AUSTRALIAN CENTRE FOR GEOMECHANICS

CSIRO | The University of Western Australia | Joint Venture

BIENNIAL REPORT 2021/2022

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JOINT VENTURE PARTNERS

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION AUSTRALIA
Mineral Resources

THE UNIVERSITY OF WESTERN AUSTRALIA
School of Civil, Environmental and Mining Engineering

Chair's Foreword

Mr Ian Suckling
Chair

The two years of this report saw the Australian Centre for Geomechanics (ACG) recover from the tough conditions of 2020. In that year, COVID-19 curtailed the scope of the ACG's activities, with constraints and changes necessitated to the nature of those activities. The ACG also had to lean hard on its financial reserves in order to maintain its functions and staffing.

During 2021, the responses the ACG made to its operations in the face of the COVID-19 strictures yielded positive results, with increases in activity, including employing various innovative online and hybrid methods of course and conference delivery developed for the purpose. Then, in 2022, the ACG thrived in response to the pent-up appetite of the geotechnical community for personal engagement and direct interaction between peers. The Centre has been extraordinarily busy through this time as it sought to maintain its invaluable role in providing the industry with its education, research and technology resources.

Both the tough COVID-19 times and the frenetic period that followed placed heavy demands on the ACG team. COVID-19 travel restrictions forced changes to the event schedule, pushing events close together and creating uncertainty regarding in-person attendance. The 2022 rebound resulted in record attendance at both the Caving 2022 and Mine Closure 2022 conferences. Additionally, demand for the services of the ACG's mXrap team continued to grow around the world.

Fortunately, the Board and I were able to have confidence that the outcomes would be excellent. This confidence rested on our knowledge of the quality of the team, but it did, however, require considerable personal dedication from the individual members of that team. I thank them for this, on behalf of the Board.

Late last year I attended a celebration of the 30th anniversary of the establishment of the ACG. Having joined the ACG Board in 2005 at the invitation of the previous Chair, Andrew Grubb, my 17 years of involvement affords me a sound perspective from which to make some observations on the ACG's first three decades.

The ACG has made very important contributions to the operation and economics of mines in Australia and around the world, and a particularly valuable contribution to the safety of their personnel. These contributions are well acknowledged and applauded by the industry's geomechanics experts and mining engineering practitioners but could, I feel, be more highly appreciated at the higher levels of management, and in government and other circles. The importance of the services the ACG provides has increased substantially since the ACG's inception, and will continue to increase as mining gets deeper, harder, and more environmentally and socially challenging. I trust that the industry recognises this.

Whilst I would prefer their work to be more widely acclaimed, I think the ACG staff are inclined to be comfortable as quiet achievers. I greatly admire them, not just for the importance of the outcomes, but also for the way they go about the task – committed, hard-working, and dedicated to, and invariably delivering, innovative and high-quality results. I've had the honour of observing this team under the inspiring leadership of Professor Yves Potvin, and now under Associate Professor Johan Wesseloo's astute guidance.

I have seen the Centre navigate the highs and lows to which our industry is prone, including times of some anxiety about the future. However, the ACG has, from its inception, benefited from Christine Neskudla's administration and her extraordinarily prudent management of the Centre's finances. It has also been able to rely upon Josephine Ruddle's diligent and effective pursuit of sponsorship and support. All this is underpinned by the excellence of the ACG's offerings, driven by the teams that make the courses and events happen – the producers of the ACG's outstanding publications, the mXrap crew (led by Dr Daniel Cumming-Potvin), the research and laboratory staff, and the continuing inputs of Professor Yves Potvin and the estimable Professor Phil Dight who provide support to the ACG's projects and courses.

As to the ACG's Board of Management, aside from Johan and Christine, the Board comprises representatives from the ACG's joint venture partners – The University of Western Australian (UWA) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) – as well as representatives from industry. My fellow Board members at the end of 2022 are Professor Tim Sercombe of the UWA School of Engineering, Dr Ewan Sellers from CSIRO, Dr Daniel Heal from BHP, Michael Dunn from Debswana Diamond Company, Dr German Flores-Gonzales from Newcrest Mining Limited, Dr Jeff Price from MMG Limited, and Andrew Mooney from OZ Minerals. Jeff and Andrew joined the Board in 2021. This is a group full of talent, wide experience, and great commitment to the ACG's goals. The ACG's management team and I have been fortunate to be able to benefit from their energetic and thoughtful guidance.

Having retired at the last Board meeting in late 2022, I am delighted to have handed the position of Chair to Dr Daniel Heal. Few people know the ACG better than Dan, and his commitment to it is unequivocal.

I conclude my final report by thanking all the ACG staff, and all those past and current members of the Board, for having made my interaction with the centre so overwhelmingly positive.

Thank you

Ian Suckling – ACG Board Chair

Director's Report

Associate Professor
Johan Wesseloo
Director

The Australian Centre for Geomechanics (ACG) has been in operation for 30 years. This milestone was reached in June 2022, and celebrated with present and past staff and Board members in December 2022. During the occasion, I reflected on, among other things, the ACG's impact and success. I repeat some of those thoughts here.

Over the years, the ACG has conducted several research projects – some of them running for several cycles. The most recent of these being the Ground Support Systems Optimisation Phase 3 project and the Stope Design and Reconciliation Phase 2 project, both currently underway. The industry's continued support for these projects testifies their relevance to industry. With the support of highly skilled and dedicated laboratory staff, the recently completed Rock Properties to Predict Rockburst Vulnerability in Three Dimensions projects boasts several world-first findings.

The mXrap software has become the vehicle to transfer research and development outcomes to its sponsor sites, thus enabling the immediate and easy use of its research outcomes on site. The fact that mXrap is now used on more than 60 mine sites testifies to the impact and relevance of the ACG's work.

Some interesting statistics include, since 1992, the ACG has presented more than 300 industry courses attracting in excess of 8,000 total attendees, and more than 40 international conferences with over 7,500 delegates. The ACG has managed the peer review and publishing of 2,685 conference papers since 2005. Most of these papers (2,012) are freely available from the ACG's Online Repository of Conference Proceedings. This is a valuable resource to industry as evidenced by 960,000 downloads at the end of 2022.

The ACG is in a strong position to continue this legacy for the benefit of our industry. This was only possible due to the dedication of the ACG team. The team's commitment was also visible during the difficulties posed by COVID-19, which continued to impact the ACG's operation in 2021, and in particular our further education and training platform.

The Centre's operating budget in 2021 presented at just over A$2.5M, compared to A$1.88M in 2020 – a respectable recovery from a challenging 2020, despite the impact of COVID-19. This result was achieved by the ACG hosting an increased number of online training courses, and only made possible thanks to the outstanding efforts of our small technical and professional team. This positive result was further supported by industry support of ACG research activities.

Following the cessation of COVID-19 restrictions in early 2022, in-person event attendance regained momentum, although online attendance of short courses was still dominant. In contrast, in person attendance at the ACG's 2022 international conferences, namely Caving 2022 and Mine Closure 2022, was overwhelming, with over 90% of delegates opting to participate in person, many from overseas.

Due to the increased number of online and hybrid training courses, and the outstanding attendance and sponsorship of our international conferences, the ACG was able to realise an unexpected operating budget of just over A$4M in 2022. This constitutes an increase in income of about 60% from 2021 and surpassed the healthy 2019 budget of A$3M by 33%. This result confirms the ACG's financially stable position and puts the ACG in good stead for future investment projects.

The hybrid conferences hosted by the ACG during 2021 proved a revival from COVID-19 and included:

- 24th International Conference on Paste, Thickened and Filtered Tailings (Paste 2021), Fremantle, Western Australia, 21–23 September 2021.
- Second International Conference on Slope Stability in Mining (SSIM 2021), Perth, Western Australia, 26–28 October 2021.

The hybrid conferences hosted by the ACG during 2022 presented an outstanding success, with an unexpected number of in-person attendees, and included:

- Fifth International Conference on Block and Sublevel Caving (Caving 2022), Adelaide, South Australia, 30 August–1 September 2022.
- 15th International Conference on Mine Closure (Mine Closure 2022), Brisbane, Queensland, 4–6 October 2022.

In early 2022, the ACG was privileged to secure industry funding for the Ground Support Systems Optimisation Phase 3 research project, with a budget of A$2.6M, supported by 11 global mining companies and five mining technology suppliers. This phase of the project will focus on four areas to achieve step changes in ground support practices – these being in situ dynamic testing of

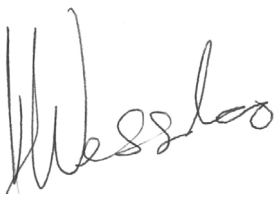
ground support using blasting, development of empirical dynamic ground support design guidelines, application of probabilistic ground support design tools, and optimisation of fibre-reinforced shotcrete-based systems in underground mines.

The Stope Design and Reconciliation Phase 2 project has been extended thanks to two additional sponsors joining the project in 2020 – namely OZ Minerals and Newmont. The overall objective of Phase 2 is to improve the transformation of stope design and reconciliation data into better information and, ultimately, into knowledge that can improve stope design and profitability. The focus is to enable this transformation from data to knowledge while streamlining the processes, thus saving time and gaining efficiency into the stope design and reconciliation processes currently used at mine sites.

The research project entitled Rock Properties to Predict Rockburst Vulnerability in Three Dimensions was completed in December 2021. The project has led to new insight and important fundamental understanding in fracture mechanics under three-dimensional stress states with application to the mechanics of strainburst.

The mXrap software platform continues to expand and provides geotechnical engineers with many data analysis, monitoring and investigation tools. The ACG's mXrap team has developed numerous apps that focus on allowing users to make high-quality geotechnical decisions as quickly and easily as possible.

The ACG looks forward to continuing to deliver high-quality research, training and technology transfer to the resources industries.



Associate Professor Johan Wesseloo – Director

ACG Board of Management[1]

Joint Venture Partner Representatives

Dr Ewan Sellers
(CSIRO – Mineral Resources)

Professor Tim Sercombe
(The University of Western Australia — Head of School and Dean, School of Engineering)

Chair (from industry)

Mr Ian Suckling
Gold Fields Australia Pty Ltd

Centre Director (non-voting)

Associate Professor Johan Wesseloo
(Australian Centre for Geomechanics – The University of Western Australia)

Industry Representatives

Mr Michael Dunn
(Debswana Diamond Company)

Dr German Flores-Gonzalez
(Newcrest Mining Limited)

Dr Daniel Heal
(BHP)

Mr Andrew Mooney*
(OZ Minerals)

Dr Jeff Price*
(MMG Limited)

The Australian Centre for Geomechanics' Board of Management (BOM) comprises of an independent chair, the director of the Centre, as well as industry and joint venture partner representatives. The BOM meets three times a year to present strategic direction for the Centre, review and approve activities and operations and to provide counsel.

In December 2022, Ian Suckling, formerly vice-president technical of Gold Fields Australia, retired from the ACG BOM after 17 years of service.

