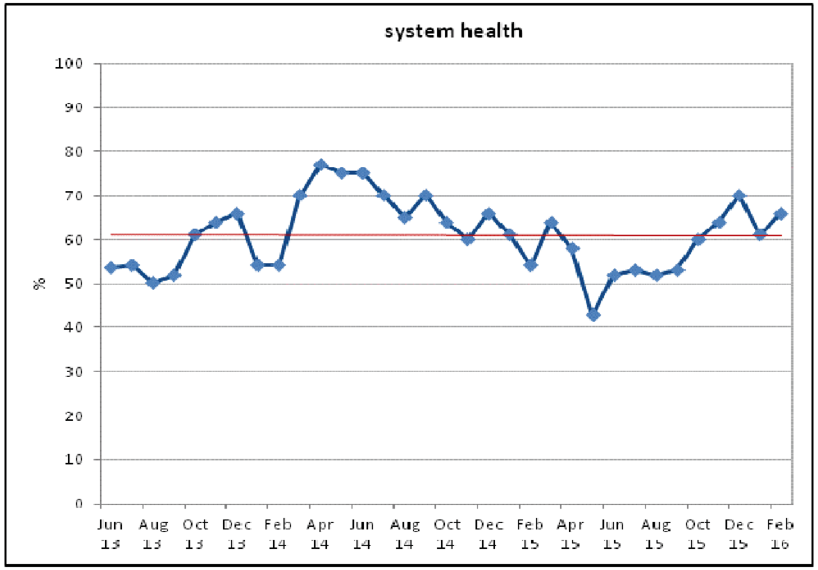
Sample day shift report (IMS, e-REP-PL-20160315-IMSv0.pdf)

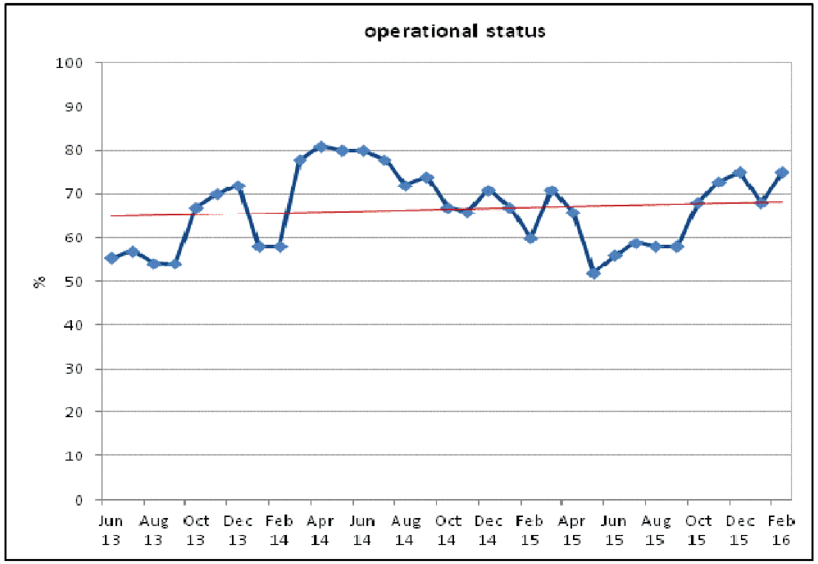
3-months system status and station health report (…3-month_Feb.pdf)

Mine CoP to combat rock fall and rockburst accidents (2015)

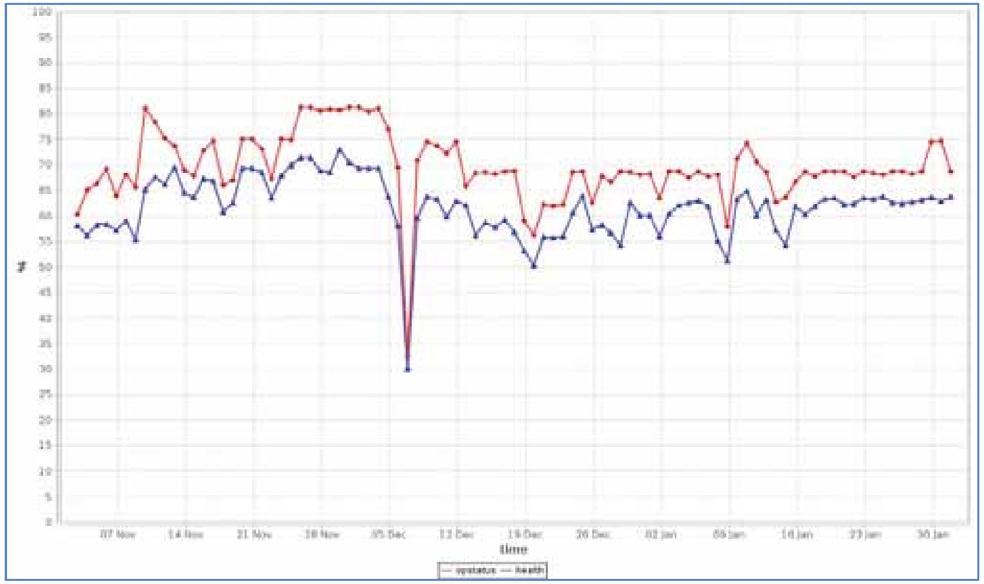
Jan- to Mar-2016 accepted seismic events.

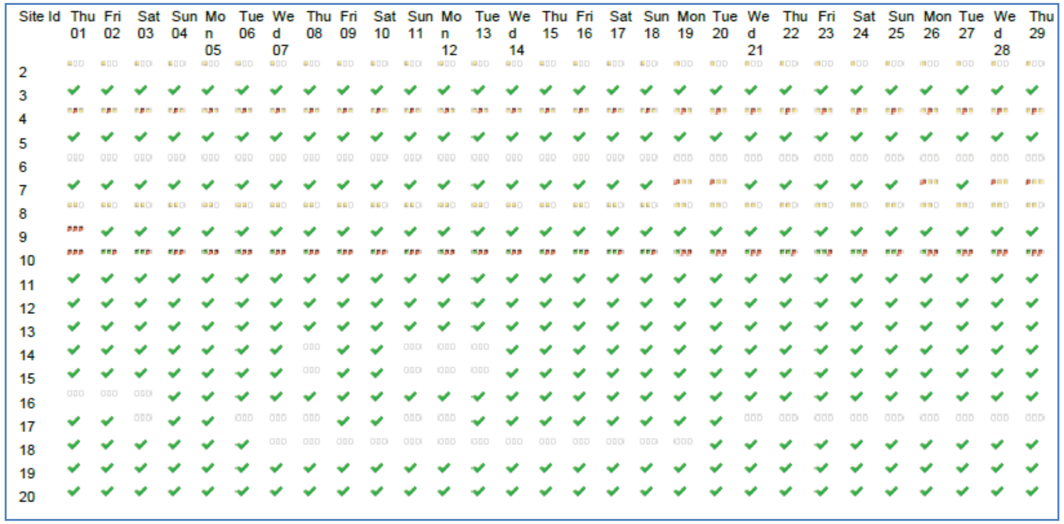
System status and station health (monthly averages):



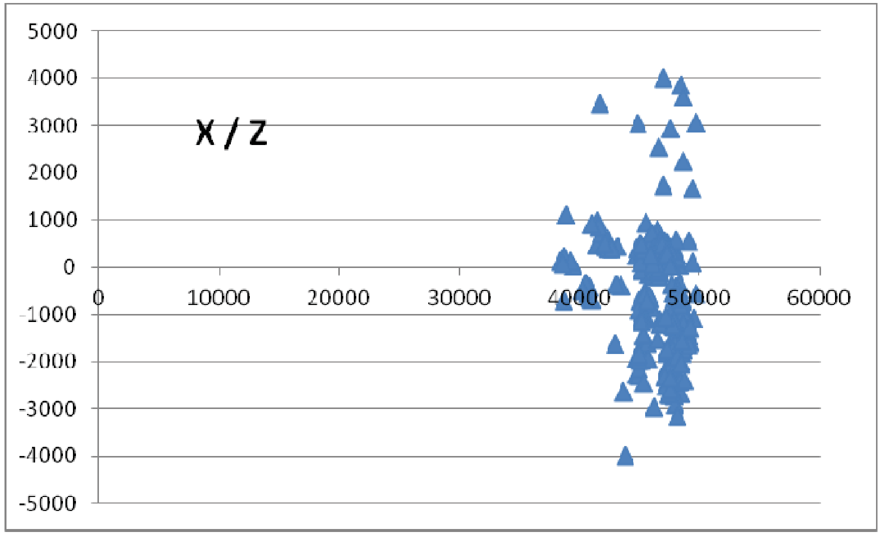




November 2015 – January 2016 (daily ratings)

