ACG AUSTRALIAN CENTRE FOR GEOMECHANICS
CSIRO | Curtin University | University of WA
Joint Venture

Volume No. 27 December 2006

AUSTRALIAN CENTRE FOR GEOMECHANICS
NEWSLETTER

Some thoughts regarding mining and rock mechanics

By Professor William Hustrulid, The University of Utah, USA

The following article is an excerpt from the keynote address that Professor Hustrulid presented at the Colorado School of Mines "50 Years of Rock Mechanics – Landmarks and Future Challenges" Symposium held in the USA in July 2006.

Professor Hustrulid reviews the historical development of rock mechanics, and focuses on some of the shortcomings of this science and identifies possible paths forward.

Background

In 1969, in their paper "Status of Rock Mechanics as Applied to Mining" Black and Hoek (1969) indicated,

"The methods of rock mechanics are not different in principle from the general methods of applied science, but they are more difficult to apply successfully. There are many reasons for this difficulty, but among the most significant are:

(1) Rock materials are non-homogeneous and often anisotropic.

(2) The significant parameters relating to a natural rock mass are infinitely variable and difficult to formulate and define precisely.

(3) Generalized models and theories of ground behavior are complex, and the mathematics involved is often intractable unless simplifications are introduced into the theory itself and to the boundary conditions applied.

(4) Field experimentation in realistic conditions is difficult to arrange, time consuming and almost always expensive.

(5) With few notable exceptions, mining companies have been unwilling to cooperate fully in the essential field and experimental work, or to support

Continued on page 2

Rock mechanics practitioners and students could benefit from comprehensive case studies

What's in this volume?

Continued from page 1

research work either by themselves or at universities or other research establishments.

For progress to be made, this last point is the vital key. A body of really useful knowledge cannot be developed unless the more academic studies are developed and validated in the field."

Development

Over the past 50 years, great progress has been made in the development of numerical tools required for addressing points (1) – (3), new methods have been developed for describing rock properties, and new tools have been developed for monitoring rock response. Point (4) is still true and will remain so. Point (5), however, which should be easily changeable, has remained largely unchanged. The geomechanics "experience" of the mining companies remains largely locked in various files and in the heads of a few individuals. The knowledge that might have been developed through open access to the collective experience base has not been developed and the mining world is poorer for this. Until this is corrected, very expensive geomechanics-based mistakes will continue to be made with few general lessons learned. Because of the paucity of the published experience base and resulting analyses, the teaching of rock mechanics at the university suffers, important tools needed by the rock mechanics engineers on the mines are lacking, and the mining companies will continue to pay high prices in terms of lost resources and, unfortunately, sometimes in injuries and lives for repeating the rock mechanics-based mistakes of others. For the field to progress, the experience base needs to be packaged into a form which can be easily accessed, communicated, discussed, and built upon. This is very much the way that the field of soil mechanics developed over the years through the contributions of consultants such as Karl Terzaghi and Ralph Peck.

Case studies

A first step in this regard is the collection of a number of well-documented case studies. Some examples in this regard might be Chapters 6: The Rio Grande Project- Argentina and 7: A Slope Stability Problem in Hong Kong included in Practical Rock Engineering by Evert Hoek (Hoek, 2000). This book is downloadable from the Rocscience web site (rockscience.com). The Hoek "Discussion Papers" on the same web site provide other examples indicating what might be gained from such an approach.

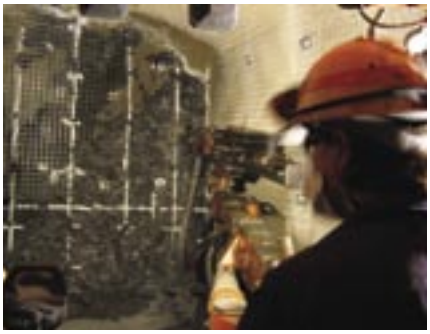
For the teacher, these case studies would form the core of a series of undergraduate and graduate courses. According to the world-renowned Harvard Business School (www.hbs.edu/case),

"The Case Method Educational Experience forces students to grapple with exactly the kinds of decisions and dilemmas managers confront every day. In doing so, it redefines the traditional educational dynamic in which the professor dispenses knowledge and students passively receive it. The case method creates a classroom in which students succeed not by simply absorbing facts and theories, but also by exercising the skills of leadership and teamwork in the face of real problems."