Ian Suckling graduated from the Western Australian School of Mines as a mining engineer in 1980. His career began at Kambalda, working for WMC Resources Limited (WMC) and gaining the practical experience required to obtain his First Class Mine Manager's Certificate. In 16 years with WMC, he worked at numerous of its nickel and gold operations, in a range of operations roles up to resident manager. He also spent two years in WMC's Melbourne head office as manager corporate finance and working on Australian and internal projects across a range of minerals and commodities.

There followed senior management roles for St Barbara in Western Australia, and, commencing in 1997, for Sino Mining based in Sydney, focusing on the establishment of their Chinese operations. Then came six years as general manager at the Jundee gold operation for, successively, Great Central Mines, Normandy and Newmont. Newmont assigned Ian oversight of their Yandal mines, Jundee, Bronzewing and Wiluna, before appointing him to senior technical and engineering positions and global responsibilities.

After a role as chief operating officer leading feasibility studies for Venturex Resources, Ian joined Gold Fields Australia in 2014. There he worked as general manager at Granny Smith before spending five years in a regional role as vice president-technical, after which he retired at the end of 2021.

Ian is proud of his roles in establishing projects and improving operations and found particular interest in improving the safety performance of operations, which was reinforced by his association with the Australian Centre for Geomechanics. Ian was honoured with the AusIMM Jim Torlach Health & Safety Award in 2010.

Ian is a long-serving contributor to the Minerals Research Institute of Western Australia (MRIWA), resigning his position as chair of the advisory committee in 2022, but remaining available as a subject matter expert.

The BOM acknowledges and thanks Ian Suckling for his many years of commitment, generous contribution and unwavering support of the ACG.

In December 2022, the ACG BOM was delighted to welcome new ACG chair, Dr Daniel Heal, general manager Newman, BHP.

Mr Ian Suckling

Dr Daniel Heal

[1] Period 2021–2022 * From 2021

mXrap Consortium

mXrap is a software platform that provides geotechnical engineers with many data analysis, monitoring and investigation tools. mXrap users can also develop their own apps using the inbuilt tools.

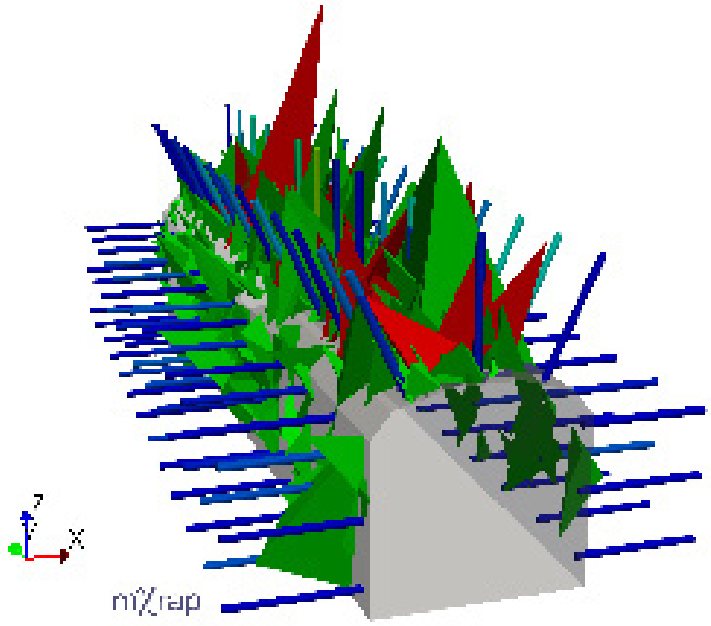
The ACG's mXrap team has developed a number of apps that focus on allowing users to make high-quality geotechnical decisions as quickly and easily as possible.

These apps cover:

- Mining induced seismicity
- Damage mapping
- Stope reconciliation
- Instrumentation
- Caving
- Surface monitoring
- Rock mass data analysis
- Backfill design
- Discrete fracture generation
- Ground support design
- Utilities

The software originated as part of the ACG Mine Seismicity and Rockburst Risk Management Project and many of the earlier developed apps are focused towards the management of mining induced seismicity and rockburst risk. In more recent years, the scope of what mXrap can achieve has expanded and a number of non-seismic geotechnical apps have been developed.

Software licences for mining companies are handled through the mXrap Consortium (along with academic and consulting licence applicants). Membership fees are related to the number of licences and apps required by the Consortium member. For more information please visit mxrap.com or contact info@mxrap.com



Ground support design

CONSORTIUM MEMBERS

The membership has grown steadily and continuously since inception of the Consortium in 2015. The table below provides a list of current mXrap Consortium members, as at November 2022.

Company	Site
29Metals	Golden Grove
Agnico Eagle Mines Limited	Laronde, Goldex, Fosterville, Kirkland Lake
Alamos Gold Inc.	Young Davidson, Island Gold
BHP	Olympic Dam
BHP Nickel West	Perseverance
Boliden	Garpenberg
CMOC-Northparkes Mines	Northparkes
Evolution Mining	EKJV, Ernest Henry, Millenium, Red Lake
Glencore Kidd Operations	Kidd Creek
Gold Fields Australia Pty Ltd	Waroonga, Granny Smith, New Holland, Hamlet, Invincible
Gold Fields South Africa	South Deep
Hecla USA	Lucky Friday
IAMGOLD Corporation	Westwood
IGO Limited	Flying Fox, Spotted Quoll, Nova
Luossavaara-Kiirunavaara AB	Kiruna, Malmberget
Ma'aden Barrick Copper	Jabal Sayid
MMG Limited	Rosebery
Newcrest Mining Limited	Cadia Valley Operations, Telfer Operations
Nevada Gold Mines	Turquoise Ridge
Niobec Inc.	Niobec
Northern Star Resources Ltd	Kundana, Kanowna Belle, Mt Charlotte, Superpit, Carosue Dam
Oyu Tolgoi LLC	Oyu Tolgoi
OZ Minerals	Carrapateena
Perilya Limited	Broken Hill
PT Freeport Indonesia	Grasberg
Red 5 Limited	Darlot
South32	Cannington
St Barbara Limited	Gwalia
Sudbury Integrated Nickel Operations (a Glencore Company)	Fraser Mine, Nickel Rim South
Vale Canada	Coleman, Creighton, Copper Cliff, Garsen, Totten
Westgold Resources Limited	Big Bell

Research Licence Holders

Laurentian University, Canada

Luleå University of Technology, Sweden

Queen's University

Spokane Mining Research Department (NIOSH), USA

Université Laval, Canada

University Nacional del Antiplano, Peru

University of Leeds, United Kingdom

University of Santiago, Chile

University of the Witwatersrand, South Africa

Consulting Licence Holders

AMC Melbourne

BESTECH

IGM Geotechnical

Mikula Geotechnics

MiningOne Canada

Open House Management Solutions

Operational Geotechs

RockEng

SCT OPerations

SRK Consulting Johannesburg

SRK Consulting Vancouver

MXRAP DEVELOPMENT TEAM

The mXrap development team includes:

Dr Daniel Cumming-Potvin
Project Lead
Australian Centre for Geomechanics

Dr Kyle Woodward
Research Fellow
Australian Centre for Geomechanics

Paul Harris
Principal Software Engineer
Australian Centre for Geomechanics

Denisha Sewnun
Research Fellow
Australian Centre for Geomechanics

Dr Matthew Heinsen Egan
Software Engineer
Australian Centre for Geomechanics

Joseph Mbenza
Research Fellow
Australian Centre for Geomechanics

Liam Niedzielski
Software Engineer
Australian Centre for Geomechanics

Stuart Tierney
PhD Student
Australian Centre for Geomechanics

Postgraduate Research

Dr Teófilo Aquino Vieira da Costa
PhD Civil, Environmental and Mining Engineering
2022

Thesis title: Brazilian banded iron formations: a geological and geotechnical characterisation from hard and fresh to weak and completely weathered rocks

Supervisors: Professor Phil Dight, The University of Western Australia, Australia, Professor Eduardo Marques, Universidade Federal de Viçosa, Brazil, Dr Kenneth Mercer, 3rd Rock Consulting, Australia (previously The University of Western Australia)

Brazilian Proterozoic banded iron formations (BIF), classified as low-grade ore, are called 'itabirites' and are divided into quartzitic, dolomitic, amphibolitic and high-grade ore 'hematitite', together with the main iron host rock of the Iron Quadrangle mines in Brazil. Their genesis is controversial, but it is agreed that metamorphic and tectonic events as well as the supergene and hypogene enrichment are responsible for modifying the original hard rock characteristics reconcentrating the iron. Weathering processes are responsible for reducing the strength, generating deep and heterogeneous weathered profiles with low strength rocks (weak rocks) reaching 400 m depth.

Based on field investigation and laboratory tests from 15 different mines, the PhD thesis determines the intact rock strength parameters and petrophysical proprieties (macro and micro scales) in different weathering profile levels (horizons and zones), highlighting geological and geotechnical characteristics considering the degree of anisotropy defined by the compositional metamorphic banding (heterogeneity), establishing relationships between petrophysical, rock strength and elastic parameters, proposing empirical correlation equations.

To reach the thesis goals, rock laboratory tests (triaxial, unconfined compressive strength – UCS, P and S wave and Brazilian tests) and soil laboratory tests (Atterberg limits, particle size distribution and soil-water characteristic curves, saturated and unsaturated direct shear tests, triaxial – CIU and permeability tests) were undertaken for each typology in different directions to account for anisotropy. In addition, petrographic thin sections, geological and geotechnical field investigation, and permeability in situ tests were assessed.

All test results and Vale's internal database were assembled and evaluated, and a complete failure envelope for each typology was determined to describe the intact rock and shear strength parameters variance in association with the geological and geotechnical characteristics along the weathering profile.

For each weathering level the following was concluded: for fresh typologies, the anisotropy ratio and index, respectively based on the UCS tests and Vp measures, are low to isotropic except for fresh dolomitic itabirites that present a fair to moderate anisotropy ratio. Even with a moderate dispersion of the UCS results, there is a direct correlation between iron content, bulk density and UCS parameters for hematitite and itabirites, and an inverse correlation with total porosity as expected. For these types, the main characteristics responsible for defining the rock strength and anisotropy are the mineralogy and the rock fabric. On this matter, hard hematitite is the stronger strength typology, followed by fresh quartzitic, amphibolitic and dolomitic itabirites. Hard hematitite also presents extremely high elastic parameters, followed by amphibolitic and quartzitic itabirites, and dolomitic itabirites presented the lower elastic behaviour.

Also, for fresh rocks positioned at the bedrock of the BIF weathering horizon, empirical correlation equations for UCS, Young´s modulus, bulk density and P and S wave velocity were established, which indicate a reliable, straightforward, and low-cost method which can be used to predict, with acceptable accuracy, intact rock strength and elastic parameters.

Moderately weathered typologies, positioned at saprorock and saprolite horizons, even with a small number of tests, showed a fair to moderate anisotropy index due to the higher total porosity and lower bulk density, behaving like a soil when highly weathered (saprolite horizon), or rock when moderately weathered (saprorock horizon). For these types, the heterogeneity is defined mainly by the total porosity, however the mineral composition plays an important role.

