SIM140204: Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2

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ACKNOWLEDGEMENTS
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- AngloGold Ashanti for their contribution and assistance during the calibration/comparison of the data.
EXECUTIVE SUMMARY

In lieu of the pending decision concerning phase 2 and post the final day of the contract for phase 1 with MHSC, the Council for Geoscience (CGS) in good faith continued to maintain and operate the stations within the KOSH region, curate and update the database, assign analysts to analyse and validate the earthquake locations, liaise with mines for data for the calibration of the KOSH data and maintain and improve the website and earthquake alerts.

During the period of the project, the CGS continued to maintain and operate the KOSH network and also procured spare equipment for quick deployment if and when necessary. The spare equipment will insure a continuous recording of the seismicity within the KOSH region should any of the stations malfunction. In addition, replacement equipment was procured through the CGS insurance for the vandalised station. Efforts are being made to relocate the stations which are situated on abandoned mines in order to reduce the occurrence of future incidents of vandalism.

One of the outputs of the project is the integration of the KOSH/CGS data with the mining data. An important step in the integration of these two datasets is the evaluation of the similarities and differences between them.

To this end, the CGS received a catalogue of processed events from the Great Noligwa seismic network, operated by Anglo Gold Ashanti (AGA), for a period from 12 December 2012 to 28 August 2014. When comparing the networks, it was found that the estimates of the Mw magnitudes by both networks are almost identical for practical application. Similarly, the scalar seismic moments offered by both networks are also very similar, with a tendency to underestimate by the AGA network in comparison to the CGS network. In addition, the radiated seismic energy estimation by both networks follows the same trend; in the range varying from $10^3$ to $10^{12}$ J, however there is a significant scattering in the value of the estimated energy observed.

Further analysis of the data showed that the corner frequencies offered by both the networks are significantly different, which could be attributable to the different instrumentation or applied processing. Added to that, when the data was plotted, it was noted that the AGA data provided a sharp delineation of the geological features in the area, while the CGS data was less distinct. However, the locations from both of the networks revealed a very similar pattern and thus the event locations obtained by the AGA network can be used as a reference for the CGS network.

The conclusion of the project was marked by a workshop which was held in order to brief the stakeholders on the progress of the project. The workshop took place on 12 June 2015 in Muldersdrift and all stakeholders were invited. The workshop not only aimed at updating the stakeholders on the progress but also opened discussions on the way forward for the project. It was very successful and a number of suggestions were made, such as expanding the network into the platinum and Free State mining regions, installing stations underground and developing an accurate velocity model in order to improve the depth calculations of the CGS network.
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1. PROJECT INTRODUCTION

Project Aims

The ultimate aim of this project is an:

Extended South African National Seismograph Network (SANSN) into the mining districts for improved accuracy of the locations by the SANSN of mine related seismic events.

Integrated database of available seismological information from the South African National Seismograph Network and mining networks for research into mine seismology.

Project Hypothesis

The extended SANSN will provide improved accuracy of the locations of mine related seismic events, which will be published in seismological bulletins and on a website.

Real time location of mine related seismic events will be beneficial for investigating and dealing with seismic related accidents.

The calibration/comparison of the data with the data from the mines will result in a comprehensive database on mine related seismic event occurrences, which will be utilised for research focused on minimizing the risk of seismicity, rockbursts and rockfalls and their impact on the lives of miners.

Project Methodology

Task 1: In lieu of the pending decision concerning phase 2 and post the final day of the contract for phase 1 with MHSC, the CGS in good faith continued to:

- maintain and operate the stations,
- curate and update the database,
- assign analysts to analyse and validate the earthquake locations,
- liaise with mines for data for calibration of KOSH data and
- maintain and improve website and earthquake alerts.

Task 2: Maintaining existing networks

The CGS will procure equipment to act as spares for the newly installed KOSH network.

The installed equipment will be maintained through regular maintenance visits and the occasional ad hoc repair visits, if and when required.

Task 3: Integrated database

The software procured in Phase 1 will provide automatic locations of the mining related seismic events recorded in the KOSH region. These automatic locations as well as the final
locations analysed by a trained analyst will be available on a website for the stakeholders to view. Ultimately, the goal is that this information will be highly beneficial for investigations into seismic related accidents.

Data from the KOSH network will be calibrated/compared against the data from the mines. This will enable the CGS to improve the locations of the network, which will assist in monitoring the area post closure of the mines.

As with the equipment, the database must be maintained, backed up and regularly upgraded in order to accommodate for additional data and potential changes in data format.

**Task 4: Stakeholder workshop**

The conclusion of phase 2 is marked by a workshop which reported to the stakeholders the progress of the output. The workshop aims to provide feedback on the status of the database in order to ensure that technology transfer will occur not only with the researchers, but also with the stakeholders involved such as the mining fraternity and the Department of Mineral Resources.