These case studies so packaged will serve as extremely valuable resource materials for graduate theses by the students of the world. The new interpretations and evaluations of the contained basic data will speed the growth of the field.

Industry application

For the mining professional faced with solving a particular problem at a specific mine, access to these case studies will provide insight and tips regarding how others have approached a similar problem. With these extended assets, the traditionally small geotechnical group is virtually increased in size. Important linkages to other mines are also facilitated. It is expected that the mines should see a major improvement in the geotechnical level and thereby in the economic bottom line.



Industry advancement requires commitment from consultancies and their mining clients

For the consulting groups, the availability of well-trained graduates is a major plus both in terms of recruiting and also in terms of the technical level of their client speaking-partners. Their focus can then be on solving the very complicated problems especially suited to such consultant efforts.

In short, the collection of first-rate case studies and their use at various levels from teaching through mine application appears to be an essential next step if the field of mining rock mechanics is to make the required contribution to the mines of today and especially for the mines of the future.

Evaluating case method success

There are a number of reasons why the proposed case study approach will not work. Some of these are listed below:

- Engineering progresses by analysing failures and learning from them. In this regard, there are major differences between civil construction and mining projects concerning the availability of such information. Civil construction data are largely in the public domain as, for example, the recent levee failures at New Orleans. In the private domain, failure data are generally not very public unless they resulted in deaths/injuries. Failures are, at the very least, embarrassing and often financial disasters. These are normally buried deep within the confines of the mining company.
- Sometimes failures become the matter for insurance companies, and seldom does the information get out.
- The case studies are considered a significant part of the intellectual

property of the consulting companies and/or mining companies.

- No one is willing to pay the costs involved in preparing the case studies.
- No one is prepared to expend the time and effort to do the job, even given the funding.
- Good case studies are very difficult to write. The possessors of the data may not be up to the job.

Now turning to the arguments as to why the case method should and could work. As Soderberg pointed out in his comments regarding the effect of slope angle on mine economics (Soderberg, 1957), there are substantial economic and safety reasons for making the case method work. It is felt that a very strong business case can be made for its success. The first step in the process is for the mining companies to recognise and accept the importance of case studies to the future development of the mining rock mechanics field and to their collective future. Once this step has been taken, the rest is relatively easy. Some practical steps to facilitate case study preparation are summarised below:

- Develop a case study "template."
- Identify a practical mechanism for "Banking" the case studies, for example, on a special website. In this form, the page limit becomes a non-factor and very comprehensive case studies can be included.
- Develop an annual award recognising the best mining rock mechanics case study.
- Include a mining rock mechanics case study design competition as part of every rock mechanics meeting.
- Involve undergraduate and graduate students in assembling case studies as part of a university special projects course.
- Have mining students work on collecting/assembling the basic information as part of summer mine work experience.
- Encourage consulting companies to involve both undergraduate and graduate students in preparing their case studies.
- Encourage the governmental R & D funding agencies to fund the case study collection.
- Encourage the national agencies involved with mining health and safety to participate in the preparation of mining rock mechanics case studies.
- Last, but surely not least, convince mining rock mechanics consulting companies that the preparation of these case studies fits into their business plan – good advertising.