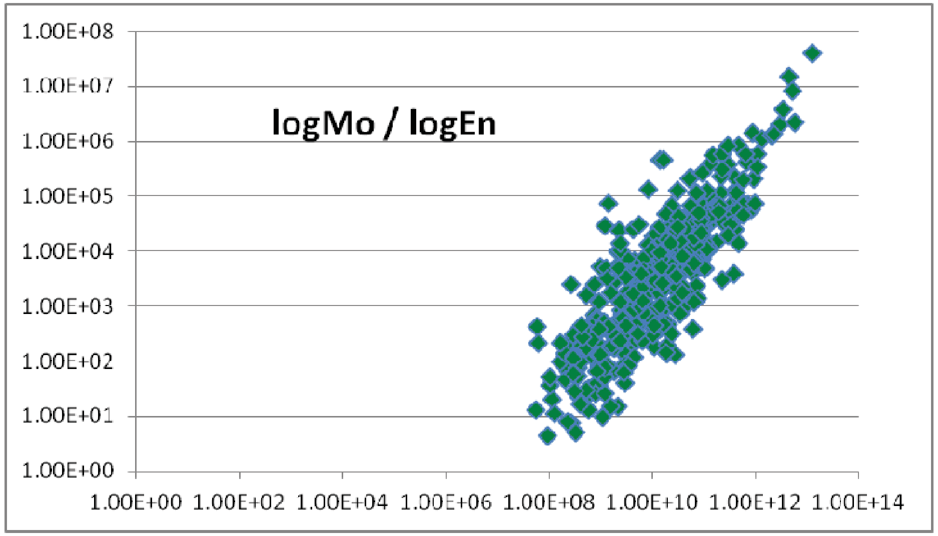


Location accuracy:




EnMo correlation




Number of triggers associated:

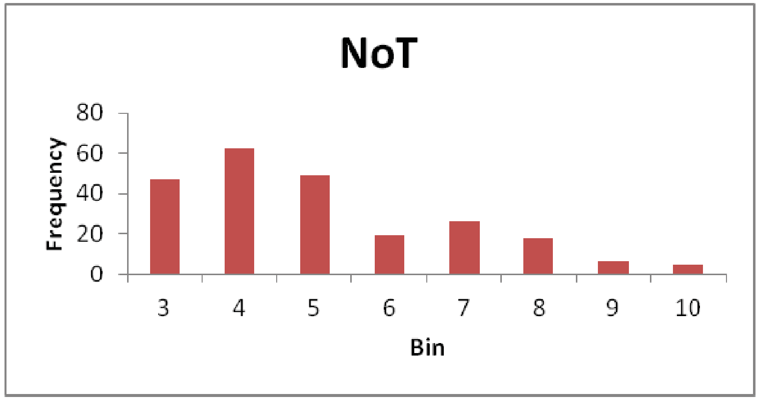


**Table 21**: **Mine/shaft:** Implats 10# **Assessed by: LL, JP and FE** **Date: 14/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 9/10*40%=36% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Division into Seismic Hazard Zones; no specific MonObs but network sensitivity and location error planned ($M_{min}$=-1, loc error<50m in plan); lower requirements for back areas. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Yes, incl. sites ahead of mining in current development ends; see sensitivity model in 2016 audit report. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | 11 u/g plus 1 surface site, deepest on 19lvl; clustered events in plan and section, few outliers (see below). | ✓ |
| | 4. Principal[7] sites defined to ensure minimum coverage at all times. | Batteries sufficient for 14 days of supply on all sites. | ✓ |
| | 5. Capacity for speedy sensor installation (<3 months). | Usually 4-5 months, but now slower due to resource constraints (drill riggs, drill bits, budget). | × |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Sampled at 3kHz at sensor, re-sampled to 1.6kHz on surface before processing. | ✓ |
| | 7. At least 80% of stations operational at all times. | Refer to records for health performance (2016 audit, see below). | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | With few exceptions, all faults resolved within 24 hours - see life-time graph. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Sensors surveyed, polarity tested using blast; corrected in system settings where required. | ✓ |
| | 10. Synchronisation of system clocks for regional events. | All on GPS with internal delays below 1 μ-sec; below 100ms when on internal battery. | ✓ |

[7] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | | | 6/6*30%=30% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | All events manually processed; during 2015 and 2016 to date approx 11 events per day recorded and <4 accepted. | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Yes (min NoT=4), but many events with NoT=2 and very few events with 4 or 5 triggers in data base (see NoT stats below); reasonable correlation of source parameters with few outliers; 7% of events have no P-energy and moment. | ✓ |
| | 3. Hypo-centre location from at least 3 sensors. | Yes, except 1# (1 surface site only); locations are clustered in plan and section (see below). | ✓ |
| | 4. Back-up procedures for seismic event data base. | Weekly to USB; monthly to server at mine's IT department. | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Energy Mag (internal); En and Mo based Mag available for external communication. | ✓ |
| | 6. Access to SANSN data for larger events. | MoU signed with CGS; exchange when needed. | ✓ |
| | | | 6/6*30%=30% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes, all reports on hazard areas, incidents etc. | ✓ |
| | 2. Seismic hazard and risk quantification. | Monthly per shaft (see samples). | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily, weekly and monthly. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | Record keeping and investigation where damage occurred, plus all events M>=1 irrespective of damage. | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | Yes; currently re-designed by consultant. | ✓ |
| | 6. Regular practice review and quality management procedures for data collection. | Last in 2008 by Geo-Hydro-Seis, no changes to network or data processing since; last internal in 2016. | ✓ |
| **Total** | | **plus: loc. accuracy calibration using rockburst sites → final score:** | **100%** |

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? __Use confirmed rockburst as master events_

**Notes:**

- Equipped with systems are 10# (7 u/g + 1 surface + 3 planned), 11# (6u+1s + 3p) and 14# (5u+1s+3p); 1# has 1 surface site; 17# close to commissioning, but stopped;
- All sensors are 4.5Hz tri-axial geophone sets; data base starts 2005/01/12.
- UPSs at u/g sites cause frequent faults due to corrosion and from surges, spikes in hlg. power supply; internal 9V batteries are more suitable;
- 10# used to be most active, now 14#; auto-processing during day, manual after blasting time (8-10pm);
- System supplier still M&M systems in JHB, recently bought out by SICK Engineering.
- Results of this audit may be shared with other mines, no stringent confidentiality prescribed.

**Additional data, information and documents made available by the mine:**

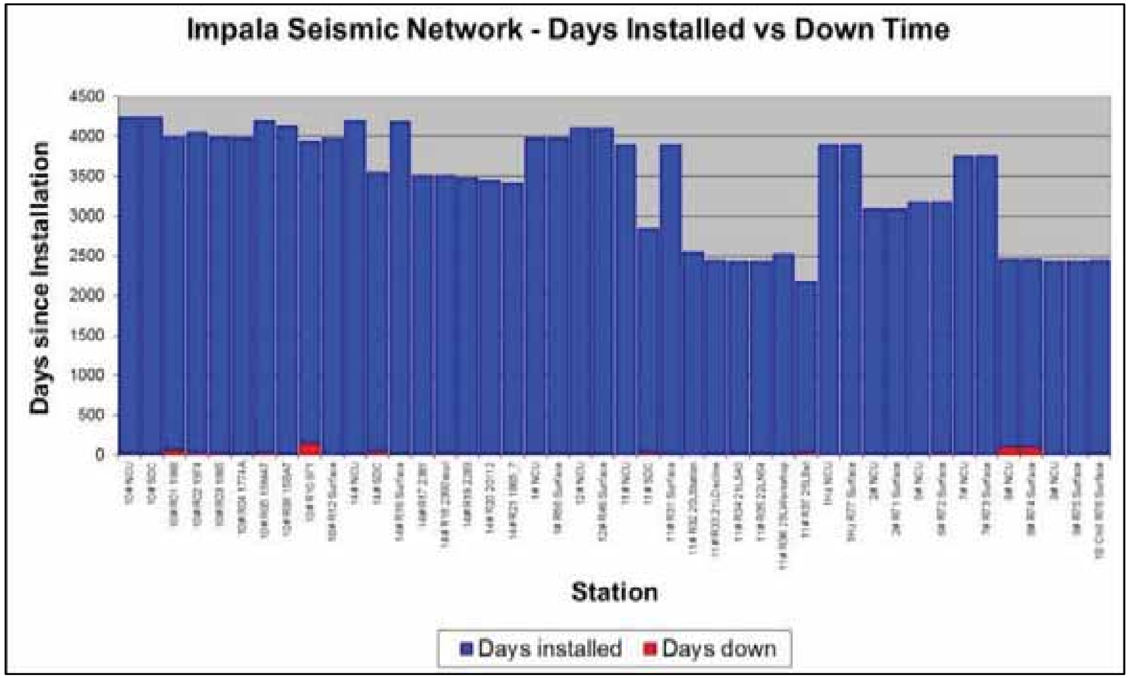
Sample seismic incident report (PC 002 2016 SEIS LSL.doc)

Feb-2016 Monthly Seismic Report

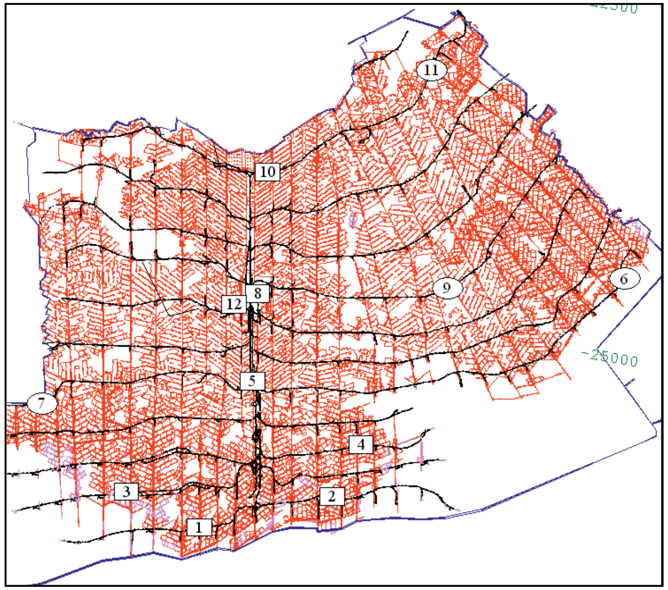
2016 Internal system audit report

2005-to-date sensor site history and event data base (Impala Platinum.mdb).