**Task 5: Project management**

The CGS team will meet with the MHSC and carry out any reporting required while also liaising with the mining companies.
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Project Milestones

<table>
<thead>
<tr>
<th>NO.</th>
<th>ENABLING OUTPUT</th>
<th>MILESTONE START &amp; END DATE (MM/YYYY)</th>
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<tbody>
<tr>
<td>1.</td>
<td>Output 1: In lieu of the pending decision concerning phase 2 and post the final day of the contract for phase 1 with MHSC, the CGS has in good faith continued to:</td>
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<tr>
<td></td>
<td>- maintain and operate the stations,</td>
<td>07/2014</td>
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<td>- curate and update the database,</td>
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<td>- assign analysts to analyse and validate the earthquake locations,</td>
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<td>- liaise with mines for data for calibration of KOSH data and</td>
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<td>- maintain and improve website and earthquake alerts.</td>
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<td>2.</td>
<td>Output 2: Maintaining existing networks</td>
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<td>2.1 Spare equipment for KOSH network</td>
<td>07/2014 – 06/2015</td>
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<td>3.1 Calibration using data from AngloGoldAshanti and license renewal</td>
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<td>4.</td>
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<td></td>
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<td>06/2015</td>
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<td></td>
<td>5.1 The CGS shall liaise with the mines concerning the data for the database</td>
<td>07/2014 – 06/2015</td>
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<td></td>
<td>5.2 Draft final report</td>
<td>06/2015</td>
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<tr>
<td></td>
<td>5.3 Final Report</td>
<td>2 weeks after receiving review of draft report</td>
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Champion Mines
All mines in the Klerksdorp-Orkney-Stilfontein-Hartbeesfontein (KOSH) region will be used in the first year of this second phase, thereafter other mining regions will be involved.
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2. MILESTONE DELIVERABLES

2.1 MILESTONE 1 - Continued maintenance of the network in lieu of the pending decision concerning phase 2 and post the final day of the contract for phase 1

Introduction to Milestone 1
Once the contract for phase 1 ended, the CGS continued to maintain and operate the stations within the KOSH network, curate and update the database of events, assign analysts to analyse and validate the earthquake locations, liaise with the mines for data to use for calibration of the KOSH data and maintain and improve the website and earthquake alerts.

Milestone 1 Results
During the interim period between contracts, the stations continued to send data to the data centre at the CGS offices where the automatic locations were recorded and later verified by analysts.
Unfortunately, one of the stations was vandalized and the incident was reported to the police, a case number was obtained and the CGS claimed the costs of the equipment back from the CGS insurance.
The automatic and verified locations were saved to the database and backed up.
The locations are continuously reflected on the website.
Contact was maintained with AngloGold Ashanti and data was obtained from them.

Milestone 1 Conclusions
The continuation of the operations of the network insured that there was no gap in the database and thus a complete record of data is available since the network was commissioned. This data is quite unique and is proving to be a very useful source for research into the seismicity in mines as was proven after the M=5.5 earthquake on 5 August 2014.

2.2 MILESTONE 2 - Maintaining existing networks

Introduction to Milestone 2
In order to obtain a continuous record of data from the KOSH region where the 25 seismological stations were installed, the CGS maintained the equipment in order to insures optimal operation. The CGS also insured that the data was acquired and stored in the database located at the CGS offices.

However, in order to insure fast turn-around times should a station malfunction, spare equipment is required to enable rapid swapping of station components.
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Milestone 2 Results

The CGS thus procured 5 digitisers and 5 episensors to act as spares for the stations within the KOSH region. In addition, 1 digitiser was procured in order to replace the one that was vandalized, however this cost was covered by the CGS insurance (see Appendix A for the commercial invoice of the equipment).

The new equipment has been tested and is ready to be deployed when required.

Milestone 2 Conclusions

The KOSH network continues to be maintained by the CGS and the spare equipment will insure smooth and continuous functioning of the stations and will allow time for the CGS to ship faulty equipment back for repairs.

2.3 MILESTONE 3 - Integrated database

Introduction to Milestone 3

The Council for Geoscience (CGS) provides maintenance and data processing for 17 seismic stations installed in the West, Central and East Rand Goldfields, 10 in the Far West Rand area (Carletonville area) and 25 in the KOSH area. It should be noted that more than 95% of the total seismicity in South Africa comes from mining districts.

Stations were installed during 2010 to monitor seismicity in the KOSH mining district. The cluster of 25 strong ground motion seismic stations greatly contributes to the improvement of the accuracy of location of mining events, allowing for identification of seismically active features in the mining district. It also provides standardized magnitude estimation in the mining district.