The "Case Method" approach has been the hallmark of the Harvard Business School since 1920 and has since been adopted by business schools worldwide. Many mining managers have progressed through such programmes. It is time for the mining industry to seriously consider the many advantages this approach has to offer in advancing mining rock mechanics. The first obvious step in the adoption of this approach is the collection of case studies. These are largely in the realm of the mining companies and the mining consultants. Without their enthusiastic support, the idea is dead and the progress projected for the next fifty years is evolutionary rather than revolutionary. The writing of the case studies offers an excellent opportunity for the operators to interact with the mining universities.

Final comments

These final comments, while those of the author, are loosely structured after those made by C. Fairhurst (1963):

- Mining rock mechanics has progressed during the past five decades, but it is still in the early stages of development.
- Many assumptions must still be made in the analysis of specific problems, and the resulting "solutions" are, consequently, only rough approximations.
- Although these "solutions" have been of considerable benefit to mining engineers, further substantive progress will depend on the wholesale collection, analysis, and presentation of actual mining experience in the form of comprehensive case studies.
- Pronounced size effects due to jointing, faulting, and bedding often make it necessary to undertake costly large-scale experimental investigations in situ. The current "quantitative" approaches used for including structural features when assigning rock mass strength and deformation properties, for example, need substantiation. That does not exist today. Well-documented case studies would be a major help in that regard.
- Close cooperation between the mining companies, the mining consultants, and mining universities is therefore necessary/essential, and should be strongly encouraged, if the principles of rock mechanics are to be more widely accepted and used in mining practice.

In looking forward, I do not see a practical mechanism by which marked progress will occur in the field of mining rock mechanics other than through the whole-hearted participation of the consultancies and their mining clients. Progress requires the careful collection, analysis and presentation of field/mine experience. This was pointed out fifty years ago at the first of the rock mechanics meetings and is pointed out here once again. Without the availability of such field data, "progress" in the field will largely occur through theoreticians talking to theoreticians. This is unacceptable. A practical way forward is through the development of comprehensive case studies. It is hoped that this paper will stimulate some healthy discussion regarding the future of mining rock mechanics and the formulation and funding of an action plan.

Please contact the ACG for the unedited article.

Professor Bill Hustrulid, The University of Utah

Stress failure of a shallow open cut mine

By David Lucas, associate engineering geologist, Coffey Mining

Introduction

Numerical modelling has been widely used for stress analysis of underground openings, while open pit slope stability has largely been considered as a gravity-driven issue which is often analysed using limit-equilibrium methods. Numerical modelling supported by state-of-the-art monitoring has benefited a large open cut mine faced with a complex failure mechanism, and has shown that stress can influence stability in open cut mines. Stress must be considered as a potential failure initiator when rock strengths are low or stresses are high compared to the pit depth.

The mine

Flinders Power owns and operates the Leigh Creek coal mine in South Australia, 550 km north of Adelaide in South Australia. Coal is extracted from two open cuts (Figure 1) and is railed 280 km to Port Augusta, where it is used for power generation. Approximately one-third of the coal is mined from the mine's Upper Series pit which is planned to be mined to a depth of 150 m (Figure 2).

Figure 1

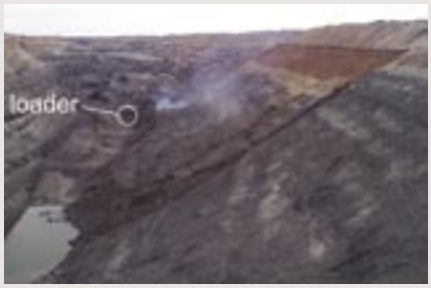


Figure 2

The failure

In June 2001 a section of footwall failed into one of the Upper Series open cut, sterilising coal and casting doubt on the future viability of the Upper Series (Figure 3). The failure volume was approximately 720,000 m^3. A loader was stationed near the footwall at the time and the operator narrowly escaped injury.

The footwall failed by sliding on a bedding shear which lies 8-10 m below the footwall, and appeared to shear through intact rock at the toe. There were no joints or other structures in the toe that could have weakened the toe rock in the direction of failure.