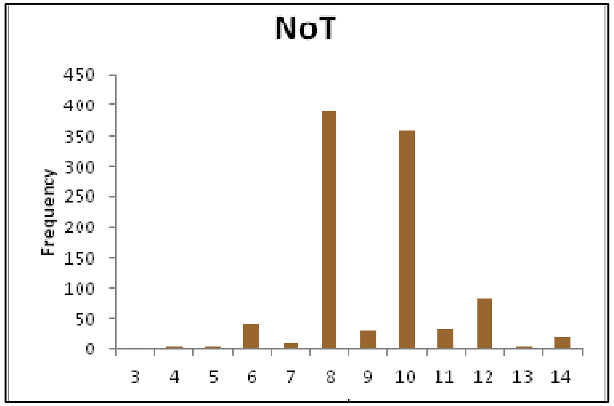
Up-time over entire life span (all Impala stations, since commissioning):



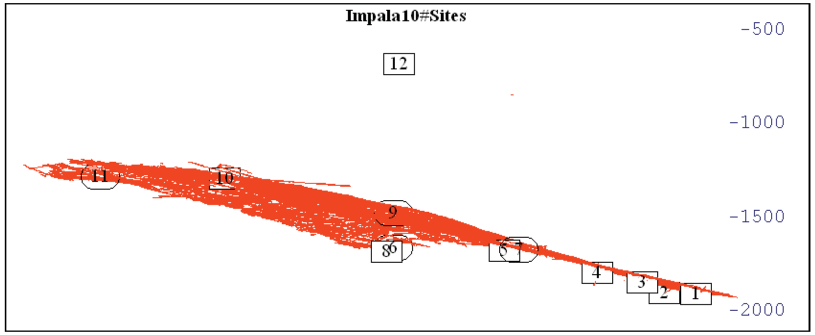

Station configuration 10#:



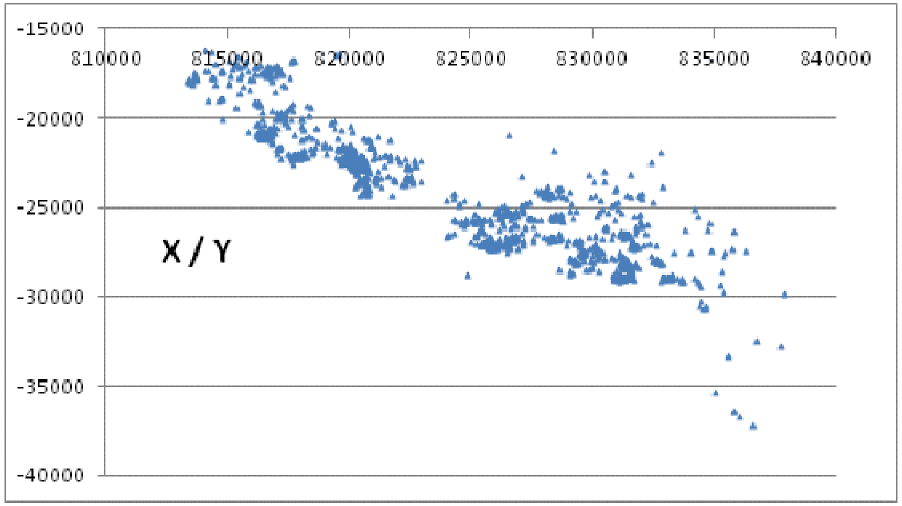

Number of triggers associated (all Impala networks):



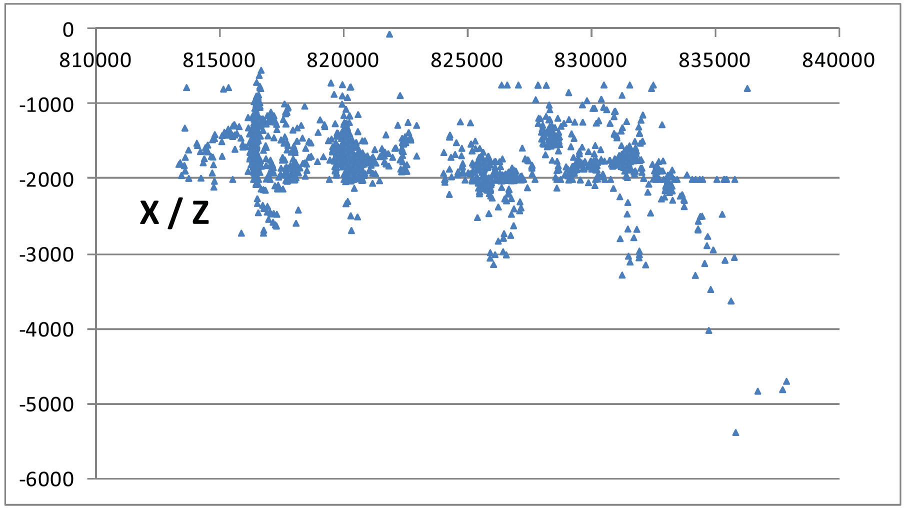

| NoT | *Count* | *Perc (%)* |
|---|---|---|
| 2 | 504 | 34% |
| 3 | 0 | 0% |
| 4 | 3 | 0% |
| 5 | 2 | 0% |
| 6 | 42 | 3% |
| 7 | 12 | 1% |
| 8 | 390 | 26% |
| 9 | 30 | 2% |
| 10 | 360 | 24% |
| 11 | 33 | 2% |
| 12 | 83 | 6% |
| 13 | 5 | 0% |
| 14 | 22 | 1% |



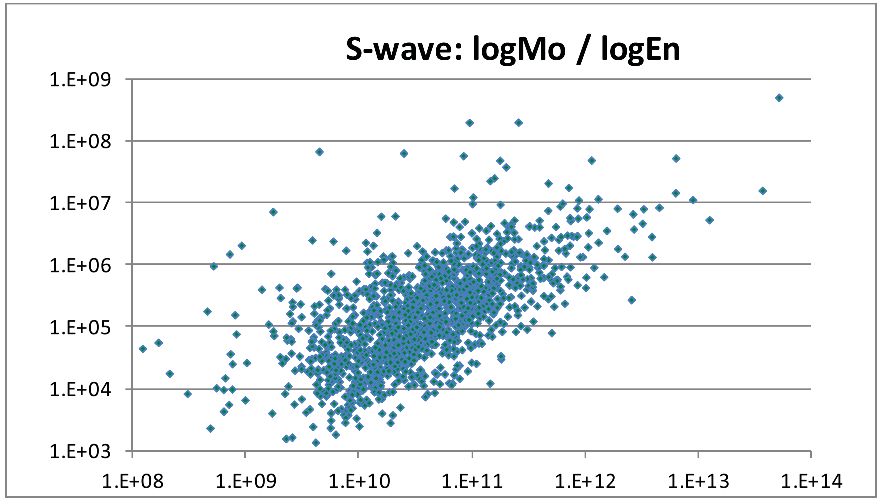
Location accuracy in plan (all Impala events Jan2015 – Mar2016):




Location accuracy in section:




Energy-Moment correlation (S-wave):




Sensitivity 10, 11 and 14#:

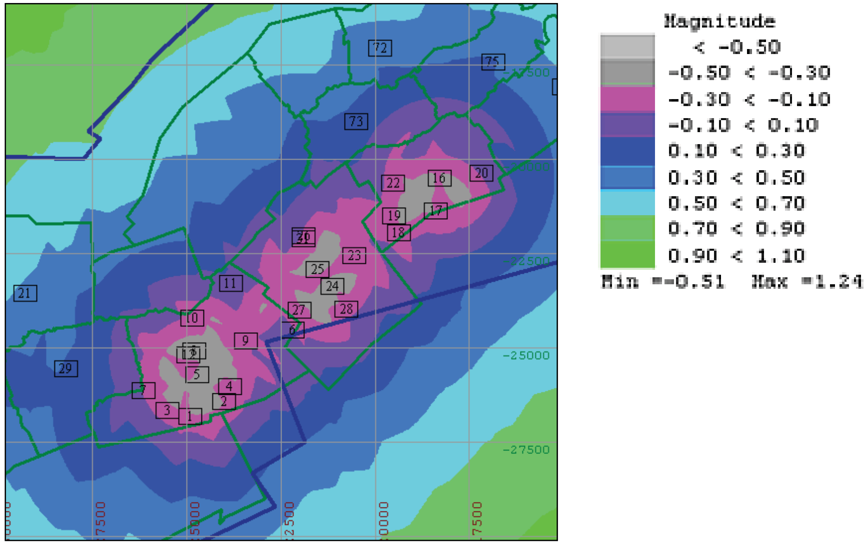


**Table 22**: **Mine/shaft:** Implats 11# **Assessed by: LL, JP and FE** **Date: 14/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 9/10*40%=36% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Division into Seismic Hazard Zones; no specific MonObs defined but desired sensitivity and min. location error were planned ($M_{min}$=-1, loc error<50m in plan); requirements reduced for mined-out back areas. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Yes, incl. sites ahead of mining in current development ends. Network performance models in 2016 audit report. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | One surface site, 6 u/g sites; event locations are clustered in plan and section with few outliers (see below). | ✓ |
| | 4. Principal[8] sites defined to ensure minimum coverage at all times. | All stations equipped with 9V batteries sufficient for 14 days recording (sampling & storage). | ✓ |
| | 5. Capacity for speedy sensor installation (<3 months). | Usually in excess of 4-5 months, of late even longer. | × |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Sampled at 3kHz on all sensor sites, re-sampled to 1.6kHz on surface before processing. | ✓ |
| | 7. At least 80% of stations operational at all times. | Refer to records for stats; system manned 6-15h00 resulting in short response time (see station up-time below). | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Remote login after blasting to check status; with few exceptions, all faults resolved within 24 hours. Life-time graph shows minimal %-age down-time. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Sensors surveyed, polarity tested with production blasts. | ✓ |
| | 10. Synchronisation of system clocks for regional events. | All on satellite time (GPS) with internal delays below 1 µ-sec. | ✓ |

