institute of mine seismology

33rd Mine Seismology Seminar

28 May – 2 June 2023, Asara Wine Estate, South Africa

Sunday 28 May 10h00 - 16h00	**Meeting of the International Research Advisory Board of the Institute of Mine Seismology**
Sunday, 18h00	Ice-Breaker including talk by Dr Gerrie van Aswegen on **History of Rockburst Studies in South Africa – a Personal Perspective**
Monday 29 May 08h45 - 18h00	**Mine Seismology Seminar Day1: Lectures and Presentations on the Intermediate and Short Term Seismic Hazard, Ground Motion Alerts and Re-entry** Keynote by Prof. Roel Snieder on **Measuring Variations in the Seismic Velocity as a Diagnostic of Rock Damage and Healing.**
Monday, 19h00	Dinner and Pre-dinner talk by Dr Steve Spottiswoode on **Reflections on 50 Years of Mine Seismology**
Tuesday 30 May 09h00 - 17h00	**Mine Seismology Seminar Day2: Lectures and Presentations on the Applications of Ambient Noise and Distributed Acoustic Sensing, DAS, in Mining.**

Training Courses, Asara Wine Estate, South Africa

Sunday 28 May 09h00 - 16h00	**Seismology Primer for Geotechnical Consultants,** IMS Seismologists
Wednesday 31 May 09h00 - 13h00	**Ground Motion and Rockburst Hazard in Underground Mines**, Dr Aleksander Mendecki and Dr Dmitriy Malovichko
Wednesday 31 May 14h00 - 17h00	**Numerical Modelling with Seismic Data: Mining Scenarios,** Jacques Gerber and Dr Dmitriy Malovichko
Thursday 1 June 09h00 - 13h00	**Ambient Noise Tutorials**, Prof. Roel Snieder, Head of the Center for Wave Phenomena, Colorado School of Mines
Thursday 1 June 14h00 - 17h00	**Modelling the Effects of Fluid Injection,** Dr Vladimir Lyakhovsky, Numerical Modelling Consultant
Friday 2 June 09h00 - 16h00	**Interpretation of Seismic Data with IMS Software,** IMS Seismologists

For more information on registration, accommodation and social programme please contact SanMarie.Botha@imseismology.org

Objectives of the Seminar

Considerable progress has been made in the quantification of seismic sources and in the quantification of seismicity. Most modern seismic systems are capable of locating seismic events accounting for rock mass heterogeneity, to quantify seismic sources by their potency and energy and to invert for source mechanism. Seismicity is routinely characterised by its size and time distributions and by parameters reflecting changes in the strain and stress regime and the rheological properties of the rock mass deformation associated with the seismic radiation. Although seismic waveforms do not provide direct information about the absolute stresses and strains, they do provide useful information about stress orientation and about the spatial and temporal strain and stress changes. However, all these seismological parameters and seismic patterns are not always translated into practical instruments to manage seismic hazard in mining.

We will discuss methodologies to assess the long, intermediate and short term seismic hazard. It will include data selection, the expected next record breaking event magnitude, the power law size distribution and its intricacies, the Ground Motion Prediction Equation, distribution of distances and mapping the ground motion hazard in space. We will also discuss the short term hazard in the context of re-entry protocol. The new method to assess the likelihood of rockburst damage will be presented. It incorporates rock mass properties, stress field, geometrical characteristics of excavations, seismic data and parameters of ground support.

Most applications of modelling with seismic data to date were limited to qualitative correlation between location and mechanisms of events with the modelled stresses. We will report encouraging results on the quantitative correlation that makes it possible to improve numerical modelling. We will also discuss methodology of modelling the influence of hydraulic fracturing on stress redistribution.