The cluster will facilitate an analysis of focal mechanisms determined from mining-related events and allow the regional stress field to be investigated. In addition, collected data will contribute to the development of a methodology to estimate the damage at the surface, which is a function of the fault geometry and the slip direction, complexity of the seismic source, local geology and the distance between source and surface infrastructure. The CGS is building a model for the prediction of ground motion from large and complex seismic events.

Processing of Seismic Data at CGS

The clusters of seismic stations are equipped with strong ground motion instrumentation appropriate for the recording of large mine related events. The seismic stations are based on Kinemetrics hardware and software. Kinemetrics provides real time monitoring and processing of strong ground motion data. The Antelope system is produced by Boulder Real Time Technologies, Inc. and marketed by Kinemetrics, Inc. The CGS Data Centre consists of several LINUX-based
computers running the Antelope system software. Antelope’s computers provide command and control of the remote seismic stations’ real-time application, off-line processing capabilities and data archiving. The Antelope Real-Time System integrates modules in order to provide automatic arrival detection, picking, association and event location. The database enables access to the data in both real-time and post-processing environments.

After automatic processing, the manual processing is performed by a group of analysts. The manual processing includes the reevaluation of the P-wave and S-wave picks and identification of missed events. The missed events are included into the database after picking the P- and S-waves and determining the location. Manual processing requires initial filtering to remove unwanted noise. The error in location reported by the CGS for mining activity is relatively small, usually of the order of less than one kilometre, and is a function of the number of stations that recorded the event, the resolution of the seismic phases as well as the accuracy of the velocity model.

To perform more advanced analyses, the software “Local Earthquakes” was developed for calculating spectral parameters of the seismic source using the MATLAB environment (Cichowicz and Birch, 2012). MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. The software that was developed used several functions from the signal processing tool box. Several GUIs were developed to interactively process event waveforms using MATLAB tools. In order to run this software, the MATLAB Development Environment is required. The “Local Earthquakes” software estimates seismic source parameters by fitting the observed spectra into theoretical (synthetic) spectra of the P- and S-waves. The seismic source is then parameterized to obtain spectral characteristics, such as: seismic moment, magnitude, corner frequency, seismic energy, source radius and static stress drop. Before processing starts, several parameters, which are unique to the data set, have to be defined. These include: the geometrical spreading between source and station, P- and S-wave velocities, attenuation functions, site effect function, parameters of the instrument used to record the data and several parameters used to control the calculation of the spectra. Several subroutines were developed to automatically find the seismograph station ID and relevant sensor type. The “Local Earthquakes” software has an interface to enable the reading of data created by both SEISAN and Antelope systems which are both used at the CGS.

Comparison of Seismic Sensors Characteristic Used by the AGA and CGS networks

The AGA network’s location of a seismic event is very accurate to within a few hundred meters due to the density of the networks that are located at different depths. Mining networks are generally equipped with a combination of 4.5 Hz, 14 Hz geophones and accelerometers, which are suitable for locating small, high frequency seismic events and for estimating seismic source parameters of these events (Cichowicz, 2001). However, sensors used by the mines are not suitable to record low-frequency seismic signals that are necessary for analyzing the source parameters of large seismic events. Mining networks are unable to monitor the ground motion on
the surface, which contributes significantly to damage. The magnitude scales that are used by mines to calculate the size of seismic events are not always correlated with either the different mining houses or with the Local Richter Scale.

The most suitable source model for regional data is a point source model, where the source time function is described by a kinematic or semi-kinematic model of the rupture plane. Most applications of body wave spectra of the seismic source are modeled using Brune's (1970, 1971) approximation. Brune's source model is an instantaneous shear release from a circular crack. Brune's amplitude spectrum has the following form for the S-wave and the P-wave:

$$S(f) = \frac{1}{1 + (f/f_0)^2}$$

where \(S(f)\) is the P- or S-wave displacement spectra according to Brune's model, \(f_0\) is the corner frequency. The asymptotic value of Brune's model at low frequencies is given by the plateau of the displacement spectrum for the P-waves or S-waves. Figure 1 shows the model of seismic source spectra (see equation 1). The low frequency plateau is proportional to scalar seismic moment. The decay part of the spectrum provides information about source size and fracture properties. The perfect seismic sensor should record both the plateau and decay part of the spectrum.
Figures 2 and 3 show the normalized displacement spectrum of Brune’s model for magnitude range varied from 1 to 3 and for the static stress drop varied from 0.01 MPa to 100 MPa. The blue area indicates regions of the frequencies where the mining networks do not record due to sensor limitation (see Figure 2) and the CGS network does not record due to sensor limitation (see Figure 3). The 4.5 Hz geophone used by mining network is suitable for estimation of spectra plateau for $M = 1$ and almost for all $M = 2$, however $M = 2.5$ and 3 are recorded well only for large stress drops. The sensors used by the CGS network will record full spectrum from magnitudes 1.5 to 6.0. Strong ground motion accelerometers have a frequency range from DC to 100 Hz.