[8] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | |
|---|---|---|---|
| | | | 6/6*30%=30% |
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | All event processing takes place at the mine; on average, 7 of 11 events are rejected. | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Yes (min NoT=4); data set shows reasonably close correlation between S-wave energy and moment (below). | ✓ |
| | 3. Hypo-centre location from at least 3 sensors. | Yes, very few events with <6 triggers; hypo-centre locations appear well clustered in plan, but with larger errors in z. | ✓ |
| | 4. Back-up procedures for seismic event data base. | Weekly to USB; monthly to server at IT department. | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Energy Mag (internal); combined EnMo-Mag available for external communication. | ✓ |
| | 6. Access to SANSN data for larger events. | MoU signed; exchange takes place whenever needed. | ✓ |
| | | | 6/6*30%=30% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes, all reports on hazard areas, incidents etc. | ✓ |
| | 2. Seismic hazard and risk quantification. | Monthly per shaft (see samples). | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily, weekly and monthly. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | Record keeping and investigation where damage occurred, plus all events M>=1 irrespective of damage. | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | Yes; currently re-designed by consultant. | ✓ |
| | 6. Regular practice review and quality management procedures for data collection. | Last in 2008 by Geo-Hydro-Seis, no changes to network or data processing since; last internal in 2016. | ✓ |

**Total** **plus bonus for loc. accuracy calibration using rockburst sites → final score: 100%**

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? __From confirmed rockburst locations_

**Notes:**

- 11# (6u+1s + 3planned); all sensors are 4.5Hz tri-axial geophone sets.
- All equipped with internal 9V batteries ;
- S Spottiswoode, M Drummond and T Stankiewicz still assist with technical support ➲ risk of sudden loss due to old age;
- System supplier is M&M systems in JHB.
- Results of this audit may be shared with other mines, no stringent confidentiality prescribed.

**Additional data, information and documents made available by the mine:**

11# Weekly Seismic Report 11 March 2016

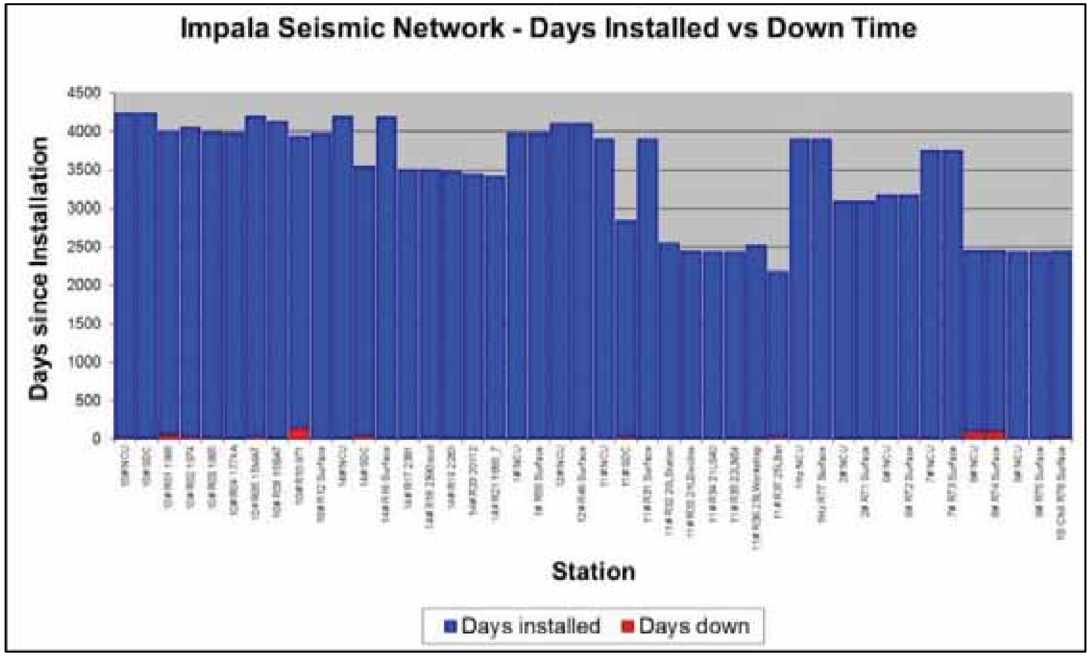
Sample seismic incident report (PC 002 2016 SEIS LSL.doc)

Feb-2016 Monthly Seismic Report

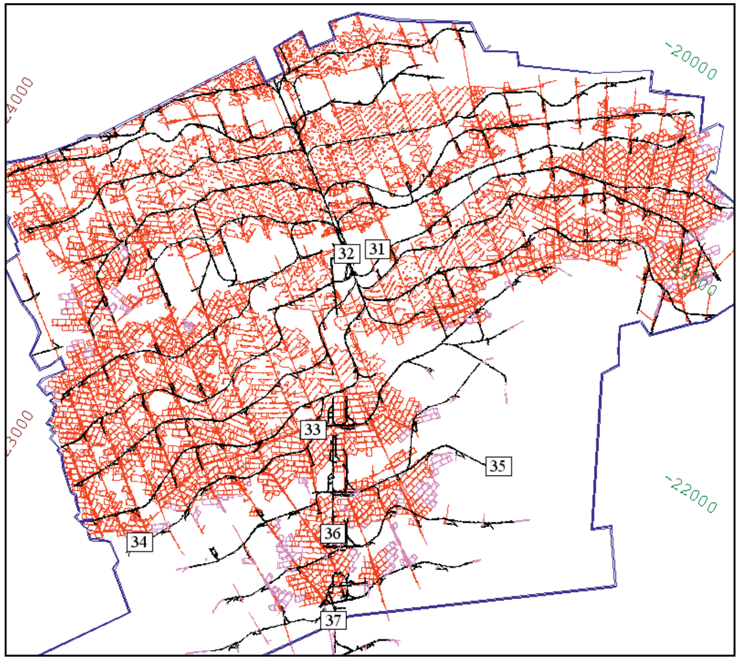
2016 Internal system audit report

2005-to-date sensor site history and event data base (Impala Platinum.mdb).

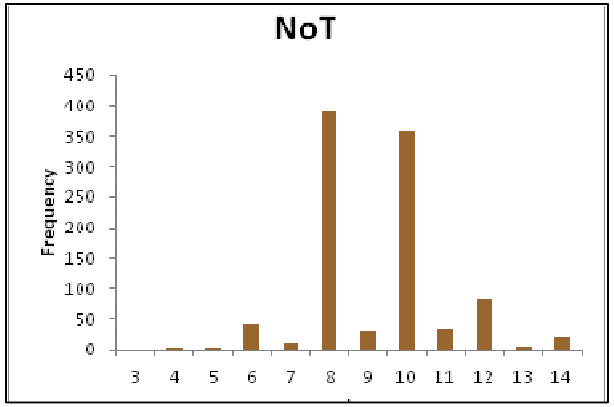
Up-time over entire life span (all Impala stations, since commissioning):



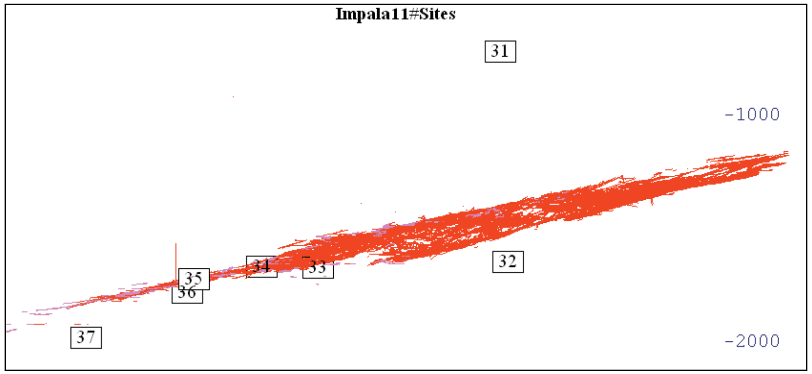

Station configuration 11#:



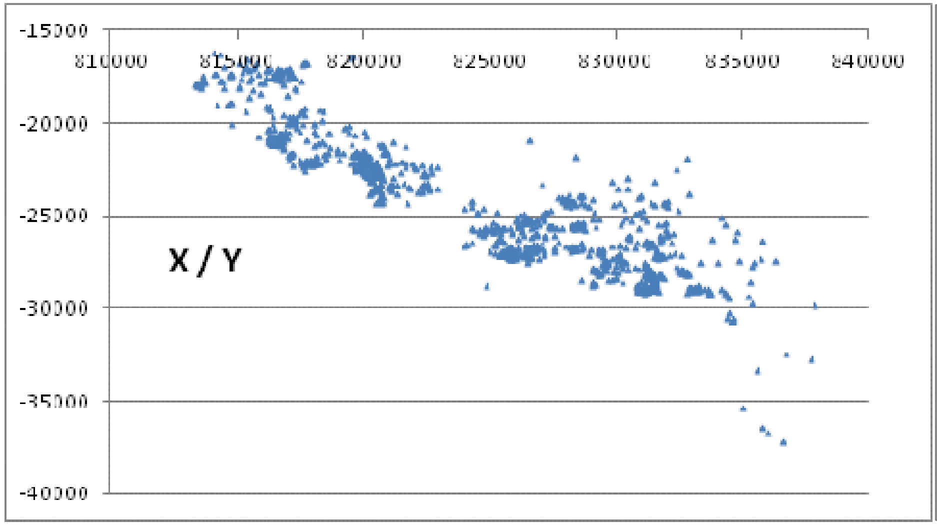

Number of triggers associated (all Impala networks):



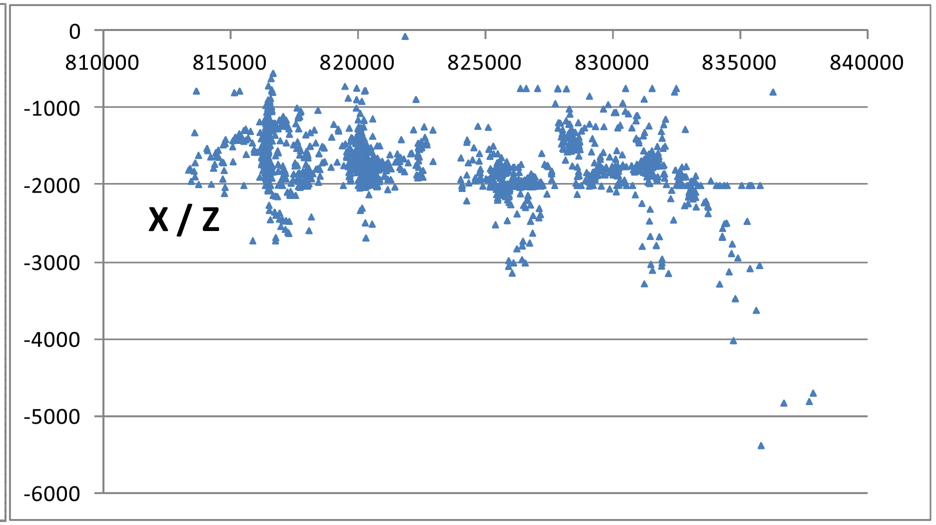

| NoT | *Count* | *Perc (%)* |
|---|---|---|
| 2 | 504 | 34% |
| 3 | 0 | 0% |
| 4 | 3 | 0% |
| 5 | 2 | 0% |
| 6 | 42 | 3% |
| 7 | 12 | 1% |
| 8 | 390 | 26% |
| 9 | 30 | 2% |
| 10 | 360 | 24% |
| 11 | 33 | 2% |
| 12 | 83 | 6% |
| 13 | 5 | 0% |
| 14 | 22 | 1% |



Location accuracy in plan (all Impala events Jan2015 – Mar2016):




Location accuracy in section:




Energy-Moment correlation (S-wave):

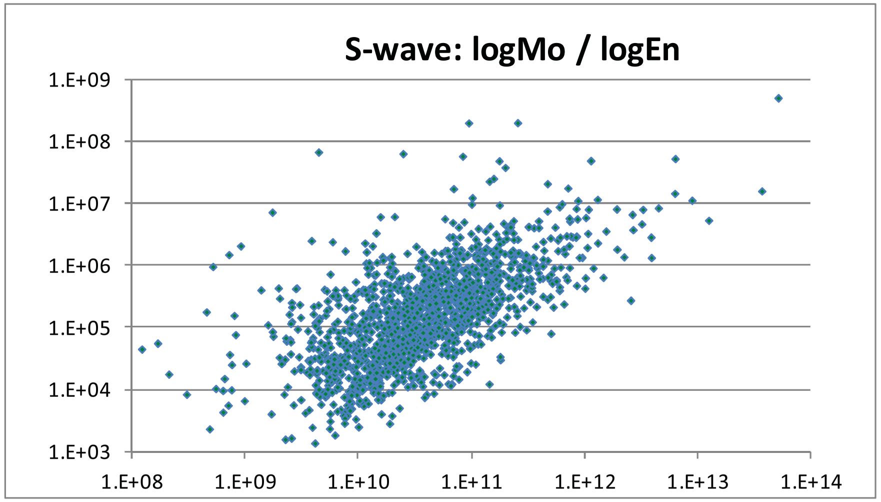


**Table 23**: **Mine/shaft:** Implats 14# **Assessed by: LL, JP and FE** **Date: 14/3/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 9/10*40%=36% |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Seismic Hazard Zones are demarcated, no specific MonObs but sensitivity $M_{min}$=-1 and LocError <50m planned; back areas have lower requirements. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Yes, incl. sites in development ends ahead of current mining; see sensitivity model below. | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | All n/works have one surface site; 14# has 5 u/g and 1 surface site; deepest on 23lvl, new 27lvl station is planned (see station configuration below). | ✓ |
| | 4. Principal[9] sites defined to ensure minimum coverage at all times. | All sites have 9V batteries for 14 days of recording (sampling & storage). | ✓ |
| | 5. Capacity for speedy sensor installation (<3 months). | Usually in excess of 5 months; competition with geological drilling. | × |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Sampled at 3kHz at sensor, re-sampled to 1.6kHz on surface before processing. | ✓ |
| | 7. At least 80% of stations operational at all times. | Refer to station health over life time records (see life-time performance of stations below). | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Dedicated team: Usually, all faults resolved within 24 hours – see %-age up-time graph below. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | Sensor sets surveyed after installation, polarity tested with prod. blasts at known locations and corrected when required. | ✓ |
| | 10. Synchronisation of system clocks for regional events. | All on satellite time (GPS)- below 100ms when on internal battery. | ✓ |

[9] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | 6/6*30%=30% |
|---|---|---|---|
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | All events are manually processed; during 2015-16 on average 11 events per day recorded and <4 accepted. | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Confirmed: Min NoT=4, but large majority have 6 or more (see NoT stats below). | ✓ |
| | 3. Hypo-centre location from at least 3 sensors. | All shafts except 1#; locations are clustered in plan along mining areas and in section (see below); vertical spread larger than in plan. | ✓ |
| | 4. Back-up procedures for seismic event data base. | Weekly to USB; monthly to mine’s central IT server. | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Internal En-based Mag; Mo-Mag available for external communication. | ✓ |
| | 6. Access to SANSN data for larger events. | MoU signed with CGS; exchange when needed. | ✓ |
| | | | 6/6*30%=30% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes, all reports on hazard areas, incidents etc. | ✓ |
| | 2. Seismic hazard and risk quantification. | Monthly per shaft (see samples). | ✓ |
| | 3. Periodic reporting to management and production sections. | Daily, weekly and monthly. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | Record keeping and investigation where damage occurred, plus all events M>=1 irrespective of damage. | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | Yes; currently re-designed by consultant. | ✓ |
| | 6. Regular practice review and quality management procedures for data collection. | Last in 2008 by Geo-Hydro-Seis, no changes to network or data processing since; last internal in 2016. | ✓ |
| **Total** | | **plus bonus for loc. accuracy calibration using rockburst sites ➔ final score:** | **100%** |

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? __Use confirmed rockbursts as master events_

**Notes:**

- 14# (5u/g+1surf+3planned), all are 4.5Hx tri-axial geophone sets.
- Batteries found to me more suitable for u/g conditions than UPSs (corrosion, technical faults due to heat and humidity).
- 10# used to be most active, now 14#.
- LL and JP make up the mine seismology team; several retired researchers and consultants provide support ➲ risk of sudden loss due to old age.
- System manned 6-15h00; remote login for fault diagnosis 24 -7.
- System manufacturer is M&M systems in Randfontein.
- Results of this audit may be shared with other mines, no stringent confidentiality prescribed.