Over the last few years we've made considerable progress in the quantification of rock mass properties and monitoring their changes in space and time. Recent advances in active seismic monitoring, seismic interferometry and ambient noise analysis achieve a resolution at least 100 times better than classical seismic velocity inversion. This is useful to monitor the real-time stress changes in 3D due to mining, as well as quantification of pillar strength and more accurate cave front tracking in block cave mines. These advances have also enabled us to directly image and monitor areas affected by mining activities where classical seismology has not been very effective, such as tailings dams, old mine workings and natural caves.

The main themes of the Seminar are:

- Ground Motion and Rockburst Hazard.
- Ground Motion Alerts and Re-entry.
- Managing Seismicity in Block Cave and Tabular Mines.
- Seismic Hazard Management Plan.
- Numerical Modelling with Seismic Data.
- In-Mine Seismic: In-mine Exploration and Rock Mass Characterisation.
- Progress in Seismic Monitoring Technology and DAS.

I'm asking all presenters to tell us: (1) why you did this work, (2) how you did it, (3) what you found, (4) what you think it means, and (5) what are the limitations.

Looking forward to see you in South Africa in May 2023

Aleksander J. Mendecki
Chairman and Head of Research
Institute of Mine Seismology

33rd Mine Seismology Seminar – Day 1

Monday 29 May, 08h45 - 18h00, Asara Wine Estate, Stellenbosch

08h45 | **Welcome and Introduction: Mine Seismology Past, Present and Future**
Dr Aleksander Mendecki, Chairman, Institute of Mine Seismology

09h00 | **Measuring Variations in the Seismic Velocity as a Diagnostic of Rock Damage and Healing**
Prof. Roel Snieder, Center for Wave Phenomena, Colorado School of Mines, USA

09h30 | **Quantitative Forecasting of Mining Induced Seismic Event Hazards**
Dr David Beck, Beck Engineering, Australia

09h55 | **Seismic Hazard Management - Something Old, Something New**
Lourens Scheepers, Sibanye Stillwater, South Africa

10h20 | **Managing Large Scale Seismicity in a Deep, High Stress Block Cave (DMLZ)**
Hendri Silaen and Turgod Nainggolan, PT Freeport Indonesia

——— Tea Break ———

11h15 | **Unusual Large M4.2, 18 May 2020 Event in the Kiirunavaara Mine, Sweden – Seismic Analysis**
Christina Dahnér and Savka Dineva, LKAB and Lulea University of Technology, Sweden, Dmitriy Malovichko, Institute of Mine Seismology, Australia

11h40 | **Mining Rock Mass Seismicity (MRS) Model - A Numerical Methodology to Assess the Seismic Potential of the Rock Mass Response to Mining**
Ronald Lachenicht, Itasca, Australia

12h05 | **Numerical Modelling of Seismic Activity in Ultra-Deep Mines Using BEM**
Jacques Gerber, Institute of Mine Seismology, South Africa

12h30 | **Underground Observations of Seismic Sources in Deep South African Gold Mines**
Johan Blignaut, Institute of Mine Seismology, South Africa

——— Lunch ———

14h00 | **Introduction to the Material Point Method for Simulating the Seismic Response to Mining**
Jurgens Gouws and Jacques Gerber, Institute of Mine Seismology, South Africa

14h15 | **Rockburst Hazard Forecasting**
Dr Dmitriy Malovichko, Institute of Mine Seismology, Australia

14h40 | **Modelling the Interaction of a Finite Thickness Source with a Tunnel**
Dr Vladimir Lyakhovsky and Dr Aleksander J. Mendecki, Institute of Mine Seismology

15h05 | **Rockburst Hazard Assessment: Cadia Case Study**
Dr Gisela Viegas Fernandes, Newcrest, Australia

15h30 | **Advanced Geotechnical and Seismic TARP's Developed for Seismically Active Mining Areas at Telfer**
Matthew Woods, Newcrest, Australia

——— Tea Break ———

16h25 | **Seismic Monitoring of Rock Mass Stability for Controlled Mining**
Dr Aleksander Mendecki, Institute of Mine Seismology

16h50 | **Ground Motion Alerts – GMAP and GMAS**
Dr Aleksander Mendecki, Institute of Mine Seismology