Postgraduate Research

The completely weathered rocks are characterised as saprolite or in situ residual soil horizons. For these BIF rock-like soil types, the bulk density, particle size distribution, permeability, total porosity, and water content are the most important parameters for typology shear strength variation. The low anisotropic ratio generally obtained has a minimal effect on the low shear strength values of weathered BIF types. The weathered argillaceous itabirite presents the lowest permeability and highest clay content that induces a matric suction effect (up to 80 kPa) and as an aquiclude can keep the negative porewater pressure (suction) describing an important unsaturated behaviour.

This thesis concludes that for BIF rocks each weathering horizon and level presents a typical intact rock strength, elastic parameters, and intrinsic petrophysical proprieties defining a specific geomechanical behaviour mainly controlled by the binomials iron content/bulk density, total porosity/permeability, and the mineral composition/bands thickness. Ultimately, the weathering profile horizon and level control slope stability and failure mechanisms not only for long-term excavations but also for temporary slopes from shallow to deep iron ore mines.

To read the thesis in full visit
https://doi.org/10.26182/e8hy-e863

Ground Support Systems Optimisation (GSSO) Research Project Phase 3

Background

Ground support remains one of the largest costs of development mining. At the same time, it is the main means of reducing rockfall/rockburst risk in underground mines. The challenge to the mining industry lies in keeping these risks as low as practicable, despite the increasing hazard associated with deepening of mineral resources. Controlling the costs and cycle time of installing efficient ground support systems remains at the forefront of most mining operations' priorities. The project entered into its third phase in May 2022.

The first phase focused on probabilistic ground support design; the use of numerical modelling for ground support design; and benchmarking of current ground support design practices. The main deliverable of the first phase was the *Ground Support in underground mines* book (acg.uwa.edu.au/product/ground-support-for-underground-mines).

Throughout the second phase, new tools and guidelines for ground support in extreme conditions (rockbursting and squeezing ground) were developed, and the use of probabilistic approaches in mining geomechanics was advanced. The Phase 2 final research report is available here.

Phase 3

The third phase of this project focuses on four areas to achieve step changes in ground support practices, namely in situ dynamic testing of ground support using blasting; development of empirical dynamic ground support design guidelines; application of probabilistic ground support design tools; and optimisation of fibre-reinforced shotcrete based systems in underground mines.

Sub-project #1: In situ dynamic testing of ground support using blasting

The main objective of the proposed in situ dynamic testing program using blasting as a dynamic source is to quantify the energy and displacement capacity of 12 ground support systems commonly used in rockburst-prone conditions in mines.

The following secondary objectives will also be pursued:

- Quantify the level of ground motion (ppv) the 12 support systems tested can sustain.
- Determine what proportion of the dynamic load is absorbed by the reinforcement compared to surface support.
- Investigate the weakest links of the 12 support systems.
- Quantify the effect of increasing bolt density on the capacity of the support systems tested.
- Investigate whether it is possible to use the dynamic capacity of individual support elements from drop testing to infer the dynamic capacity of support systems.
- Better understand assumptions behind the Canadian Rockburst Handbook design approach.

Sub-project #2: Development of an empirical dynamic ground support design method

The main objective of this sub-project will be to advance the development of the ground support system survivability matrix and, in particular, use a comprehensive high quality rockburst damage database to achieve an in depth understanding of the performance reliability of different support systems subjected to a wide range of dynamic loading.

A secondary objective will be to expand the database of rockburst damage built during GSSO 2. This expansion will aim at increasing the number of mines providing rockburst damage data and expand rockburst damage data involving shotcrete and different dynamic reinforcement.

Sub-project #3: Application of probabilistic ground support design tools

The primary objective of Sub-project #3 is to implement probabilistic ground support design techniques at sponsors' sites, based on a series of mXrap apps developed during GSSO 2. This will involve refinement and optimisation of the apps as required by sponsors.

For the block stability analysis approach, an important part of the implementation will be to work with sponsors' sites to build and calibrate discrete fracture networks (DFNs) for the main structural domains of each sponsor's mine to enable easy and rapid use of the app towards ground support optimisation at sponsors' sites. This will be accompanied with training material covering the necessary theoretical background and software training with walkthrough examples.

Other objectives will include to improve automation in the data input and DFN calibration processes. More complicated block geometries, as well as pseudo dynamic loading functionalities, will be added to the apps.

For the rock mass modelling approach, a simple linear elastic stress solver will be implemented into mXrap to streamline the process of evaluating the probability of the depth of yielding.

Sub-project #4: Optimisation of shotcrete in underground mines

The primary objective of Sub-project #4 is to develop new specifications for fibre-reinforced shotcrete in mining, given the cavity filling strategy is implemented.

Secondary objectives will include:

- Proving the cavity filling strategy and modelling results from GSSO 2 based on a simple physical model to be tested in a laboratory.
- Investigating whether there are benefits in the cavity filling strategy for foliated ground.
- Tactical ground support design: adapting bolting standards to match 'shotcrete plugs'.

Project sponsorship and support

Financial and in-kind support is kindly provided by the following industry sponsors:

Major sponsors

29Metals
Agnico Eagle
BHP Nickel West
Canadian Malartic
Evolution Mining
Gold Fields Australia
MMG Limited
OZ Minerals
Rio Tinto
St Barbara Mines
Vale Sudbury Operations

Minor sponsors

DSI Underground
Geobrugg
Jennmar
Normet
Sika

Researchers

Professor Yves Potvin, Project Manager, all projects

Associate Professor Johan Wesseloo, Sub-project Leader, Sub-projects 1, 3 and 4

Dr Daniel Cumming-Potvin, Research Support, Sub-projects 1 and 2

Ms Denisha Sewnun, Research Support, Sub-projects 2 and 3

Mr Joseph Mbenza, Research Support, Sub-project 4

Dr Matthew Heinsen Egan, Software Development, Sub-project 3

Ms Audrey Mathieu, Research Support, Sub-project 2

PROJECT TEAM

Professor Yves Potvin

Project Manager, Australian Centre for Geomechanics

Associate Professor Johan Wesseloo

Sub-project Leader, Australian Centre for Geomechanics, Sub-projects 4, 5, 6, 7

Dr Daniel Cumming-Potvin

Sub-project Leader, Australian Centre for Geomechanics, Sub-projects 1, 4, 5

Denisha Sewnun

Research Support, Australian Centre for Geomechanics, Sub-projects 4, 5

Joseph Mbenza

Sub-project Leader, Australian Centre for Geomechanics, Sub-project 6

Dr Matthew Heinsen Egan

Software Development, Australian Centre for Geomechancis, Sub-projects 1, 4, 5

Audrey Mathieu

Master's Student, Université Laval, Sub-project 1

Stope Design and Reconciliation Research Project Phase 2

This article is an excerpt of McFadyen et al. 2021, previously published at the AusIMM Underground Operators Conference held in Perth, Australia, in March 2021.

Introduction

Open stope mining is the predominant method used in Australian and Canadian underground mines. Profitability of open stope mining relies on the capacity of mine site personnel to design and accurately execute the mining of stopes. Ideally, a mined stope will maximise the amount of mined ore while minimising the amount of overbreak (OB) and underbreak (UB) generated. The stope design process often relies on the Stability Graph method, which was first developed in the 1980s. This method considers stope geometry and broad geotechnical parameters to inform the stability of the design. Nearly 40 years of technology advancement has enabled the collection of a high volume of data and allowed for more powerful stope performance analysis, which can be fed back into the stope design process. As part of the stope design and reconciliation project, which started in 2017 at the Australian Centre for Geomechanics, new tools are being developed for better stope design decisions and to facilitate stope optimisation. Sponsored by mines from Canada and Australia, a new and powerful tool for stope reconciliation and analysis was first developed (Woodward et al. 2019) as part of the first phase of the project. The second phase of this project focuses on a new interactive tool for open stope design. This paper presents this new approach to open stope design that, when completed, will go well beyond the Stability Graph.

Proposed approach to stope design

The main limitations of the Stability Graph are the limited parameters considered, the precision and resolution of the predictions, and its inability to predict UB. The new design approach aims at solving these limitations by generating accurate predictions of OB and UB, using the octree data and a wide range of critical parameters. The general steps of the stope design approach are illustrated in Figure 1 and are further discussed in this section.

The critical parameters influencing stope performance for a mine site can be determined through stope reconciliation and root cause analysis. Due to the requirement for a tool that can cover a wide range of parameters, the performance predictions are generated with multivariate statistical models. These critical parameters form the input for the predictive model, with the stope performance (projected distance between design and cavity monitoring system [CMS]) being the output. A training dataset is composed of previously mined stopes and used to initially build the model. This can then be applied on future stopes to predict their performance. This stope design approach aims at optimising stope performance for active mining sectors. Due to this stope design approach being data driven, modelling improves as mining progresses and additional data is included in modelling.

The quantification of stope performance on a per octree basis represents a very powerful dataset for predicting the stope performance. The multivariate statistical model being used is random forest regression (Breiman 2001) and is designed as a predictive model. The input data represents the critical parameters from mine sites, and is used to predict the OB and UB for each octree. In the stope design process, the root cause analysis and multivariate model are initially required and only updated if there are changes in the mining process or mining environment that would influence the predictive capabilities of the model. These changes can be observed through stope reconciliation and model performance analysis.

The engineer can input the critical data into the model for each stope design and obtain the OB and UB values of each octree block on the design surface. As the predictions are done for each octree across the stope design surface, the predicted location and magnitude of OB and UB can be identified and used to predict the mined shape. This allows for a predicted void to be constructed and compared with the design shape (Figure 2). Reconciliation of the predicted void and the design shape provides a great deal of information prior to mining the stope – for example, estimates of the total OB and UB volumes for the stope. This information can then be used in stope design meetings for planning operations and execution of the design stope. If the predicted stope performance is unacceptable, the stope design shape and drill design can be modified to further optimise the stope performance. An interactive tool allows the engineer to model a new stope and ring design and to obtain new predictions regarding the stope performance. The interactive and iterative nature of modelling helps the engineer to work towards a final and optimum stope design.