**Additional data, information and documents made available by the mine:**

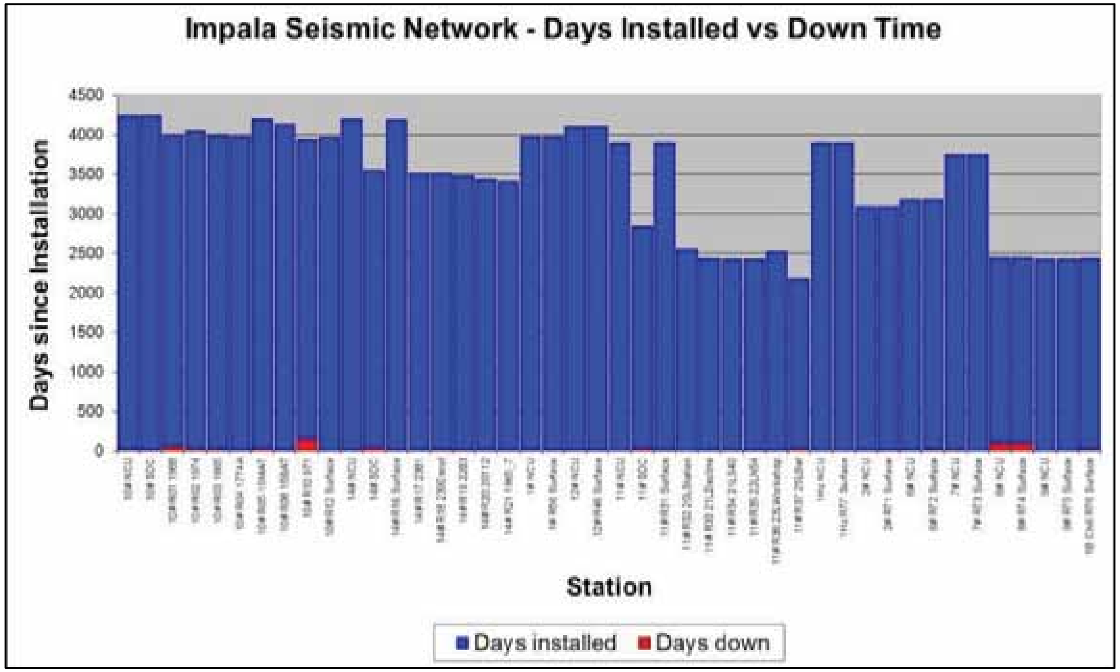
Sample seismic incident report (PC 002 2016 SEIS LSL.doc)

Feb-2016 Monthly Seismic Report

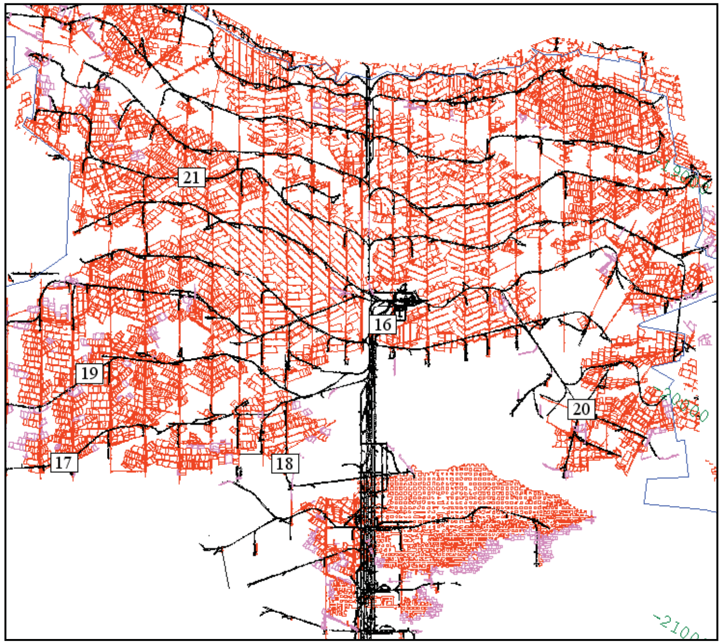
2016 Internal system audit report

2005-to-date sensor site history and event data base (Impala Platinum.mdb).

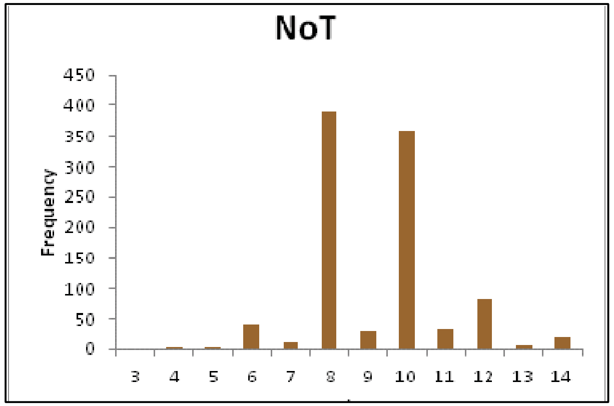
Up-time over entire life span (all Impala stations, since commissioning):



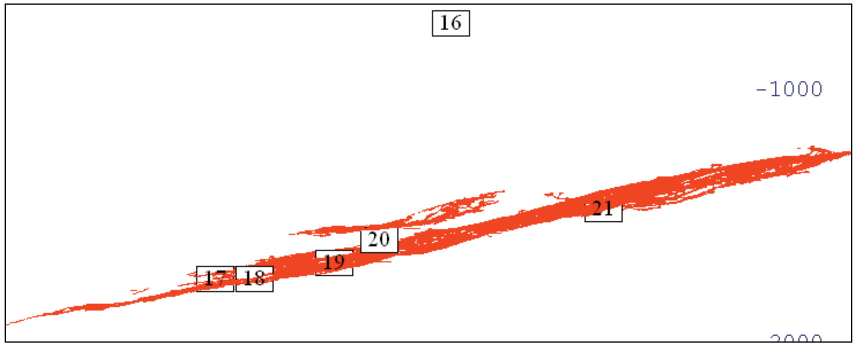

Station configuration 14#:



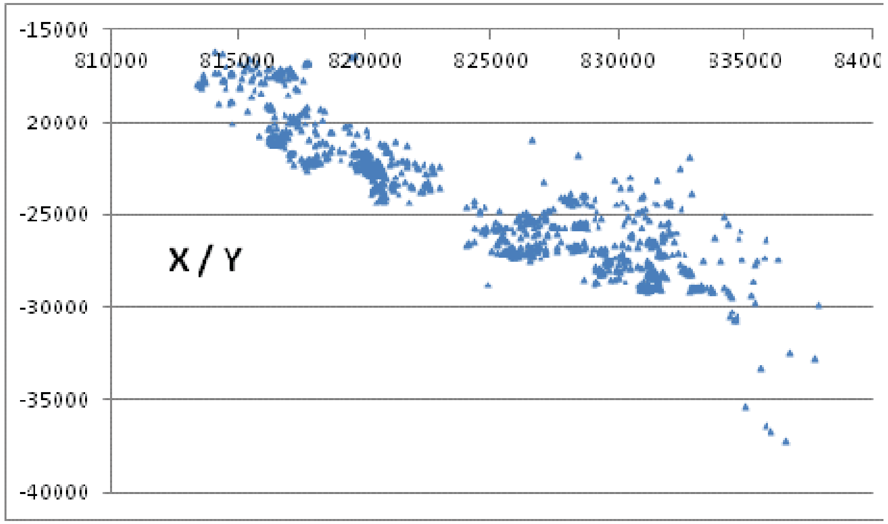

Number of triggers associated (all Impala networks):



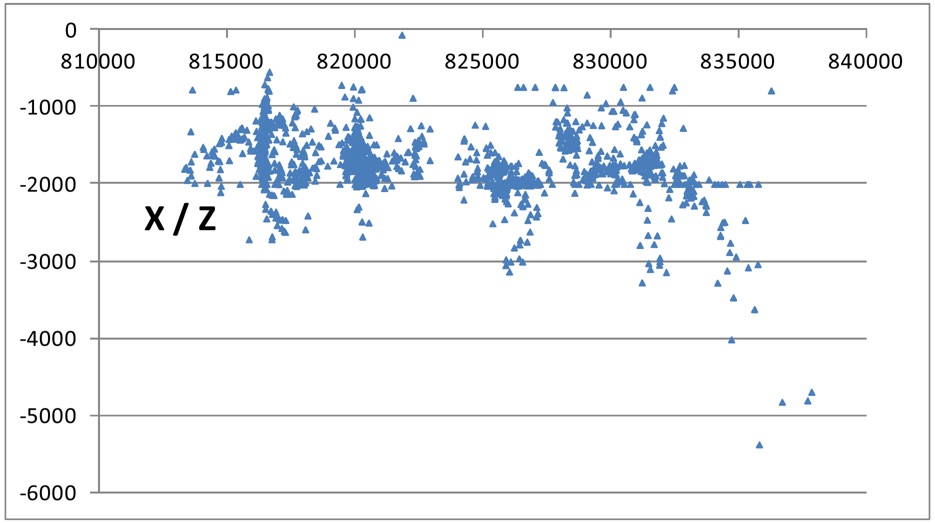

| NoT | *Count* | *Perc (%)* |
|---|---|---|
| 2 | 504 | 34% |
| 3 | 0 | 0% |
| 4 | 3 | 0% |
| 5 | 2 | 0% |
| 6 | 42 | 3% |
| 7 | 12 | 1% |
| 8 | 390 | 26% |
| 9 | 30 | 2% |
| 10 | 360 | 24% |
| 11 | 33 | 2% |
| 12 | 83 | 6% |
| 13 | 5 | 0% |
| 14 | 22 | 1% |



Location accuracy in plan (all Impala events Jan2015 – Mar2016):




Location accuracy in section:




Energy-Moment correlation (S-wave):