17h15 | **GMAS – Technology for a Real-time Ground Motion Alerts**
Dolf Bredenkamp, Institute of Mine Seismology, South Africa

17h40 | **Ground Motion Based Fixed Exclusion Rules for Blasting and Large Seismic Events**
Dr Cornel du Toit, Institute of Mine Seismology, South Africa

19h00 | Dinner at Asara Hosted by the Institute of Mine Seismology

Pre-dinner talk by Dr Steve Spottiswoode: **Reflections on 50 Years of Mine Seismology**

33rd Mine Seismology Seminar – Day 2

Tuesday 30 May, 09h00 - 17h00, Asara Wine Estate, Stellenbosch

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08h45 | **Welcome and Introduction**
Prof. Roel Snieder, Center for Wave Phenomena, Colorado School of Mines, USA

09h00 | **Introduction to Ambient Noise Methods**
Dr Francois Malan, Institute of Mine Seismology, South Africa

09h25 | **Properties of the Fault That Hosted the 2014 M5.5 Earthquake Beneath Moab Khotsong Gold Mine (South Africa) Revealed by 2- and 3D Reflection Seismics, Aftershocks and ICDP-DSeis Drill Core and Borehole Logs.** Authors: Prof. Hiroshi Ogasawara, Ritsumeikan University, Japan, Yasuo Yabe, Tohoku University, Japan, Musa Manzi and Prof. Ray Durrheim, University of the Witwatersrand, South Africa
Presented by Prof. Ray Durrheim, University of the Witwatersrand, South Africa.

09h50 | **Eramin-FUTURE project to image the Wrench Fault at South Deep Mine (South Africa) Using Active and Passive Sources Monitored by Sensors Deployed on the Surface, in Tunnels and Boreholes.** Authors: Musa Manzi and Moyagabo Rapetsoa, University of the Witwatersrand, South Africa, Alireza Malehmir, Uppsala University, Sweden, Valentina Socco, Polytechnico Torino, Italy and Prof. Ray Durrheim, University of the Witwatersrand, South Africa
Presented by Kenneth (Moyagabo) Rapetsoa, PhD candidate of University of the Witwatersrand, South Africa

10h15 | **Combining Microseismic Monitoring and Continuous Ambient Noise for Slope Stability Monitoring**
Dr Monty Rohwer, Institute of Mine Seismology, South Africa

——— Tea Break ———

11h10 | **Ambient Noise for Greenfields and Brownfields Exploration**
Dr Ruan Viljoen, Institute of Mine Seismology, South Africa

11h35 | **Monitoring an In-Stope Pillar in a Deep Gold Mine by Active Seismic Source**

Mark Green, Institute of Mine Seismology, South Africa

12h00 | **Relation Between Seismicity and Stress Changes in Underground Mine: From Research Challenges to Practical Tools (Project for Four Mines in Sweden)**
Savka Dineva and Christina Dahnér, LKAB and Lulea University of Technology, Sweden

12h25 | **Seismicity and Caving to an Open Pit (GBC)**
Zaki Fajri, PT Freeport Indonesia

——— Lunch ———

14h00 | **Introduction to Oyu Tolgoi Advance Monitoring System Design - An Integrated Ground Hazard and Cave Performance Monitoring System**
Erdenetogtokh Bayar, Oyu-Tolgoi, Rio Tinto Copper, Mongolia

14h25 | **3D Elastodynamic Modelling Applied to Complex Blasting Problems**
Dr Lindsay Linzer, SRK, South Africa

14h50 | **Development of Seismic Re-Entry Rules for a New Caving Panel at Cadia East**
Dr Gisela Viegas Fernandes, Newcrest, Australia

——— Tea Break ———

15h45 | **Recent Development in Automatic Processing of Seismic Monitoring Data**
Dr Martin Gal, Institute of Mine Seismology, Australia