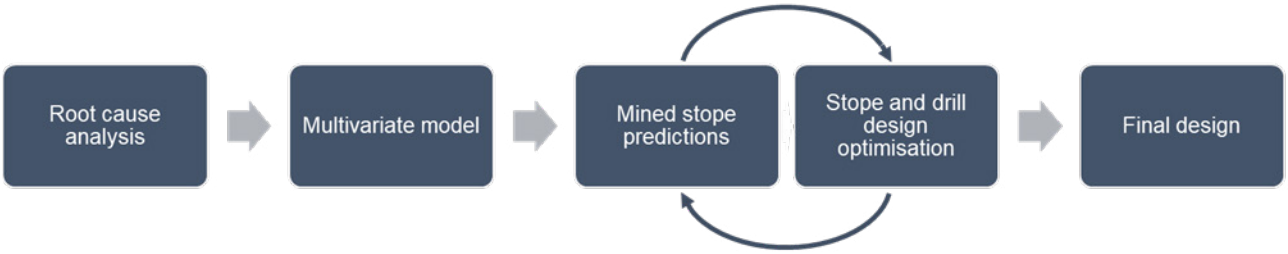


Figure 1. Stope design process for the proposed approach

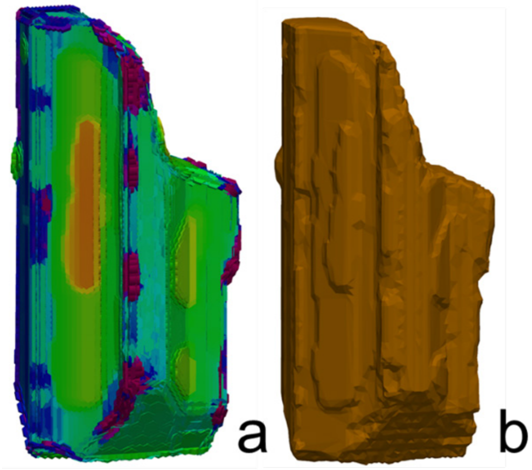


Figure 2. Example of a predicted CMS; (a) Predicted distances per octrees; (b) Predicted CMS shape built from the octree predictions

Example of predicted stope design

Stope A is shown in Figure 3, excluding the drifts cut out of the design shape (Figure 8a) and implements a fanned drill and blast pattern (Figure 8b). Reconciliation of the stope at a resolution of half a metre generates a total of 10,600 octree blocks (Figure 8c).

Once the multivariate predictive model is built and validated, the engineer can input the stope critical parameters for each model to obtain the predictions of each octree block's OB and UB. Figure 4 illustrates Stope A in 3D using two different viewing angles (hanging wall [HW] and footwall [FW]). It shows the observed distances, the predicted distances, and the prediction error (the difference between the two). It also shows the mined shape and the predicted distance contoured on the design shape. The overall prediction performance of Stope A is indicative of the actual mined shape. Although some areas of the stope are not as well predicted, in general, the patterns and location of larger OB and UB that are present in the observed stope are repeated in the predicted stope.

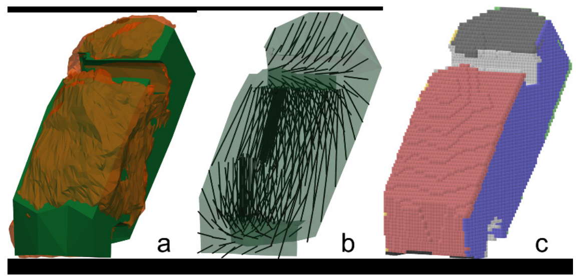


Figure 3. Stope A: (a) Stope design shape in green and CMS in orange; (b) Stope drill rings; (c) Stope design octrees coloured by face

This allows the engineer to optimise the stope design by modifying the drill and blast design in order to minimise the OB in the HW and the UB in the FW. In current practice, engineers modify blasting design by not charging certain holes if large OB is expected. The impact of the

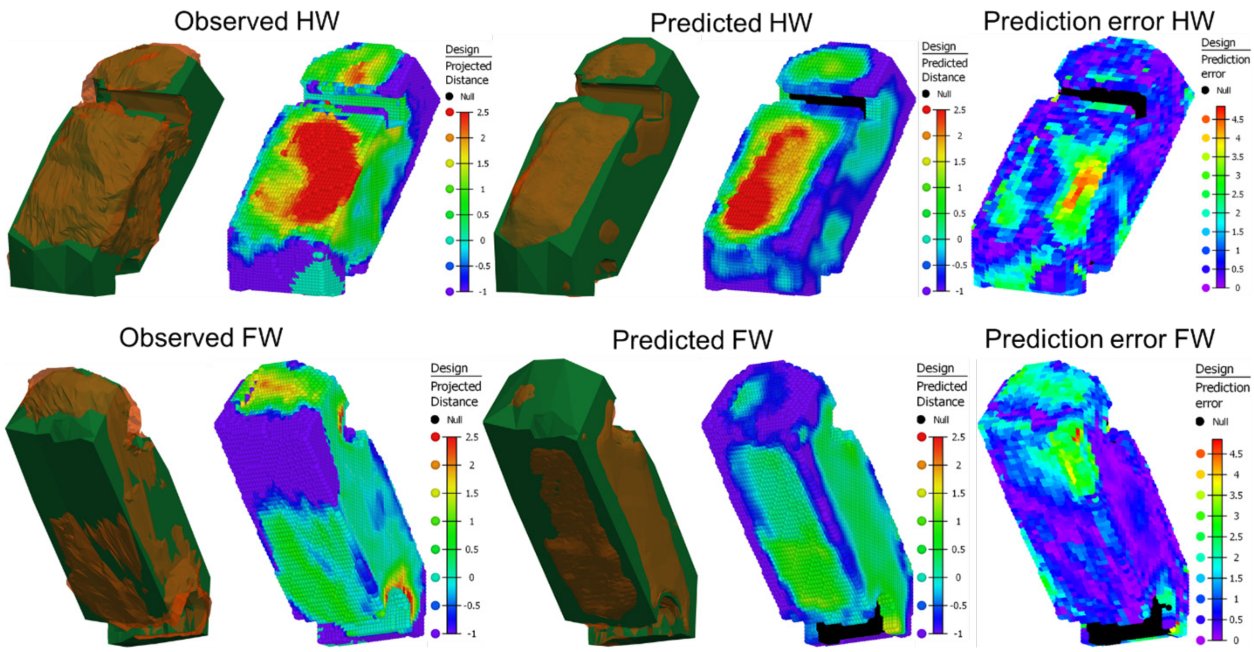


Figure 4. Stope A view of the observed distances versus the predicted distances; (a) Hanging wall (HW); (b) Footwall (FW)

Table 1. Stope A observed versus predicted stope overbreak (OB) and underbreak (UB)

Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
OB m^3		UB m^3		OB %		UB %	
1,289	761	807	597	20.5	12.1	12.8	9.5

modifications made to the design can be quantified using this design tool and gives the engineer a better understanding of how various critical factors will impact the stope's performance.

The design shape is reconciled with a predicted mined shape built from the statistical model. The results for this stope are given as OB and UB volumes for the whole stope (Table 1). These results provide guidance for the expected volumes that will be mined. This information can be used in an iterative stope design process to establish the final optimal design shape and its mining process.

Conclusion

The development of the Stope Reconciliation app in mXrap was completed in 2021 and is now available widely to mXrap consortium members. A preliminary version of the Stope Design app has recently been completed and is being tested at four sponsoring mines. The rollout of the Stope Design app will be expanded gradually until the final product becomes available to all consortium members.

References

Breiman, L 2001, 'Random forests', Machine Learning, vol. 45, pp. 5–32, https://doi.org/10.1023/A:1010933404324

Woodward, K, McFadyen, B, Potvin, Y & Wesseloo, J, 2019 Probabilistic Stope Design, MRIWA Project M0489, Australian Centre for Geomechanics, Perth.

PROJECT TEAM

Professor Yves Potvin
Project Lead, Australian Centre for Geomechanics

Benoit McFadyen
PhD Student, Université Laval

Associate Professor Johan Wesseloo
Technical Advisor, Australian Centre for Geomechanics

Dr Kyle Woodward
Research Fellow, Australian Centre for Geomechanics

Rock Properties to Predict Rockburst Vulnerability in Three Dimensions Research Project

Background

This ACG research project aimed to equip the mining industry with knowledge to mitigate strainburst/rockburst risk.

As mines continue to extend deeper and open pits expand, strainbursts and rockbursts are increasing the cost of mining safely, i.e. ground support requirements, microseismic monitoring, restrictions to production and sequencing, as well as delays in re-entry, sometimes leading to the premature closure of a mine. These problems are a major threat to the future exploitation of deep resources. Several strainburst/rockburst risk management approaches are available and are currently used by many mines. However, once the mining method and sequence are determined, the hazard state is more or less locked in, leaving implementation of appropriate support as one of the only short-term controls of excavation damage potential. Knowledge of the location of potential bursts is key to appropriate and timely selection. To aid industry to design more appropriate support systems to mitigate the potential problem, in 2016, the ACG commenced an industry and Minerals Research Institute of Western Australia (MRIWA) funded research project into Rock properties to predict rockburst vulnerability in three dimensions (MRIWA Project M0464). The project was completed in December 2021.

Project objectives

This ACG research project examined the properties of rocks in 3D. This work identified the Principal Components of many rock properties in 3D including the pre-peak and post-peak behaviour Brazilian tensile strength and fracture toughness in order to identify where rockburst could occur. Pre-peak behaviour is dominated by rock brittleness and fracture generation.

Dight et al. (2013) have shown that the energy from the self-sustaining behaviour can be related to the ejection velocity once the rockburst potential can be identified, which means that the demand on and parameters for ground support may be determined for dynamic situations.

The ultimate benefit of the project to the mining industry will lead to much better management of hazards and early adoption of mitigation approaches. Thus, fewer mines would be closing due to rockburst. The project may benefit mines by helping to identify approaches for reducing the consequences of rockbursts, in particular, by designing more appropriate support systems. This will contribute to making deep mines safer and more sustainable in the future.

The research project team explored

- In situ stress recovery.
- Pre-peak intact properties.
- Post-peak properties (energy demand from Type 2 behaviour).
- Demand for the design of dynamic support.

Project sponsors

- Minerals Research Institute of Western Australia
- Aeris Resources, Tritton Resources Limited
- Agnico Eagle Mines Limited, LaRonde Mine
- AngloGold Ashanti Australia, Sunrise Dam Gold Mine
- BHP Nickel West
- BHP Olympic Dam
- Ernest Henry Mining Pty Ltd
- Gold Fields Australia Pty Ltd, Granny Smith Mine
- Gold Fields Australia Pty Ltd, South Deep, Agnew and St Ives Gold Mines
- IAMGOLD Corporation, Westwood Mine
- Luossavaara-Kiirunavaara AB, Kiruna and Malmberget Mines
- Newcrest Mining Limited, Cadia Valley Operations
- Northern Star Resources Limited, Kalgoorlie Operations
- Sudbury Integrated Nickel Operations (a Glencore Company), Nickel Rim South Mine

For more information, please visit acg.uwa.edu.au/sburst or contact the ACG. Article references are available on request.

Project leader

Phil Dight
Professor of Geotechnical Engineering
Australian Centre for Geomechanics

Collaborating universities

The majority of the research work was conducted at The University of Western Australia. Research undertaken by Monash University included the consideration of pre-peak and dynamic studies through the application of geological investigations and numerical modelling in three dimensions.

The research project team

The project team was led by the ACG's Professor Phil Dight and comprised the following researchers:

- Dr Hongyu Wang, research associate, formerly Australian Centre for Geomechanics
- Dr Ariel Hsieh, research fellow, formerly Australian Centre for Geomechanics
- Dr Selahattin Akdag, research fellow, formerly Australian Centre for Geomechanics
- Ai Li (Ellie), laboratory technician, Australian Centre for Geomechanics
- Professor Arcady Dyskin, chair, Computational Mechanics Discipline Group, The University of Western Australia
- Adjunct research associate Max Lee, geotechnical specialist, Monash University
- Dr Hossein Hasoumi, senior lecturer, Monash University

This team is supported by the following PhD candidates:

- Broadus Jeffcoat-Sacco, The University of Western Australia (ACG)
- Ali Keneti, Monash University

Example of strainburst in the field showing support challenges

Following a strainburst near the surface rock has split off from the face and the ground support has not prevented the unravelling

Current Research Projects in 2021/2022

The ACG research portfolio is considerable, our major research projects underway are summarised below.