![Figure 2. Limits of applicability of 4.5 Hz geophones used by mining networks. The geophone is suitable for estimation of the spectra plateau for $Mag = 1$ and almost for all $Mag = 2$. However, $Mag = 2.5$ and 3 are recorded well only for large stress drops.](image)
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Figure 3. The CGS sensor will record the full spectrum from Mag 1.5 to 6.0. Strong ground motion accelerometers have a frequency range from DC to 100 Hz.

Method for the Estimation of Source Spectral Parameters.

Software was developed to calculate the following parameters of the seismic source model: the scalar seismic moment, moment magnitude ($M_w$), radiated seismic energy, corner frequency, source radius and the apparent and static stress drops. A more detailed description of the software can be found in Cichowicz and Birch (2012).

The software has the capability to consistently process three component waveforms recorded by accelerometers and/or geophones. Windows containing the P- and S-wave groups are extracted from all suitable waveforms to provide a robust estimation of the seismic source parameters. Scalar seismic moments for P-wave and S-wave and corner frequencies, $f_{op}$ and $f_{os}$, are calculated using Brune’s amplitude spectrum for the S- and P-wave:

$$S_s(f) = \frac{\Omega_0s}{1 + (f/f_{os})^2}$$

$$S_p(f) = \frac{\Omega_0p}{1 + (f/f_{op})^2}$$
where $S_p(f)$ and $S_s(f)$ are the P- and S-wave displacement spectra according to Brune’s model. The asymptotic value of Brune’s model at low frequencies is given by the plateau of the displacement spectrum $\Omega_0$, for the P-waves, $\Omega_{0p}$ and S-waves, $\Omega_{0s}$. The value of the flat part of the displacement spectrum, $\Omega_0$, is proportional to the seismic moment $M_0$. In conclusion, only two independent parameters: $f_0$ and $\Omega_0$ are used to characterize the simplified observed spectrum shape for the P- and S-waves.

The scalar seismic moments, $M_{0p}$ and $M_{0s}$ are obtained from $\Omega_{0p}$ and $\Omega_{0s}$.

The source dimension is proportional to the pulse width of the displacement signal. To determine the fault radius, $r$, from the displacement spectra a relationship given by Brune (1970, 1971) is used.

$$ r = \frac{k V_s}{2 \pi f_{0s}} $$

$$ r = \frac{k V_p}{2 \pi f_{0p}} $$

where $k = 2.34$ for S-waves and $k = 1.92$ for P-waves. This relation was subsequently corrected by Madariaga (1976, 1979).

Assuming a complete stress release, in the context of a kinematic source model, Brune’s model estimates for the stress drop are given by Kelis-Borok (1959) and Brune (1970 and 1971).

$$ \Delta \sigma = \frac{7}{16} \frac{M_0}{r^3} $$

where $\Delta \sigma$ is the static stress drop. Models used for static stress drop estimations assume a fixed value for the rupture velocity and represent the uniform reduction in shear stress acting to produce seismic slip over a circular fault.

The estimation of the magnitude is of fundamental importance. Magnitude $M_w$, based on the seismic moment is calculated from $M_0$ (Hanks and Kanamori, 1979).

$$ M_w = \frac{2}{3} \log_{10} M_0 - 9.1 $$

where $M_0$ has the units Nm. There are a number of formulas describing the relation between $M_0$ and $M_L$ for various sets of observations.

**Milestone 3 Results**

Relationships between Spectral Parameters Obtained from the AGA and the CGS Networks.
As it was pointed out in the previous part of this report, seismic events recorded by the two networks should have similar values of spectral parameters for magnitudes varying from 1.0 to 3.0. The important step in the integration of these two databases is the evaluation of similarities and differences between them.

The spectra observed by the CGS network have to be corrected for attenuation. Accurate evaluation of attenuation is important to evaluate a magnitude for earthquakes, source dimension and radiated seismic energy. Cichowicz and Birch (2010) conducted a detailed study of attenuation in the KOSH area. The Q-coda and the coda normalization techniques were applied to evaluate the attenuation. The best fit model parameters for $Q_c^{-1}(f)$ for the three components are: $Q_c^{-1}(f)_{Z}=0.0135 f^{-1.14}$, $Q_c^{-1}(f)_{N}=0.0141 f^{-1.18}$ and $Q_c^{-1}(f)_{E}=0.0115 f^{-1.14}$ where $Q_c^{-1}(f)_{Z}$, $Q_c^{-1}(f)_{N}$, and $Q_c^{-1}(f)_{E}$ are the frequency dependent quality factors for the three component data and $f$ is the frequency. The coda normalization method was extended to include optimal parameters of the geometrical spreading used to obtain the quality factors. A detailed derivation of methodology is presented together with its application to real data in Cichowicz and Birch (2011).