16h10 | **Advances in Seismic Monitoring Technologies Including Integration of DAS Into a Real-time Monitoring System**
Gareth Goldswain, Institute of Mine Seismology, Australia

Courses And Tutorials

Pre-Seminar Course – Seismology Primer

Sunday 28 May, 09h00 - 16h00, Asara Wine Estate, Stellenbosch

Instructors:
Dr Gerrie van Aswegen, Dr Francois Malan, **Shane Kohler, Johan Blignaut** and **Dr Cornel du Toit,**
Institute of Mine Seismology South Africa

1. Objectives of seismic monitoring: rescue, prevention, hazard assessment, alerts and back analysis.
2. Seismic waves: sources of seismic waves, acceleration, velocity and displacement of ground motion, ground velocity vs propagation velocity.
3. Ambient noise: what is it, data collection and processing, applications, requirements.
4. Seismic events: event locations and location errors, design principles of seismic network configuration, velocity calibration, calibration blasts and Wadati diagram.
5. Direct source parameters: origin time and location, Fourier transformation, frequency decomposition, spectra and spectral parameters, seismic potency, seismic moment, radiated energy, corner frequency and size.
6. Derived source parameters: static and dynamic stress drop, apparent stress, apparent volume, energy index, time histories of seismic parameters, cumulative plots.
7. Magnitude scales: local, moment or potency magnitudes, energy magnitudes.

8. Source mechanisms: types of faults, radiation patterns and fault plane solutions, moment tensors, slip inversion, stress inversion.
9. Size distribution hazard: size distribution (Gutenberg-Richter relation), seismic hazard and risk, probabilities and hazard maps.
10. Short term hazard: short term hazard assessment, ground motion alerts and re-entry.
11. Ground motion hazard

Ground Motion and Rockburst Hazard in Underground Mines

Wednesday 31 May, 09h00 - 13h00, Asara Wine Estate, Stellenbosch

Instructors:
Dr Aleksander J. Mendecki, Institute of Mine Seismology, South Africa and Australia
Dr Cornel du Toit, Institute of Mine Seismology, South Africa
Dr Dmitriy Malovichko, Institute of Mine Seismology, Australia

1. Ground Motion Hazard
1.1 Ground motion at source – limits and scaling.
1.2 Peak Ground Velocity (PGV), Acceleration (PGA) and Displacement (PGD). Ejection velocity. Duration of strong ground motion. Cumulative Absolute Displacement (CAD) and Cumulative Absolute Inelastic Displacement ($CAID$).
1.3 Ground Motion Prediction Equation (GMPE) and its utility.
1.4 Seismic fragility curves and damage potential.
2. **Ground Motion Alerts for Mines: GMAP and GMAS.**
2.1 GMAP is an influence based polygon-less two parameter method where one takes into account the influence of ground motion generated by all available seismic events, regardless of their location, on a particular working place. It is based on the rates of cumulative absolute inelastic deformation, $CAID$, and on its activity, $ACAID$.
2.2 GMAS is an influence based polygon-less two parameter real time system where $CAID$ and its activity $ACAID$ are automatically derived by the GMAS hardware unit from the recorded continuous data stream of ground motion.
2.3 Re-entry and exclusion rules for blasting and large seismic events.

3. Rockburst Hazard
3.1 Terminology – shakedown and strain-bursting damage mechanisms, rockburst potential and rockburst hazard.
3.2 Input of rockburst hazard assessment – rock mass properties, geometry of excavations, stress model, seismic data, ground support.
3.3 Utilisation of seismic data – assessment of strain-bursting depth and duration of bulking, probability and percentage of the dynamic realisation of extreme depth of failure, increase in the depth of failure and consumption of ground support capacity.
3.4 Calculation and presentation of results – mapping of parameters and results on tunnel nodes, energy vs displacement plot of ground support capacity and demand, safety margin of displacement.