Ground Support Systems Optimisation Phase 3

4-year project (commenced May 2022)

Budget: $2,600,000

Key researchers: Professor Yves Potvin, Associate Professor Johan Wesseloo, Dr Daniel Cumming-Potvin, Ms Denisha Sewnun, Mr Joseph Mbenza, Mr Matthew Heinsen Egan, Australian Centre for Geomechanics; Ms Audrey Mathieu, Laval University, Canada.

Major sponsors: 29Metals; Agnico Eagle; BHP Nickel West; Canadian Malartic; Evolution Mining; Gold Fields Australia; MMG Limited; OZ Minerals; Rio Tinto; St Barbara Mines; Vale Sudbury Operations.

Minor sponsors: DSI Underground; Geobrugg; Jennmar; Normet; Sika.

This project focuses on four areas to achieve step changes in ground support practices, namely in situ dynamic testing of ground support using blasting; development of empirical dynamic ground support design guidelines; application of probabilistic ground support design tools; and optimisation of fibre-reinforced shotcrete-based systems in underground mines.

For further information, visit: gsso.com.au/phase-3

Stope Design and Reconciliation Phase 2

2-year project (commenced July 2020), plus 1 year extension to July 2023.

Budget: $420,000

Key researchers: Professor Yves Potvin, Dr Kyle Woodward, Associate Professor Johan Wesseloo, Australian Centre for Geomechanics; Benoit McFadyen, PhD Student, Université Laval.

Sponsors: BHP Olympic Dam; Glencore Mount Isa Mines; IAMGOLD Corporation; MMG Limited, Newmont Australia, and OZ Minerals.

This research project is looking at new ways of performing stope reconciliation and optimising open stope design in underground mining.

For further details, please visit: shorturl.at/rxK08

Rock Properties to Predict Rockburst Vulnerability in Three Dimensions

4-year project (commenced October 2016; completed December 2021)

Budget: $2,140,000

Key researchers: Professor Phil Dight, Dr Hongyu Wang, Australian Centre for Geomechanics.

Sponsors: Aeris Resources, Tritton Resources Limited; Agnico Eagle Mines Ltd., LaRonde Mine; AngloGold Ashanti Australia, Sunrise Dam Gold Mine; BHP Olympic Dam; BHP Nickel West; Ernest Henry Mining Pty Ltd; Gold Fields Australia Pty Ltd, Granny Smith Mine; Gold Fields Australia Pty Ltd, Agnew and St Ives Gold Mines; IAMGOLD Corporation, Westwood Mine; Luossavaara-Kiirunavaara AB, Kiruna and Malmberget Mines; Newcrest Mining Limited, Cadia Valley Operations; Northern Star Resources Limited, Kalgoorlie Operations; Sudbury Integrated Nickel Operations (a Glencore Company), Nickel Rim South Mine; and the Minerals Research Institute of Western Australia.

This ACG research project aimed to equip the mining industry with support systems knowledge to mitigate strainburst/rockburst risk. The ultimate benefit of the project to the mining industry will lead to fewer mines closing due to rockburst and help identify approaches for reducing the consequences of rockbursts, in particular, by designing more appropriate support systems. This will contribute to making deep mines safer and more sustainable in the future.

For further details, please visit: acg.uwa.edu.au/sburst

Safe, Sustainable Management of Filtered Tailings

3-year project (commenced October 2018; completed December 2022)
Budget: $482,500
Key researchers: Professor Andy Fourie, Dr Jinglong Gao, The University of Western Australia.

Sponsors: Alcoa of Australia; Alumina Quality Workshop (AQW) – currently represented by South32; BHP; Rio Tinto; The International Aluminum Institute, UK; and the Minerals Research Institute of Western Australia.

The key objective of this project was to facilitate the widespread adoption within the mining and processing industry of filtered and stacked tailings as a viable, safe and cost-effective management strategy.

For further information, please visit: shorturl.at/yQT59

Towards a Mechanistic Understanding of Electrokinetic In-situ Leaching

3-year project (commenced January 2020; due for completion December 2023)

Budget: $842,605

Key researchers: Professor Andy Fourie, Dr James Jamieson, The University of Western Australia; Professor Henning Prommer, The University of Western Australia and CSIRO; Associate Professor Massimo Rolle, Technical University of Denmark.

Sponsors: BHP; Evolution Mining; Newcrest Mining; Newmont Australia; and the Minerals Research Institute of Western Australia.

In situ leaching coupled with electrokinetics (EK-ISL) potentially enables recovery of metals from (sub-economic) ores with a significantly smaller environmental footprint than current mining approaches. This project is seeking a refined process understanding of the gold EK-ISL system and explores the potential of EK-ISL on liberating and recovering other metals such as copper.

Evidence-Based Design and Practical Implementation of Protocols to Manage the Exposure of Personnel to Seismic Hazard in Underground Mines

3-year project (commenced June 2018; extended till May 2023)

Budget: $300,000

Key researchers: Stuart Tierney (PhD Student), A/Professor Johan Wesseloo, Australian Centre for Geomechanics.

Sponsors: IAMGOLD Corporation, Canada; Luossavaara-Kiirunavaara AB, Sweden; Newcrest Mining Limited, Australia; and the Australian Centre for Geomechanics.

This project aimed at providing proven and quantified methodologies for short-term seismic hazard assessment and exposure control measures that can be practically implemented on site. Improvement in this area will reduce the risk of injuries to personnel and the lost production resulting from unnecessary exclusions.

Advancing the Physical and Numerical Modelling of Caving Mechanics

2-year project (commenced May 2018; extended till July 2023)

Budget: $98,000

Sponsor: Newcrest Mining Limited.

Key researchers: Associate Professor Johan Wesseloo, Dr Daniel Cumming-Potvin, Australian Centre for Geomechanics.

This project aims to improve the industry's understanding of cave propagation. It involves testing of physical models of caving using a geotechnical centrifuge in order to visually observe cave propagation, something which is not achievable in caving mines. The results of the testing are used to calibrate numerical models, as well as to learn about caving mechanisms and the link between caving and seismicity. This project is being performed in collaboration with the Geotechnical Centrifuge Laboratory at the University of Pretoria's Civil Engineering Department (UPCE) in South Africa.

For further information, please visit: shorturl.at/yKLS4

Physical Modelling of Cave Breakthrough

2-year project (January 2019; extended till July 2023)

Budget: $57,000

Key researchers: Dr Daniel Cumming-Potvin; Associate Professor Johan Wesseloo, Professor Yves Potvin, Australian Centre for Geomechanics.

Sponsor: OZ Minerals Carrapateena Pty Ltd.

The main aims of this project are to: better understand the process of cave breakthrough into an existing cave and the associated mechanisms; test the efficacy of commonly used seismic analysis techniques in describing cave propagation and breakthrough; and test the efficacy of

numerical modelling in describing cave propagation and breakthrough, including the impact of different levels of knowledge on the numerical modelling efficacy.

This project is carried out in collaboration with the Geotechnical Centrifuge Laboratory at the University of Pretoria's Civil Engineering Department (UPCE) in South Africa.

Blast Testing of Ground Support at Cadia Mine

2-year project (commenced November 2018; extended till December 2023)

Budget: $275,000

Key researchers: Professor Yves Potvin, Denisha Sewnun, A/Prof Johan Wesseloo, Dr Daniel Cumming-Potvin; Australian Centre for Geomechanics.

Sponsor: Newcrest Mining Limited.

This project involves testing of ground support capacity in order to improve measures to limit rockburst damage following blasting at the Cadia underground mine. Ground support is one of the main control measures used to limit rockburst damage in underground mines and thus control the seismic risk. In order to minimise damage, the capacity of the installed ground support should exceed the demand placed on it by the rockburst and the components of the support system should work as a unit.

Geomechanics Education and Training

As with the global events industry, COVID-19 continued to impact the delivery of the ACG further education and training platform throughout 2021. Our events team quickly pivoted to provide our content via both in-person and remote attendance. This initiative buoyed the overall number of event attendees and extended the ACG's international reach into both new and existing markets.

Following the cessation of the COVID-19 restrictions in early 2022, in-person attendance regained momentum, although online attendance of short courses was still dominant. In contrast, in-person attendance at the ACG's 2022 international conferences was overwhelming, with over 90 per cent of delegates opting to participate in person, with many from overseas.

As a leading provider of specialist and advanced training and education for those in mining and environmental geomechanics, the ACG continued to support industry to reach their training and business objectives.

THE ACG'S GEOMECHANICS TRAINING AND EDUCATION PLATFORM PROVIDES A SOLID BASE FOR THE TRANSFER OF TECHNOLOGICAL DEVELOPMENTS AND PRACTICES BASED ON KNOWLEDGE GATHERED FROM LOCAL AND INTERNATIONAL SOURCES

2021 EVENTS

Underground Mine Backfill Seminar
Perth, Western Australia, 19–22 April 2021

Geotechnical Design for Underground Metalliferous Mines Course
Perth, Western Australia, 31 May–4 June 2021

Geomechanics of Cave Mining Seminar
Perth, Western Australia, 14–17 June 2021

2021 Caving Community of Practice, Unconference Online
Perth, Western Australia, 18 June 2021

Managing Seismic Risk in Underground Metalliferous Mines Course
Perth, Western Australia, 16–20 August 2021

Is the Future Filtered? Paste and Thickened Tailings Short Course
Perth, Western Australia, 20 September 2021

Paste 2021: 24th International Conference on Paste, Thickened and Filtered Tailings
Fremantle, Western Australia, 21–23 September 2021

Instrumentation and Slope Monitoring Workshop
Perth, Western Australia, 25 October 2021

SSIM 2021: Second International Conference on Slope Stability in Mining
Perth, Western Australia, 26–28 October 2021

Risk-based Design and Management of Open Pit Slopes Workshop
Perth, Western Australia, 29 October 2021

Ground Support in Underground Mining Short Course
Perth, Western Australia, 8–12 November 2021

Introduction to the Application of Risk-based Methods in Underground Mining Geomechanics Workshop
Perth, Western Australia, 16–19 November 2021

Static Liquefaction Workshop
Perth, Western Australia, 7–8 December 2021

2022 EVENTS

mXrap User Case Studies for Mines Seminar
Perth, Western Australia, 14 March 2022

Geomechanics Data for Underground Mines Course
Perth, Western Australia, 15–17 March 2022 (A.M.) and 16–18 March 2022 (P.M.)

Mine Fill Seminar
Perth, Western Australia, 4–7 April 2022

Geotechnical Design for Underground Metalliferous Mines Course
Perth, Western Australia, 16–20 May 2022 (A.M. and P.M.)