CGS received from AngloGold Ashanti a catalogue of processed events from the Great Noligwa seismic network for a period from 12 December 2012 to 28 August 2014. During that period the CGS network was operational, therefore the comparison of databases was possible. The AGA network records seismic events with much smaller magnitudes than 1.0. The CGS network did not record these smaller events because its sensors are located on the surface which is at a distance where the signals from the events are attenuated. Together with the AngloGold Ashanti catalogue, the CGS received the list of sensors used by the mining network. The Great Noligwa seismic network has mostly 4.5 Hz geophones and a few accelerometers.

The mining networks use a local Cartesian system for expressing the locations of the seismic events. The CGS, on the other hand, according to international seismological standards, uses the geographical coordinate system. Therefore, in the first step a new function was written to convert the local Cartesian system to the geographical coordinate system. Table 1 shows constants added to the central meridian $L_0 27^0$ and depth for the West Wits and Vaal River. Since 1 January 1999, the official co-ordinate system for South Africa is based on the World Geodetic System 1984 ellipsoid, commonly known as WGS84, with the coordinate of the Hartebeesthoek Radio Astronomy Telescope used as the origin of this system. The datum is known as the Hartebeesthoek94 Datum. The WGS84 reference ellipsoid is used for all calculations. The reference ellipsoid parameters are $a = 6378137.000$ m and $b = 6356752.314$ m, where ‘$a$’ is the semi-major axis of the reference ellipsoid and ‘$b$’ is the semi-minor axis of the reference ellipsoid. The equations used for conversion are based on the Gauss Conformable coordinate ($y,x$) conversion to Geographical coordinate (longitude, latitude) (see Parker,2011/2012 ).
The relationship between the mine $M_w$ and the CGS $M_L$ magnitudes is presented in Figure 4. This relation is very important for the comparison of data from mining networks with data from the CGS network. $M_L$ magnitude is usually used by national networks around the world. There is a pleasant surprise that the relationship is very simple and, therefore, easy to apply:

$$M_{mine} = 0.68 \times M_{CGS} + 0.43$$

The correlation coefficient between two magnitudes is very high and is equal to 0.94.

The relationship between $M_w$ magnitudes obtained using data from the mining network and from the CGS network is presented in Figure 5. This relation is very close to one, therefore in the practical application we can state that both the $M_w$ magnitudes can be used interchangeably. It should be noticed, that Figure 5 includes the largest event observed in the mining district of magnitude $M_L = 5.5$. The value is according to CGS records and very close to values obtained by an international monitoring organizations.
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(5.4 or 5.3 ). At the same time, the mining network observed two events of $M_w$ magnitude 3.7. Thus, the mine’s 4.5 Hz geophones were not able to adequately record the 5.5 M event.

![Magnitudes Comparison](image)

Figure 5. Relationship between $M_w$ magnitudes’ estimation obtained by two networks in the full magnitude range from 0.8 to 5.5.

To get more realistic relationship between the $M_w$ estimations obtained by the mine software and the CGS software, the 5.5 magnitude, which is an outlier, was excluded from the comparison. Figure 6 shows the comparison between both estimations of $M_w$ between the magnitude range from 0.8 to 3.5. The relationship is even closer than that shown in Figure 5.
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![Magnitudes Comparison](image)

**Figure 6.** Relationship between $M_w$ magnitude estimation obtained by the two networks in the magnitude range from 0.8 to 3.5.

Figures 7 and 8 show the relationship between the scalar seismic moments obtained from both networks. The scalar seismic moment obtained by the CGS network has the tendency to be larger than that obtained from the mine network. This tendency is extremely strong for the larger event with magnitude 5.5. Fortunately, the shift is very small so it does not influence the estimation of $M_w$ magnitude significantly (see Figure 6).
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008.Phase 2”.

**Figure 7.** Relationship between scalar seismic moment estimation obtained by two networks using the S-wave signal where the red line indicates a one-to-one relationship.

**Figure 8.** Relationship between scalar seismic moment estimation obtained by two networks using the P-wave signal where the red line indicates a one-to-one relationship.

The relationship between seismic energy of the mine S-wave and the CGS SV-wave is presented in Figure 9. The range of the SV-wave energy is from $10^3$ to $10^{12}$ J. Both estimations scatter symmetrically around the red line indicated in Figure 9. This indicates that there is not a systematic shift between the networks.
Therefore, both networks similarly record the frequency content responsible for estimation of seismic energy for seismic events above magnitude one. Additionally, the estimation of seismic energy is very sensitive to the attenuation correction which is used and it could be concluded, that, since there is such a close correlation between the networks, the attenuation corrections used by the networks, although different, are suitable.

Figure 9. Relationship between the radiated seismic energy estimation obtained by two networks using the S-wave signal where the red line indicates a one-to-one relationship.