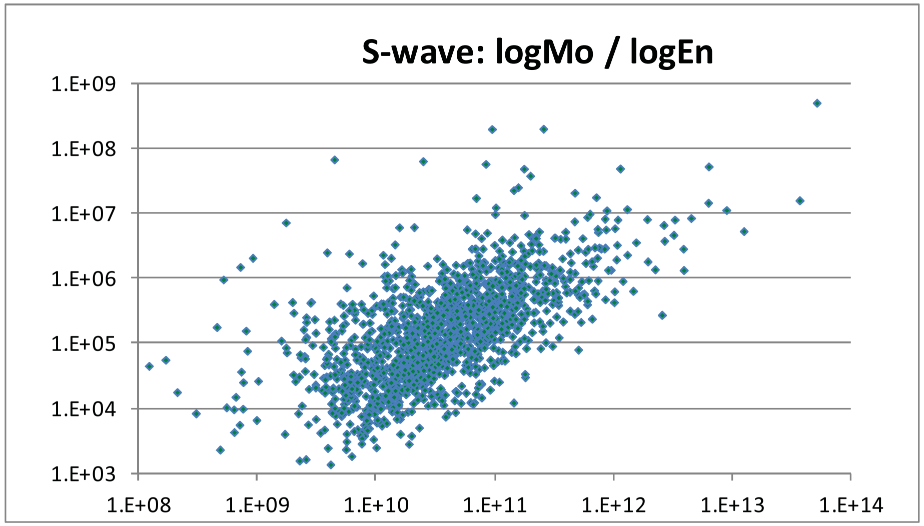


**Table 24**: **Mine/shaft:** Union **Assessed by:** **LS and FE** **Date: 26/4/2016**

| Section No. | Criteria | Comments | Score |
|---|---|---|---|
| | | | 9/10%40%=36 % |
| 1. Seismic network planning, system settings & configuration | 1. Monitoring objectives defined for different areas of the mine. | Stations roughly equally spread to cover few deep MER panels and majority shallow UG2 panels. | ✓ |
| | 2. Network station configuration planned according to monitoring objectives. | Planned to result in sensitivity of $M_{min}$=0.5 (achieved – see below) | ✓ |
| | 3. Shallow or deep sites added to reduce location error in depth. | 1 surface station, 5 u/g sites | ✓ |
| | 4. Principal[10] sites defined to ensure minimum coverage at all times. | All equipped with UPS, planned for MUX as well. | ✓ |
| | 5. Capacity for speedy sensor installation (<3 months). | Can be completed within 2 months. | ✓ |
| | 6. Filter settings and sampling rate match relevant Magnitude range. | Setting for M=-0.5 events and larger. | ✓ |
| | 7. At least 80% of stations operational at all times. | Yes, but major disruptions which are quickly repaired (see below). | ✓ |
| | 8. Sensor health checked and reported on, and always above 80%. | Improved over recent years, mostly above 80% since mid 2015. | ✓ |
| | 9. Sensor orientation and polarity checked (not required for smart sensors). | North line when installing; verticality and installed angle not checked. | × |
| | 10. Synchronisation of system clocks for regional events. | GPS time base (satellite); suitable for exchange with other n/works. | ✓ |

[10] Principal sites receive priority with respect to repair and maintenance and are each equipped with a UPS.

| | | | 5/6*30%=25% |
|---|---|---|---|
| 2. Seismic source quantification | 1. Minimum quality standards for events before data analysis. | Quality controls as per IMS ISO9001 procedures; close E-M correlation (see below). | ✓ |
| | 2. At least 4 P- and 4 S-picks for source parameter calculation (tri-axial). | Min. 3P + 3S (see NoT graph below). | × |
| | 3. Hypo-centre location from at least 3 sensors. | Planar location considered accurate. | ✓ |
| | 4. Back-up procedures for seismic event data base. | RTS backed up to mine's IT server periodically. IMS keeps all events and 3 months of sgrams. | ✓ |
| | 5. Standardisation of Magnitude relation with neighbouring mines. | Anglo standard (Stankiewicz Mag). | ✓ |
| | 6. Access to SANSN data for larger events. | No direct access, but previously exchanged info by phone (regional event). | ✓ |
| | | | 4/4*30%=30% |
| 3. Event and rockburst analysis and reporting | 1. Data analysis by mine seismologist. | Yes (IMS service). | ✓ |
| | 2. Seismic hazard and risk quantification. | Low seismic hazard, approx. 2 events per day; no event polys, but capacity exists should seismic response increase. | N/A |
| | 3. Periodic reporting to management and production sections. | Daily and monthly report by IMS; monthly RE report to management; occasional back analysis of larger events. | ✓ |
| | 4. Rockburst data gathering and analysis, including mine plans. | No RBs experienced yet, but capacity exists and is currently used for FOG investigations. | ✓ |
| | 5. Rockburst data base complete, accurate and consistent. | N/A (no damage observed). | N/A |
| | 6. Regular practice review and quality management procedures for data collection. | Internal AngloPlats RE audit. | ✓ |

| **Total** | | | **91%** |
|---|---|---|---|

★ Bonus question: Were calibrations blasts used to calibrate source parameters, e.g. location accuracy? __No, but planned.___

**Notes:**

- 6 panels on MER (deep section, down to 1 480m b.s.), 82 panels on UG2 (shallow to intermediate, 45m middling);
- Faults and dykes mentioned in CoP as potential sources of seismicity;
- 1 surface plus 5 u/g sites; upgraded to SYNAPSE.
- $M_{max}$=1.7 to date
- No rockbursts experienced
- Confidentiality: Not requested.

**Additional data, information and documents made available by the mine:**

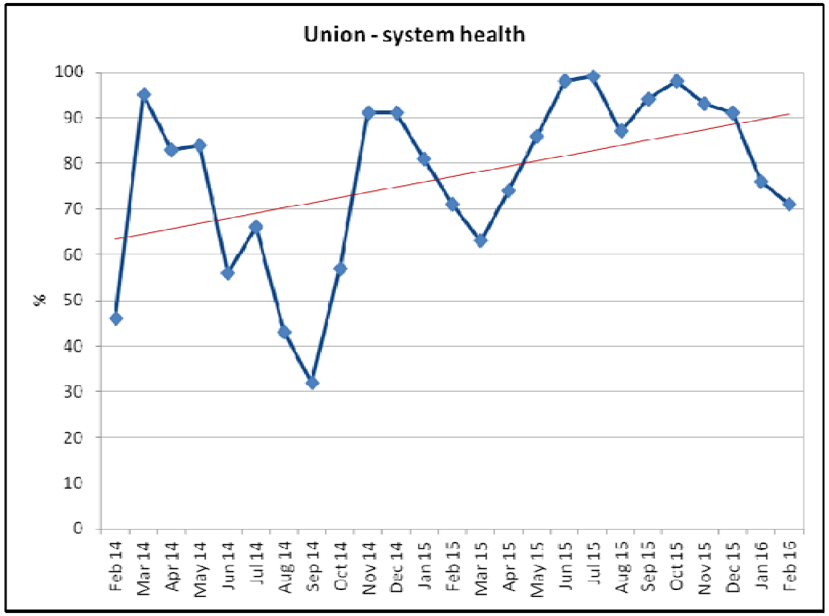
Sample monthly report (UNM-REP-MNTH-20160128-RCv0.pdf, UNM-REP-MNTH-20160428-RCv0.pdf)

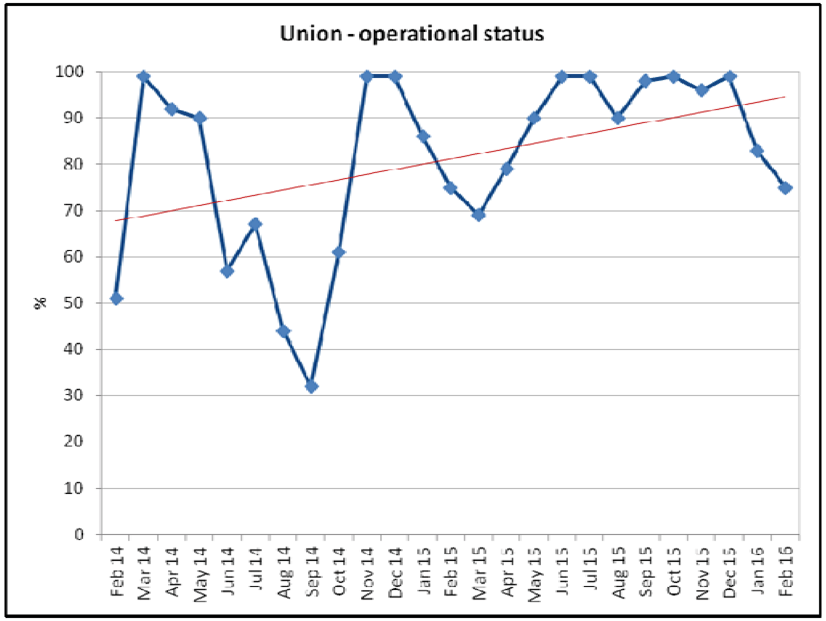
Sample day shift report (IMS, UNM-REP-PL-20160427-IMSv0.pdf, UNM-REP-PL-20160428-IMSv0)

1 year of accepted seismic events

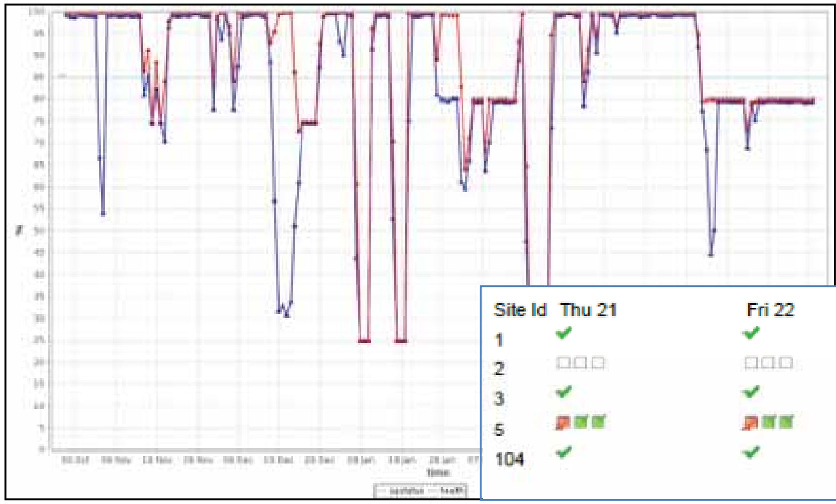
CoP Chapter 4.3.3 “Seismological Setting of the Mine”.