Numerical Modelling with Seismic Data

Wednesday 31 May, 14h00 - 17h00, Asara Wine Estate, Stellenbosch

Instructors:
Jacques Gerber, Institute of Mine Seismology, South Africa
Dr Dmitriy Malovichko, Institute of Mine Seismology, Australia

1. Validation and Improvement of Input Modelling Parameters.
1.2 Failure criteria – cohesion and friction angle for rock mass and weak structures.
1.3 Methodology – trial-and-error vs iterative calibration.

1.4 Examples.
2. Modelling of Seismic Sources and Seismicity.
2.1 Boundary Element and Material Point Methods – modelled parameters of seismic events: location, seismic potency, source mechanism. Catalogues of modelled seismic events.
2.2 Utilisation – forensic analysis of damaging events, ground motion hazard for the scenarios of mining.
2.3 Examples.

Ambient Noise Tutorial

Thursday 1 June, 09h00 - 13h00, Asara Wine Estate, Stellenbosch

Instructor. **Prof. Roel Snieder**, Head of the Center for Wave Phenomena, Colorado School of Mines

1. Time-lapse Changes and Healing of Earth Materials
2. Seismic Interferometry

Modeling the Effects of Fluid Injection: Stable vs Runaway Fracturing

Thursday 1 June, 14h00 - 17h00, Asara Wine Estate, Stellenbosch

Instructor. **Dr Vladimir Lyakhovsky**, Numerical Modelling Consultant.

1. General Observations and Concepts: fracture and friction, three-body model, linear and non-linear rock elasticity.
2. Elasticity of the Damaged Rocks.
2.1 Elastic energy of the damaged rocks.
2.2 Pore-elastic media, Biot effective stress.
2.3 Effective moduli and dilation.
2.4 Seismic waves.
3. Kinetic of the Damage, Accumulation and Healing.
3.1 Basic thermodynamic relations: Scalar damage model, coupling damage and porosity, effective stress and coupling with fluid flow.
3.2 Yielding cap for porous rocks.
3.3 Critical damage and synthetic seismic event.
4. Numerical Aspects.
4.1 Finite Element Method (FEM) for fluid pressure.
4.2 Fast Lagrangian Analyze of Continua (FLAC) for mechanical part.
4.2 Stress drop simulation in quasi-static long-term model.
5. Model Application to Hydro-fracturing: injection-induced seismicity.
5.1 Role of the intermediate principal stress on the direction of damage zone.
5.2 What controls the rate of fracturing and induced seismicity?
5.3 Injection pressure vs fluid flux controlled fracturing.
5.4 Stability of the stimulated process.
5.5 Run-away versus stable hydro-fracturing.
5.6 Interaction with pre-existing faults: re-activation vs. stabilization.

Interpretation of Seismic Data with IMS Tools

Friday 2 June, 09h00 - 16h00, Asara Wine Estate, Stellenbosch

Instructors: IMS Seismologists.

1. *Ticker3D*: initial configuration, viewing recent seismicity, long term seismicity, system health and Ground Motion Alert Programme (GMAP).

2. *Trace:* seismological processing: location, source parameters, velocity structure, user management.
3. *Vantage* Visualisation: interacting with the 3D viewer, loading and customising mine plans, loading seismic data from IMS database server, colouring and sizing of events, temporal and spatial filtering of the data, displaying source mechanisms.
4. *Vantage* Advanced Analysis: analysis in temporal, spatial and parameter domains, time histories, contours (event parameter gridding onto meshes), energy-potency plots, rank statistics of ground motions, event size distribution: open-ended and upper-truncated models, maximum size of event, probability table, source mechanisms: stereo-net of principals axes, nodal planes and poles, Hudson's source type plot, Frohlich's ternary graph.
5. Rockburst Hazard Assessment – *RBHA*: Importing geometry of excavations, rock mass properties, stress model, seismic data, ground support parameters; establishing tunnel nodes; using timeline; calculation of results (rockburst potential and rockburst hazard); presentation of results - maps, time histories, energy vs displacement plot.