The ratio of radiated energy to seismic moment, multiplied by the shear modulus yields the apparent stress. It should be noted, that the seismic moment, seismic energy and apparent stress estimations are not model dependent. Figure 10 shows the relationship between the apparent stress drops estimated by two networks. The CGS estimation is, on average, larger than the estimation obtained by the mine network. The shift is caused by similar shift in the scalar seismic moment.
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

Figure 10. Relationship between the apparent stress drop estimation obtained by two networks using the S-wave signal where the red line indicates a one-to-one relationship.

Figure 11 shows the relationships between the corner frequencies obtained by the two networks. There are significant differences. The mining network has a clear cut off at 10Hz. The CGS network estimates the corner frequencies for the group of events within the range varying from 6 to almost 30Hz, while the mining network has an almost fixed value of 10 Hz. The second feature is that the mining network corner frequency is up to 200Hz, while the CGS maximum corner frequency is around 50Hz. Both the differences are caused by instrument limitations. The mining network distorts the corner frequency below 10 Hz and the CGS network distorts the corner frequency above 50 Hz.
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008.Phase 2”.

Figure 11. Relationship between the corner frequency estimations obtained by two networks using the S-wave signal.

The relationship between the seismic moments and corner frequencies is one of the most important characteristics of seismic parameters for a studied area. Figure 12 shows seismic moment versus corner frequency for the S-waves. The diagonal lines follow constant stress drops. The data from the CGS shows a cluster lying between the constant stress drops varying from 0.01 MPa to 10 MPa. The CGS cluster follows a pattern observed typically in seismological investigations.

The dense underground mining network provides better locations than the CGS network which is located above ground and covers the whole KOSH area. The mine location could be used as a reference location and thus the comparison was made between the CGS location and the reference location. The best example for testing the CGS locations is provided by the very characteristic pattern of aftershocks associated with the M=5.5 earthquake in August 2014.
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

Figure 12. The relationships between scalar seismic moment and corner frequency for data from the KOSH network. The lines of constant static stress drop $\Delta \sigma$ are shown as diagonal blue lines (Top) Data for the mine network (Bottom) Data for the CGS network.

The spatial patterns of seismicity associated with the aftershocks of the magnitude 5.5 earthquake are shown in Figures 13 and 14 for the time window: 2014/05/08 - 2014/05/25. The size of the dots is proportional to $M_w$ magnitude. The location of the events recorded by both networks reveals a very similar pattern. The mine network delineates the fault with a higher accuracy but both networks offer the same distribution on a plan view and with depth intersection.
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

Figure 13. Epicenters of aftershocks in the KOSH area for time window from 5 August 2014 to 25 August 2014. (Top) Data for the mine network (Bottom) Data for the CGS data.
Final Report on “SIM 140204 - Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

Figure 14. Vertical cross section (E-W versus depth) of the locations of aftershocks in the KOSH area for time window from 5 August 2014 to 25 August 2014. (Top) Data for the mine network (Bottom) Data for the CGS network.
Milestone 3 Conclusions

The estimated Mw magnitudes from both the AGA and CGS networks are almost identical for practical application. Similarly, the scalar seismic moments offered by both networks are comparable, but with a tendency to underestimate by the mine network in comparison to the CGS network. In addition, the radiated seismic energy estimated by both networks follow the same trends, however, in the range varying from $10^3$ to $10^{12}$ J, significant scattering of the estimated energy value is observed.

When considering the corner frequencies offered by both the networks, the observation is that they are significantly different. This could be attributed to the different instrumentation or applied processing. This difference is also observed when summarising the processing of spectral parameters by the networks because it is usually presented as the relationship between the scalar seismic moments versus the corner frequencies. This relation calculated for the CGS network is very similar to those that are usually observed within international seismological investigations.

Thus, the locations obtained by the AGA network can be used as a reference for the CGS network, especially since the locations from the AGA network provide a sharp delineation of the geological features in the area, while the CGS data is less pronounced.

2.4 MILESTONE 4 - Stakeholder workshop

Introduction to Milestone 4

In order to update the stakeholders on the progress of the project, the MHSC and CGS organised a workshop in which discussions on the project could be held and previous products developed for the project displayed. A similar workshop was held at the end of Phase 1.

Milestone 4 Results

An agenda and invitation letter was sent to the stakeholders to alert them of the workshop (please see appendix B and C). The agenda was short because the number of milestones in Phase 2 were not as many as previously in phase 1 and thus the workshop only lasted half the day.

The workshop was attended by a number of people (see Appendix D for attendance register) and consisted of one presentation from the MHSC and two presentations from the CGS. In addition, the delegates were honoured by the presence of a visiting professor from Japan, Prof Hiroshi Ogasawara, who presented a talk on his team’s work within the South African mines.