Geotechnical Engineering with mXrap Seminar
Online, 31 May 2022

Introduction to Open Pit Slope Stability Course
Perth, Western Australia, 1–5 August 2022

After the Big Bang Workshop
Adelaide, South Australia, 28 August 2022

Geomechanics Education and Training

Panel/Block Caving Workshop: From Data to Design
Adelaide, South Australia, 29 August 2022

Caving 2022: Fifth International Conference on Block and Sublevel Caving
Adelaide, South Australia, 30 August–1 September 2022

2022 Caving Community of Practice, Unconference
Adelaide, South Australia, 2 September 2022

Collaborative Mine Closure Planning Workshop
Brisbane, Queensland, 3 October 2022

Geochemical Modelling for Mine Closure Course
Brisbane, Queensland, 3 October 2022

Mine Closure 2022: 15th International Conference on Mine Closure
Brisbane, Queensland, 4–6 October 2022

Understanding the Costs of Closure Through Integrated Mine Closure Planning Workshop
Brisbane, Queensland, 7 October 2022

Ground Support in Underground Mining Course
Perth, Western Australia, 17–21 October 2022

Geotechnical Design and Implementation for Open Pits Seminar
Perth, Western Australia, 21–25 November 2022

Hands–on Future Tails Laboratory Course
Perth, Western Australia, 22–24 November 2022

Tailings Management Seminar
Perth, Western Australia, 6–7 December 2022

Cone Penetration Testing Workshop
Perth, Western Australia, 8 December 2022

GEOMECHANICS ONSITE TRAINING

The ACG's onsite training courses seek to deliver the latest technologies and information to the mining workforce in accordance with site-specific requirements and applications. Our training and further education platform provides a strong base for the transfer of technological developments and practices based on knowledge gathered from local and international sources.

2219 & 2022 ONSITE TRAINING

Geotechnical Engineering for Open Pit Mines (online)
IAMGOLD Corporation, Canada, 31 May–4 June 2021

ON THE HORIZON

Ground Support 2023: 10th International Conference on Ground Support in Mining
Perth, Western Australia, 10–12 October 2023

Ground support remains the main means to manage rockfalls; one of the major risks in underground mines. The latest developments and applications of ground support in mining are of prime interest to mining practitioners worldwide where the objective is to mitigate rockfall.

acggroundsupport.com

SSIM 2023: Third International Slope Stability in Mining Conference
Perth, Western Australia, 14–16 November 2023

Best practice with respect to pit slope investigations, design, implementation and performance monitoring will be discussed during this conference.

acgsurfacemining.com

Deep Mining 2024: 10th International Conference on Deep and High Stress Mining
Montreal, Canada, 24–26 September 2024

Underground mining continues to progress at deeper levels and industry is now extracting mineral reserves at depth that previously would have been considered unmineable. Deep mining is a very technical and challenging environment. A high level of understanding and technically sound approaches are essential to deal with the significant geotechnical challenges of deep and high stress mining, and best practice and innovation need to be implemented.

acgdeepmining.com

Geomechanics Education and Training

Associated International Events

14th International Conference on Mine Closure

Online, 17–19 August 2021

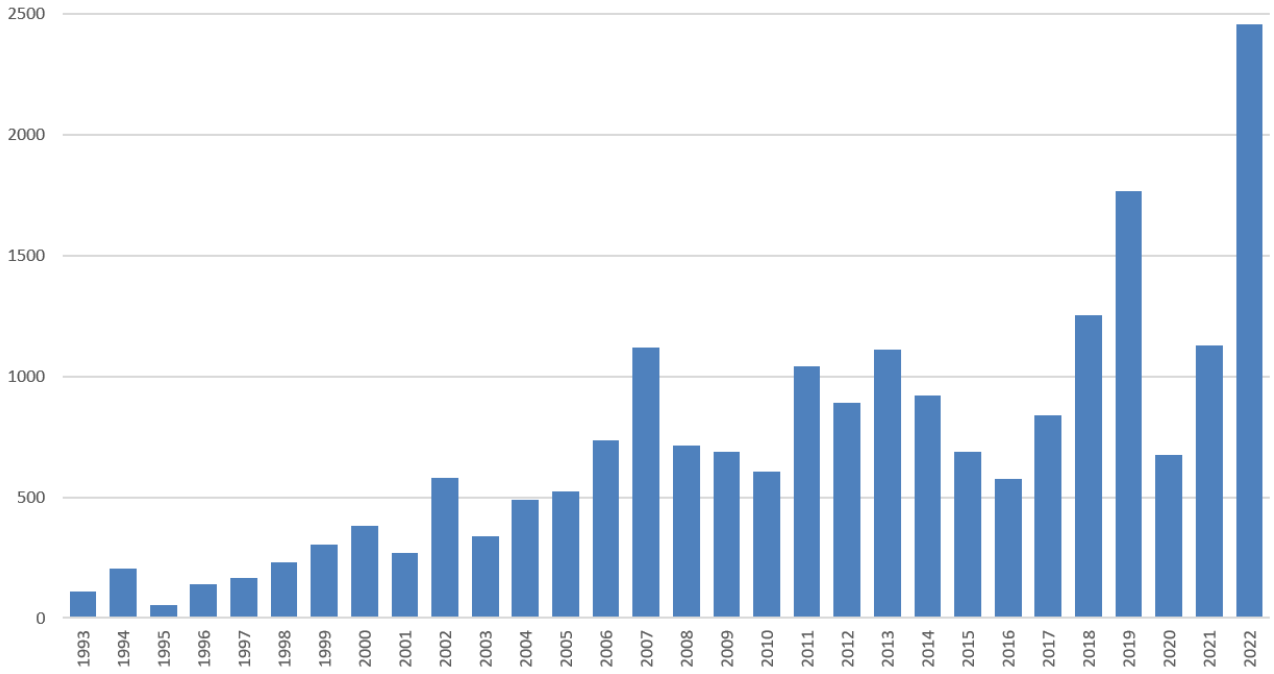
The ACG supported QMC LLC Mongolia to host Mine Closure 2020 online. This event was scheduled to be held in Ulaanbaatar, Mongolia, in 2020. Due to COVID-19 it was postponed till August 2021.

The ACG has close to 30 years of experience in hosting international mining events globally that have regularly attracted between 150 and 550 local and international mining professionals. Our dedicated events team is skilled and trained to manage and coordinate all aspects of international events including delegate registration, marketing and promotion, abstract and paper generation, venue coordination, sponsorship, committee, and program development.

The ACG also has a dedicated publications team that produces peer-reviewed conference proceedings. This work is undertaken in-house where we can ensure the high standard of the publication is maintained. Our conference papers are freely available from our Online Repository of Conference Proceedings.

The ACG has been instrumental in initiating many highly acclaimed series of international mining conferences held either annually or regularly throughout the world. In close collaboration with leading mining universities such as The University of the Witwatersrand, South Africa; University of Reading, UK; Universidade Federal de Minas Gerais, Brazil; The University of British Columbia, Canada; University of Science and Technology Beijing, China; Laurentian University, Canada; Pontificia Universidad Católica de Chile, Chile; UNSW Sydney, Australia; University of Alberta, Canada; and University of Nevada, USA the ACG is pleased to have been the founding body and/or key collaborator for the following conference series:

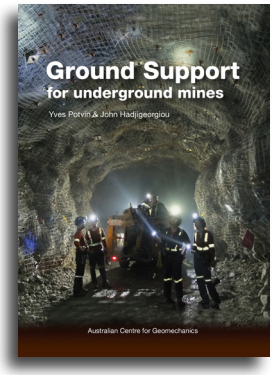
- International Conference on Paste, Thickened and Filtered Tailings
- International Conference on Mine Closure
- International Conference on Deep and High Stress Mining
- International Conference on Block and Sublevel Caving
- International Conference on Slope Stability in Mining
- International Conference on Underground Mining Technology



Total ACG course attendance by year. 2020 reflects the downturn in events due to COVID-19

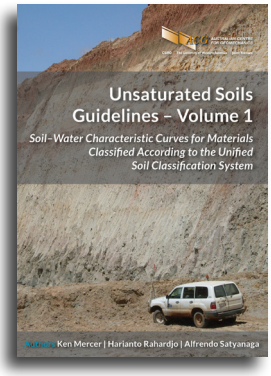
ACG Specialist Publications

The following ACG specialist publications can help industry personnel maintain and develop skills, knowledge and capabilities.



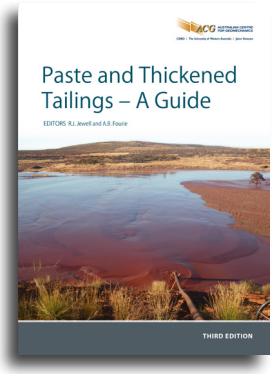
Ground Support for underground mines

Target audience: practicing geotechnical and mining engineers having the task of designing ground support systems in mines.



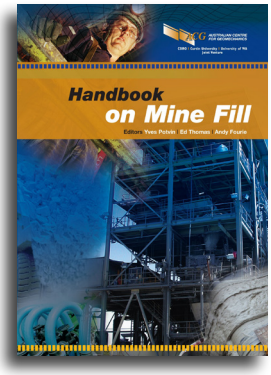
Unsaturated Soils Guidelines – Volume 1

Soil-water characteristic curves for matrerials classified according to the Unified Soil Classification System.



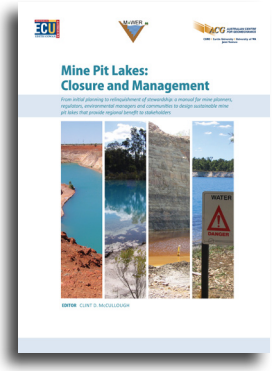
Paste and Thickened Tailings – A Guide (third edition)

These guidelines are such a highly valued and relevant reference for all those working in the mining industry having responsibilities for paste, thickened and filtered tailings (P&TT).



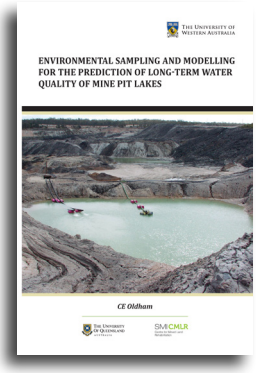
Handbook on Mine Fill ebook

This ebook is a concise summary of the considerable body of mine fill knowledge and experience and provides mining engineers and those responsible for the application of fill with a one stop reference, covering the most significant aspects of fill.



Mine Pit Lakes: Closure and Management

A concise summary of the considerable body of mine pit lake knowledge and experience whic provides a one-stop reference. It is applicable to underground and surface mining operations.



Environmental Sampling and Modelling for the Prediction of Long-Term Water Quality of Mine Pit Lakes

A summary of experiences and learnings with respect to developing water and chemical mass balances and conceptual models for mine pit lakes.

These and other ACG publications can be purchased at acg.uwa.edu.au/publications

Geomechanics Training Products

COLLABORATING WITH INDUSTRY TO DEVELOP STATE-OF-THE-ART TRAINING AND AWARENESS MATERIAL **FOR MINE WORKERS**

For many mining companies, ACG training products have become an integral and essential component of their training programs.

UNDERGROUND MINING GEOMECHANICS

Underground Drilling and Blasting
Best practices for drilling and blasting. A safety training video for underground metalliferous mine workers.