System status and station health report (30/11/2015 – 1/3/2016):

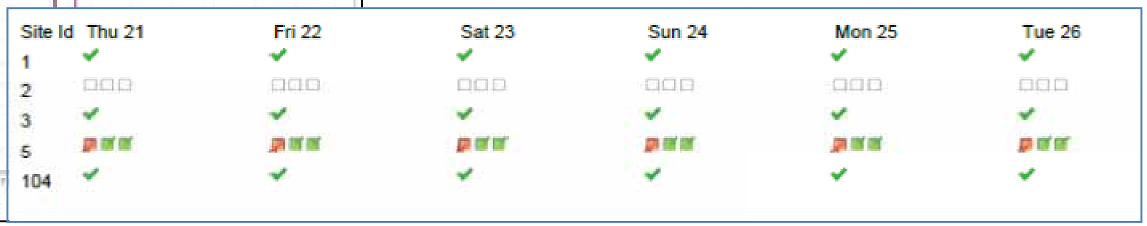


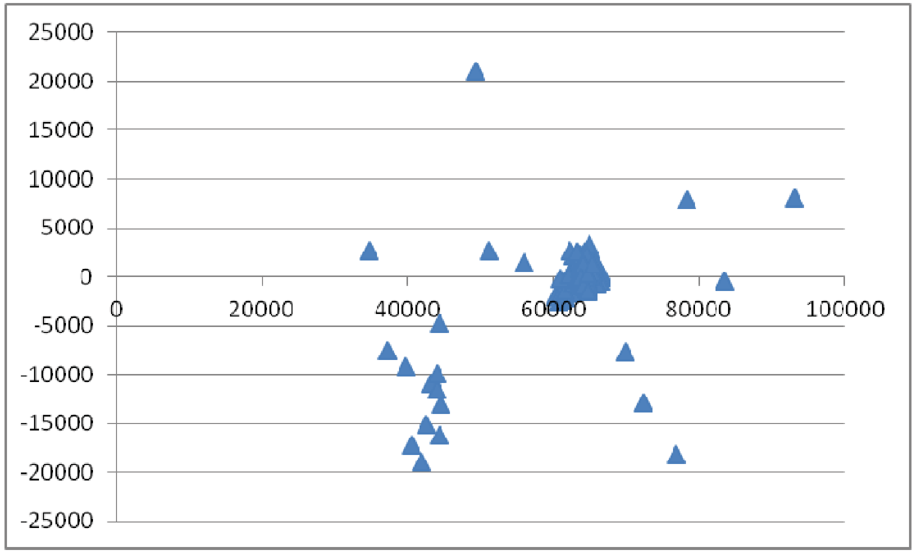

Station status and system health Nov-2015 to Apr-2016):



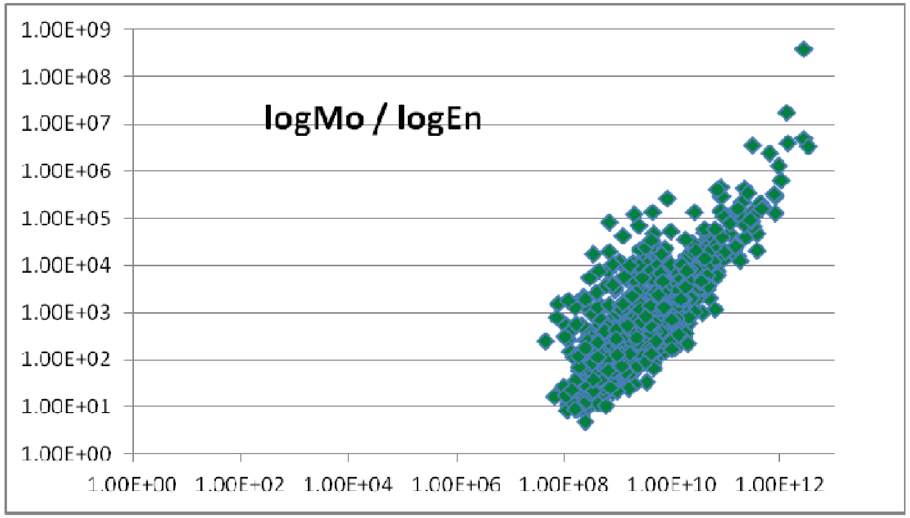
System health and station status (21-26 April 2016):



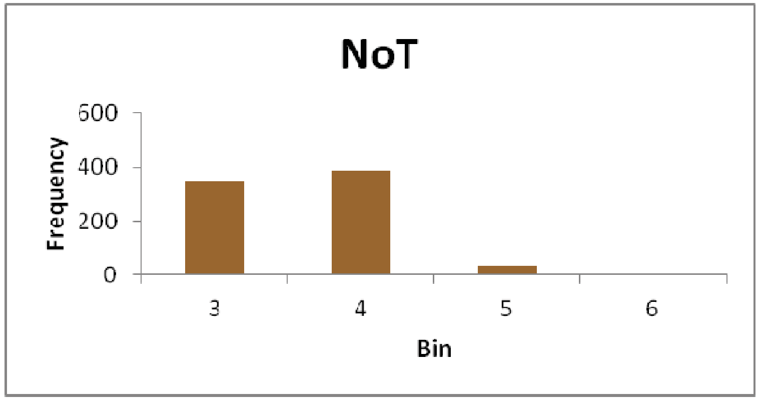
Location accuracy:



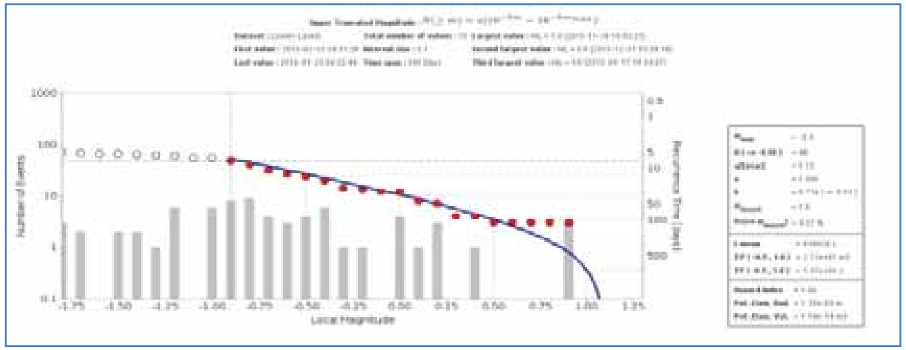

EnMo correlation




Number of triggers associated:




GR plot MER mining polygon ($M_{min}$=-0.9):



# 19. APPENDIX V

**Table 25:** Distribution of training material sets for mine rock engineering personnel

| WBV: | Staff | % | Out of 280 | Allocation | *Collector* |
|---|---|---|---|---|---|
| Impala | 43 | 22% | 61 | 55 | Luigi Ferreira |
| Amplats | 71 | 36% | 100 | 95 | Wynand JvR |
| LONMIN | 37 | 19% | 52 | 50 | M du Plessis |
| RBPM | 10 | 5% | 14 | 19 | Theresa |
| Northam-Z | 10 | 5% | 14 | 15 | Noel Fernandes |
| 6 | | | | | |
| | **Estimate (No feedback)** | | | | |
| | | | | | |
| **EBV/NBV:** | | | | | |
| TwoRivers | 7 | 4% | 10 | 11 | Petrie Wessels |
| Northam-B | 2 | 1% | 3 | 5 | Noel Fernandes |
| Marula | 5 | 3% | 7 | 10 | Godwin Hlungwe |
| Modikwa | 5 | 3% | 7 | 10 | " " |
| Twickenham | Amplats, incl above | | | | |
| Bokoni | 4 | 2% | 6 | 6 | Bertus vd Kevie |
| Ivanplats | 4 | 2% | 6 | 6 | Adam Cooper |
| | | | | | |
| | 198 | | 280 | 282 | |
| | | | | | |
| Allocation ratio: | 1.42 | | | | |
| | | | | | |
| <u>Other stakeholders:</u> | | | | | |
| MHSC | Wits | Others | | | |
| CGS | NUM | 1 | | | |
| OHMS&ESG | DMR | 2 | | | |
| Univ. of PTA | IMS | 3 | | | |
| Middindi | RETC | 4 | | | |
| | | 14 | | | |