The presentations were followed by a discussion session in which the way forward was proposed.
Throughout the workshop, the website and the automatic alert system, which were both designed in phase 1, were on display.

**Milestone 4 Conclusions**
The workshop covered many of the aspects in Milestones 1 to 4, and it was widely acknowledged that the database proved to be a very useful source for research into the large magnitude 5.5 event that occurred in August 2014. The event sparked a very good collaboration between AngloGold Ashanti and the CGS and Prof Hiroshi Ogasawara.

It was also highlighted during the workshop that the comparison of the data from the two networks was surprisingly similar and indicated that the data from the KOSH network is of superior quality. However, the differences between the two should be further investigated.

During the discussion session, the following questions/comments were raised from the delegates:

- What are the advantages of having this network to the local community?
- How does load shedding affect data acquisition?
- How do we monitor the stations’ performance?
- Will the CGS be releasing large event data on the website?
- Modeling of big event shows that mining could not have caused the event
- Are we doing FIS research in other regions, especially KOSH
- Mentioned that FIS can cause larger events than mining because the events occur on large geological features.
- There was a suggestion that the network expands into the Platinum and Free State mining regions.
- Impacts of illegal mining
RECOMMENDATIONS FOR FURTHER RESEARCH

The recommendations from all the milestones are as follows. The following are recommended:

- Perform similar comparisons, where recorded data are available, between cluster network data and mining data for other regions, such as Carletonville.
- Conduct detailed studies to explain the observed differences in the estimation of spectral parameters between the two networks. Observing the mining data processing centre would perhaps assist in assessing the similarities in the processing of seismograms.
- Improve the velocity structure model for more accurate locations of the CGS network, especially for post mine closure monitoring.
- Install one or two seismological stations underground where possible.
- Carry out a similar monitoring project in other regions, such as Platinum mining region in order to build up a good database of information before the mining gets deeper.

CONCLUSIONS

The KOSH network is fully operational and has been well received by the stakeholders. The importance of the network was highlighted after the magnitude 5.5 earthquake on 5 August 2014, where the data was available and was merged with other mining data in order to better understand the mechanisms of the earthquake.

When comparing the data with the mining networks, it was very rewarding to notice the similarities between the two sets of data. The differences between the data can be addressed via improved velocity structure models.

The stakeholders were very positive about the project and encouraged similar studies in other mining regions, such as Platinum and Free State.

Thus, in conclusion, Phase 2 was successfully completed and it is highly recommended that the project expands to other mining regions, such as the Platinum and Free State mining areas.
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

WEB PAGE

The following website has been designed for this project and displays the automatic locations in the KOSH region:

http://197.96.144.124/seismicevents
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008.Phase 2”.

REFERENCES

Cichowicz, A. 2001, Quantification of complex seismic sources, Rockburst and Seismicity in Mines-RaSiM5, South African Institute of Mining and Metallurgy, 91-97


Cichowicz, A. and D. Birch, 2012. Estimation of Seismic Source Parameters milestone of project "Fluid-Induced Seismicity in the Central Basin Area: Ground Motion Prediction and the Development of an Early Warning System for Risk Reduction"


Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

FINANCIAL SUMMARY

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<td>1.1</td>
<td>- maintain and operate the stations,</td>
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<tr>
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<td>- curate and update the database,</td>
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<td>- assign analysts to analyse and validate the earthquake locations,</td>
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<tr>
<td></td>
<td>- liaise with mines for data for calibration of KOSH data and</td>
<td></td>
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<tr>
<td></td>
<td>- maintain and improve website and earthquake alerts.</td>
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| 2.  | Output 2: Maintaining existing networks | |
| 2.1 | Spare equipment for KOSH network | 150,000 | 1,541,890.59 |

| 3.  | Output 3: Integrated database | |
| 3.1 | Calibration using data from AngloGoldAshanti and license renewal | 308,585 | 312,500 |

| 4.  | Output 4: Stakeholder workshop | |
| 4.1 | Workshop on the integration of the networks | 220,500 |

| 5.  | Output 5: Project management | |
| 5.1 | The CGS shall liaise with the mines concerning the data for the database | 92,090 |
| 5.2 | Draft final report | 219,775 |
| 5.3 | Final Report | 439,550 |
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

**PROJECT CLOSURE**

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<td>Extended South African National Seismograph Network (SANSN) into the mining districts for improved accuracy of the locations by the SANSN of mine related seismic events. Integrated database of available seismological information from the South African National Seismograph Network and mining networks for research into mine seismology</td>
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<td>The SANSN has been extended into the KOSH region and the data has been compared and integrated with the data from the mining networks.</td>
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34
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

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<td>Recommendations to MHSC</td>
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<td>Report on MHSC Website</td>
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<td>Approval</td>
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Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

LIST OF APPENDICES

Appendix A: Commercial invoice of the equipment received.
Appendix B: Agenda of workshop.
Appendix C: Invitation letter.
Appendix D: Attendance register.
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

Appendix A: Commercial invoice of the equipment received.