Rockburst – Unleashing Earth's Energy
A geotechnical hazard awareness training video for underground mine workers.

Securing the Ground
A training video for underground mine workers.

Reading the Ground
A geotechnical hazard awareness training video for underground metalliferous mine workers.

OPEN PIT MINING GEOMECHANICS

Down to Earth
A training video for open pit mine workers.

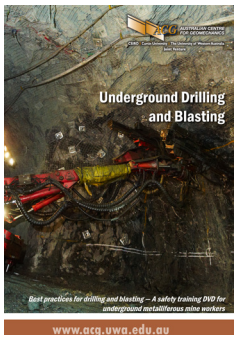
Unearthing Black Gold
A geotechnical hazard awareness training video for open pit coal mine workers.

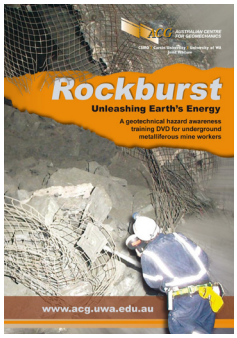
ENVIRONMENTAL GEOMECHANICS

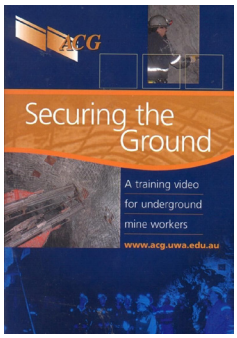
Tailings – From Concept to Closure
Best practices for tailings disposal. A training video for owners and operators of tailings storage facilities.

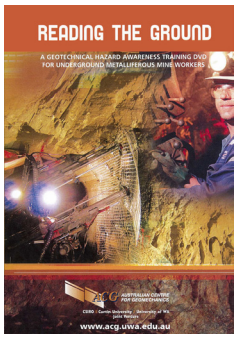
The range of ACG training videos are available to stream online from the ACG website, acg.uwa.edu.au/trainingvideos

UNDERGROUND MINING GEOMECHANICS

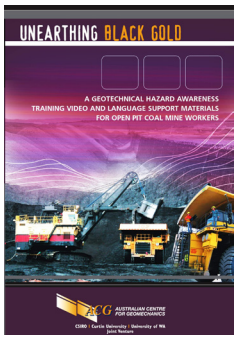




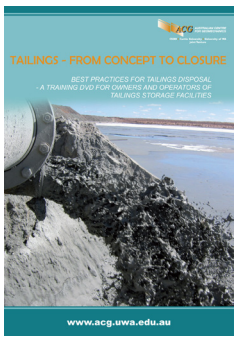




OPEN PIT MINING GEOMECHANICS



ENVIRONMENTAL GEOMECHANICS



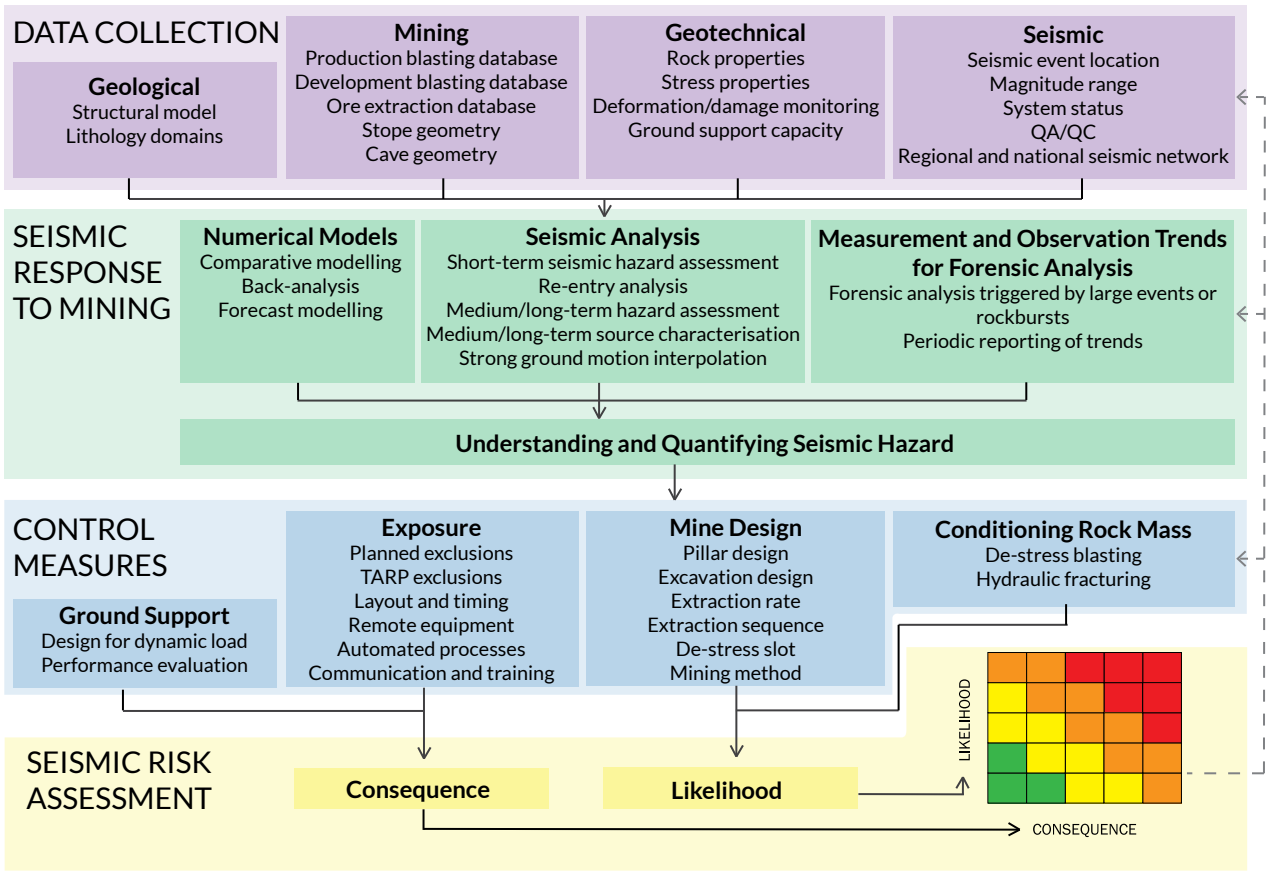
Seismic Risk Management Practices in Underground Mines Website

With the support of Newcrest Mining Limited, the Australian Centre for Geomechanics (ACG) undertook a survey to obtain a cross-section of the seismic risk management practices used in underground hard rock mines around the world. The survey included contributions from 16 mine sites around the world. The results of this survey were compiled and made available through a website, providing a flowchart summarising seismic risk management processes (SRMPs) in hard rock mines.

The SRMP flowchart outlines four major activities: data collection, seismic response to mining, control measures, and seismic risk assessment. It provides an overview of what is being done and is by no means an indication of what should be done. As our methods and understanding of mining-induced seismicity improve, so too will our risk management practices. The content of the flowchart and its associated website will be updated in the future.

The SRMP enables users to assess their own practices written in their Seismic Risk Management Plan against standard and advanced practices that can be applied for the management of seismic risks. It is also a valuable framework for the development and evaluation of a site-specific Seismic Risk Management Plan. Some mine sites are now using the process presented here as a generic framework and guideline for structuring and developing their site-specific Seismic Risk Management Plans.

SEISMIC RISK MANAGEMENT PRACTICES



For more information please visit acg.uwa.edu.au/srmp, or contact info-acg@uwa.edu.au

Financial Statement 2021–2022

STATEMENT OF FINANCIAL POSITION AS AT 31 DECEMBER 2022

	2022 A$	2021 A$	2020 A$
Cash	3,560,679	2,598,237	2,485,267
Receivables	0	0	0
Total current assets	3,560,679	2,598,237	2,485,267
Plant and equipment	0	0	0
Total non-current assets	0	0	0
Total assets	3,560,679	2,598,237	2,485,267
Creditors and borrowings	0	0	0
Provisions (leave liabilities)	288,446	289,095	271,621
Total current liabilities	288,446	289,095	271,621
Net assets	3,272,233	2,309,142	2,213,646
Shareholder's equity			
Partner contributions	243,980	243,980	243,980
Retained profits/acc (losses)	3,028,253	2,065,162	1,969,666
Total shareholder's equity	3,272,233	2,309,142	2,213,646

The balance sheet should be read in conjunction with the accompanying notes.

INCOME STATEMENT FOR THE YEAR ENDED 31 DECEMBER 2022

	2022 A$	2021 A$	2020 A$
Income			
Affiliate membership fees	30,000	34,584	38,335
Project administration	273,174	200,450	217,557
Project income – staff time	163,360	308,738	576,647
Project income – rock testing contracts	394,180	265,843	320,694
Project income – consulting, contracts and reimbursements	162,644	-13,435	-57,062
Event fees and sponsorships	2,942,340	1,499,497	526,325
Publications and training materials	45,466	51,347	93,260
Publications contracts and sponsorships	0	28,098	0
Interest	0	0	17,442
Profit on trade-in of vehicle	0	0	1,542
UWA student and research allocation	0	0	0
Industry funded special projects	24,522	130,372	148,048
Total income	**4,035,686**	**2,505,494**	**1,882,788**
Expenses			
Personnel	2,017,895	1,925,007	1,847,611
Personnel – relocation expenses	0	0	25,206
Provisions – leave liability (increase/decrease)	-649	17,474	-11,653
Office space incl. furniture and computers	5,620	807	8,061
Project, contract and consulting related expenses	212,020	245,313	149,330
Events, training and royalties	739,162	175,854	245,297
Travel, conferences and motor vehicle allowances	5,584	23,963	10,003
Operating overheads incl. printing	20,830	15,908	20,345
Professional services incl. online repository	3,345	4,950	12,164
Depreciation	0	0	0
Loss on trade-in of vehicle	0	0	0
Specialist publications	21,043	0	36,292
Student related expenses incl. special projects	47,747	722	851
Total expenses	**3,072,597**	**2,409,998**	**2,346,507**
Net profit (loss)	**963,089**	**95,496**	**-463,719**
Opening retained earnings	736,596	641,100	1,104,819
Closing retained earnings	**1,699,685**	**736,596**	**641,100**

The income statement account should be read in conjunction with the accompanying notes.

Financial Statement 2021–2022

STATEMENT OF CASHFLOWS FOR THE YEAR ENDED 31 DECEMBER 2022

	2022 A$	2021 A$	2020 A$
Cash flow from operating activities			
Receipts from customers	4,035,686	2,505,494	1,863,804
Payments to suppliers and employees	-3,073,246	-2,392,524	-2,356,618
Interest received	0	0	17,442
Net cash flows from/(used in) operating activities	962,440	112,970	-475,372
Acquisitions of plant and equipment	0	0	0
Net cash flows from/(used in) investing activities	0	0	0
Cash flows from financing activities			
Net increase/(decrease) in cash held	962,440	112,970	-475,372
Add: Opening cash brought forward	2,598,239	2,485,267	2,960,639
Closing cash carried forward	3,560,679	2,598,237	2,485,267

The statement of cash flows should be read in conjunction with the accompanying notes.

NOTES TO AND FORMING PART OF THE FINANCIAL STATEMENTS AT 31 DECEMBER 2022

1 Summary of Significant Accounting Policies

The financial statements have been prepared in accordance with the historical cost convention. Cost in relation to assets represents the cash amount paid or the fair value of the asset given in exchange.

The financial statements have been made out in accordance with applicable accounting standards.

The accounting policies adopted are consistent with those of the previous year unless otherwise specified.

(a) Depreciation

Depreciation is provided on a straight line basis on all tangible fixed assets, other than freehold land, at rates calculated to allocate their cost or valuation less estimated residual value, against the revenue derived over their estimated useful lives.

As of 2007, in line with The University of Western Australia's policies, equipment purchases of less than $5,000 in value are no longer recorded as an asset. The at cost plant and equipment value was amended accordingly in 2008.

(b) Income Tax

Tax effect accounting procedures are not applied as the Australian Centre for Geomechanics is a tax free research and education centre run on a not for profit basis.

(c) Income Recognition

Government grants are recorded as income when received.

Membership fees are recognised as income in line with the membership period covered in the subscription.

(d) Employee Entitlements

Provision is made for long service leave and annual leave estimated to be payable to employees on the basis of statutory and contractual requirements. Vested entitlements are classified as current and non-current liabilities.

The contributions made to superannuation funds by the entity are charged against profit.

Financial Statement 2021–2022

NOTES TO AND FORMING PART OF THE FINANCIAL STATEMENTS
AT 31 DECEMBER 2022 (continued)

		2022 A$	2021 A$	2020 A$
2	**Operating Profit/(Loss)**			
a.	The operating profit/(loss) before income tax is arrived at after charging/(crediting) the following items			
	Depreciation – plant and equipment	0	0	0
	Provision for employee entitlements	288,446	289,095	271,621
b.	Included in the operating profit/(loss) are the following items of operating revenue			
	Affiliate membership fees	30,000	34,584	38,335
	Industry funding special projects and reimbursements	187,166	116,937	90,986
	Project administration, staff time and contracts	830,714	775,031	1,114,898
	Event fees and sponsorships	2,942,340	1,499,497	526,325
	Publications and training materials sales	45,466	51,347	93,260
	Interest – other persons/corporations	0	0	17,442
	Profit on sale of vehicle	0	0	1,542
	Publications contracts and sponsorships	0	28,098	0
	UWA student and research allocation	0	0	0
	Total revenue	4,035,686	2,505,494	1,882,788
3	**Receivables**			
	Other debtors	0	0	0
	Total receivables	0	0	0
4	**Plant and Equipment**			
	At cost	136,223	136,223	136,223
	Provision for depreciation	-136,223	-136,223	-136,223
	Total plant and equipment	0	0	0

NOTES TO AND FORMING PART OF THE FINANCIAL STATEMENTS
AT 31 DECEMBER 2022 (continued)

		2022 A$	2021 A$	2020 A$
5	**Creditors and Borrowings (current)**			
	Trade creditors and accruals	**0**	**0**	**0**
6	**Provisions (current)**			
	Employee entitlements	288,446	289,095	271,621
7	**Partner Contributions**			
	CSIRO opening/closing balance	60,320	60,320	60,320
	WA School of Mines opening/closing balance	60,320	60,320	60,320
	UWA Geomechanics opening/closing balance	60,520	60,520	60,520
	UWA Geology	60,320	60,320	60,320
	DMP* (previously DoIR) opening/closing balance	2,500	2,500	2,500
	* contribution mainly provided in-kind			
	Total partner contributions	243,980	243,980	243,980
8	**Statement of Cash Flows**			
	Reconciliation of net profit/(loss) to the net cash flow from operations			
	Net profit/(loss)	963,089	95,496	-463,719
	Changes in assets and liabilities			
	– Other debtors	0	0	0
	– Trade creditors and accruals	0	0	0
	– Employee entitlements provision	-649	17,474	-11,653
	Depreciation	0	0	0
	Loss on trade-in of vehicles	0	0	0
	Net cash flow from operating activities	962,440	112,970	-475,372

Publications

The Australian Centre for Geomechanics provides industry with an excellent source of geomechanical knowledge through event proceedings, research reports and relevant industry publications. In response to industry need for high quality, comprehensive and state-of-the-art information, the ACG produces peer and technically reviewed event proceedings.

PHIL DIGHT

Books (Editor)

2021

Dight, PM (ed.) 2021, SSIM 2021: Proceedings of the Second International Slope Stability in Mining Conference, Australian Centre for Geomechanics, Perth.

Journals

2022

Wang, H, Dyskin, A, Pasternak, E & **Dight, P** 2022, 'Possible mechanism of spallation in rock samples under uniaxial compression', Engineering Fracture Mechanics, vol. 269, https://doi.org/10.1016/j.engfracmech.2022.108577

Wang, H, Dyskin, A, Pasternak, E, **Dight, P** & Jeffcoat-Sacco, B 2022, 'Fracture mechanics of spallation', Engineering Fracture Mechanics, vol. 260, https://doi.org/10.1016/j.engfracmech.2021.108186

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ANDY FOURIE

Books (Editor)

2022

Tibbett, M, **Fourie, A** & Boggs, G (eds) 2022, Mine Closure 2022: Proceedings of the 15th International Conference on Mine Closure, Australian Centre for Geomechanics, Perth.

Proceedings

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Veenstra, RL, Zhao, X, **Fourie, AB** & Grobler, JJ 2021, 'A comparison of cemented paste backfill shotcrete barricade design methods', in AB Fourie & D Reid (eds), Paste 2021: 24th International Conference on Paste, Thickened and Filtered Tailings, Australian Centre for Geomechanics, Perth, pp. 409-424, https://doi.org/10.36487/ACG_repo/2115_33

Reid, D, Fanni, R & **Fourie, AB** 2021, 'Some considerations when preparing thickened tailings for shear strength testing in the laboratory from a slurry', in AB Fourie & D Reid (eds), Paste 2021: 24th International Conference on Paste, Thickened and Filtered Tailings, Australian Centre for Geomechanics, Perth, pp. 203-216, https://doi.org/10.36487/ACG_repo/2115_17

Journals

2021

Nasharuddin, R, Luo, G, Robinson, N, **Fourie, A**, Johns, ML & Fridjonsson, EO 2021, 'Understanding the microstructural evolution of hypersaline cemented paste backfill with low-field NMR relaxation', Cement and Concrete Research, vol. 147, https://doi.org/10.1016/j.cemconres.2021.106516

Martens, E, Prommer, H, Sprocati, R, Sun, J, Dai, X, Crane, R, Jamieson, J, Ortega Tong, P, Rolle, M & **Fourie, A** 2021, 'Toward a more sustainable mining future with electrokinetic in situ leaching', Science Advances, vol. 7, no. 18, https://doi.org/10.1126/sciadv.abf9971

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Reid, D, **Fourie, A**, Ayala, JL, Dickinson, S, Ochoa-Cornejo, F, Fanni, R, Garfias, J, Da Fonseca, AV, Ghafghazi, M, Ovalle, C, Riemer, M, Rismanchian, A, Olivera, R & Suazo, G 2021, 'Results of a critical state line testing round robin programme', Géotechnique, vol. 71, no. 7, pp. 616 630, https://doi.org/10.1680/jgeot.19.P.373

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Guo, W, Huang, Y, **Fourie, A** & Wu, Y 2021, 'Mathematical model revealing the evolution of particle breakage and particle-size distribution for rockfill during triaxial shearing', European Journal of Environmental and Civil Engineering, vol. 25, no. 5, pp. 893-908, https://doi.org/10.1080/19648189.2018.1552898

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illite(001) surface: Implications for soil pollution and reclamation', Environmental Pollution, vol. 312, https://doi.org/10.1016/j.envpol.2022.120072

YVES POTVIN

Books (Editor)

2022

Potvin, Y (ed.) 2022, Caving 2022: Proceedings of the Fifth International Conference on Block and Sublevel Caving, Australian Centre for Geomechanics, Perth.

Proceedings

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McFadyen, B, Woodward, K & **Potvin, Y** 2021, 'Open stope design; beyond the Stability Graph', Underground Operators Conference 2021, The Australasian Institute of Mining and Metallurgy, Carlton.

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2022

Morkel, IG, Wesseloo, J & **Potvin, Y** 2022, 'Seismic event location uncertainty in mining with reference to caving', in Y Potvin (ed.), Caving 2022: Fifth International Conference on Block and Sublevel Caving, Australian Centre for Geomechanics, Perth, pp. 445-460, https://doi.org/10.36487/ACG_repo/2205_30

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2022

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JOHAN WESSELOO

Proceedings

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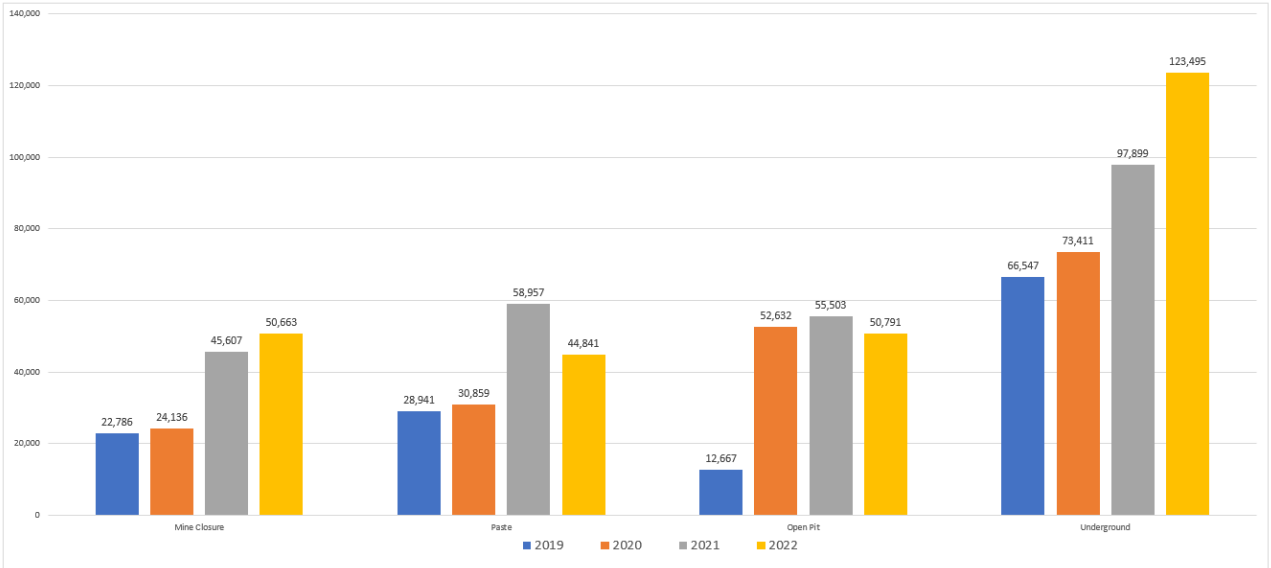

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