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Insurance: 855.00

Total: CIF Johannesburg International Airport SOUTH AFRICA: 130,220.00

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Freight, carriage and documentation: 300.00

Insurance: 100.00

Total - DDP Johannesburg International Airport SOUTH AFRICA: 15,140.00

GRAND TOTAL: 125,370.00

Shipped via White-Robling

These commodities, technology or software were exported from the United States in accordance with the Export Administration Regulations. Shipment contrary to U.S. Law is prohibited.
Appendix B: Agenda of workshop

### Workshop on the SIM14-02-04 Project Entitled

“INTEGRATION OF THE SOUTH AFRICAN NATIONAL SEISMOGRAPH NETWORK AND DATABASE WITH MINING NETWORKS AS PER THE RECOMMENDATION IN CHAPTER 1 OF THE PRESIDENTIAL MINE HEALTH AND SAFETY AUDIT 2008 – PHASE 2”

**AGENDA**

**Venue:** Avianto hotel; Muldersdrift  
**Date:** 12th of June 2015  
**Time:** 08H30 – 14H00

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<th>Time</th>
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<td>1</td>
<td>Arrival, Tea and Registrations</td>
<td>Delegates</td>
<td>09:30 – 10:00</td>
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<tr>
<td>2</td>
<td>Welcome and introduction</td>
<td>SIMRAC</td>
<td>10:00 – 10:15</td>
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<tr>
<td>3</td>
<td>Presentation: Overview of the MHSC and 2014 OHS summit milestones</td>
<td>MHSC</td>
<td>10:15 – 10:45</td>
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<tr>
<td>4</td>
<td>Presentation: Introduction to SIM 14-02-04 and the progress thus far</td>
<td>CGS</td>
<td>10:45 – 11:15</td>
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<td>5</td>
<td>Presentation: Comparison of data from the mining networks and the KOSH network</td>
<td>CGS</td>
<td>11:15 – 12:00</td>
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<tr>
<td>6</td>
<td>Discussions and Way Forward</td>
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<td>7</td>
<td>Vote of thanks</td>
<td>SIMRAC Chairperson</td>
<td>12:50 – 13:00</td>
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<td>8</td>
<td>Lunch &amp; Networking</td>
<td>Delegates</td>
<td>13:00 - 14:00</td>
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Appendix C: Invitation letter

INFORMATION TO A WORKSHOP ON THE PROJECT SIM140204
“INTEGRATION OF THE SOUTH AFRICAN NATIONAL SEISMOGRAPH NETWORK AND DATABASE WITH MINING NETWORKS AS PER THE RECOMMENDATION IN CHAPTER 1 OF THE PRESIDENTIAL MINE HEALTH AND SAFETY AUDIT 2008 – PHASE 2”

Dear Sir / Madam

The MHSC would like to invite you to a workshop at the Avianto Hotel in Muldersdrift, at 09H30 on the 12th of June 2015.

The purpose of the workshop is to share the results of the project SIM 140204 “Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008 - Phase 2.”

Phase 2 was mainly focused on comparing data from both the Klerksdorp-Orkney-Stilfontein-Hartbeesfontein (KOSH) and mining networks, in order to enable improvements to the locations of the KOSH network, which will assist in monitoring the area post closure of the mines.

The target audience for the workshop include rock engineering practitioners, seismologists, geologists, production officials, mine managers and mine inspectors.

Please confirm your attendance by emailing Enoch Ntiakane at ertiakane@mhsc.org.za or Michelle Grobbelaar at michelle@geosciente.org.za by no later than the 5th of June 2015 at 12H00.

Kind regards

Mohlago Masekela
Acting Chief Research and Operations Officer

Attachments:
1. Programme for the workshop
Final Report on “SIM 140204- Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.

Appendix D: Attendance register

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<td></td>
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<tr>
<td>F. Eskoloe</td>
<td><a href="mailto:feskoloe@mines.org.za">feskoloe@mines.org.za</a></td>
<td>SIM H.C.</td>
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<tr>
<td>N. Naicker</td>
<td><a href="mailto:nn@mines.org.za">nn@mines.org.za</a></td>
<td>Gold Fields</td>
<td></td>
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<tr>
<td>D. Bheri</td>
<td><a href="mailto:dbheri@mines.org.za">dbheri@mines.org.za</a></td>
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<tr>
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<td><a href="mailto:gvanassewe@mines.org.za">gvanassewe@mines.org.za</a></td>
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Final Report on “SIM 140204 - Integration of the South African National Seismograph Network and Database with Mining Networks as per the recommendation in chapter 1 of the Presidential Mine Health and Safety Audit 2008. Phase 2”.