The sudden and catastrophic nature of the failure had the potential to close the Upper Series pit unless a full understanding of its cause could be gained for future design.

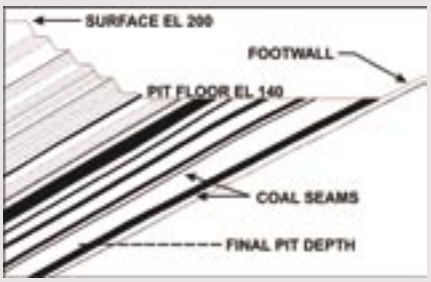


Figure 3

Stability analysis

Flinders Power had been aware of the presence of footwall bedding shears for several years, and had investigated the failure potential by drilling to locate the bedding shears, testing their shear strength, installing piezometers and analysing the footwall stability using conventional limit equilibrium and buckling analysis.

These analyses had shown that the footwall should have been stable, with typical Factors of Safety (FOS) of 1.60-1.70. Following the failure, several possible explanations were tested to explain the cause including variations in piezometric pressure, lower-than-expected rock strength, undercutting and adverse jointing creating a failure path through the toe.

None of these possibilities could be reconciled against the available evidence and it was speculated that the footwall had failed by some other mechanism.

Numerical modelling

Limit equilibrium analysis is frequently and successfully used for pit slope stability analysis but has several shortcomings: it assumes a sliding failure mechanism with instantaneous sliding of the entire failure path including rupture of the rock toe, and it does not allow for deformation or progressive failure.

Coffey Mining (formerly BFP Consultants) and MA Coulthard & Associates worked with Flinders Power to develop a numerical modelling approach using Itasca's UDEC (Universal Distinct Element Code) software. Numerical modelling does not pre-define the mechanism as part of the analysis, but instead allows a failure to develop according to material strength and the in-situ and mining-induced stress conditions.

UDEC is a two-dimensional modelling program that is ideally suited to a failure such as this example, because the footwall is long (measured along strike) compared to its cross-sectional dimensions. Three-dimensional edge effects which are often a feature of more confined failures are insignificant in this example.

Excavation was simulated in UDEC to commence at a pre-mining stage and levels were extracted in a way that resembles the actual mining sequence. While this occurs, stress magnitude and direction both change around the pit walls and the model deforms in response to these induced stresses.

Failure mechanism

As mining continues, a stress concentration develops at the toe of the footwall (Figure 4). When the model is mined to a depth of 98 m, the maximum principal stress at the toe exceeds the unconfined compressive strength of the rock and localised failure occurs (Figure 5).

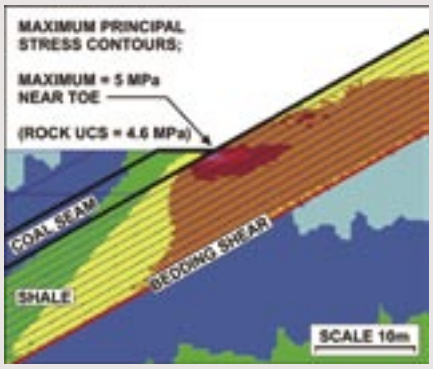


Figure 4

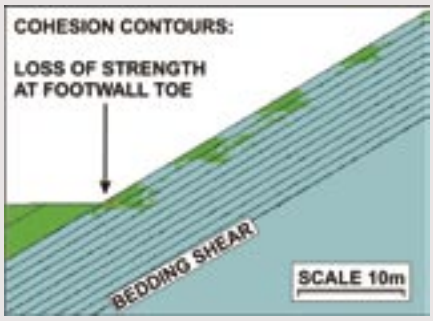


Figure 5

Failure of the toe causes a transfer of the stress concentration deeper within the footwall which also fails, transferring the stress to the next layer. This process continues until a weakened rupture zone has formed through the footwall toe from the surface to the bedding shear (Figure 6).

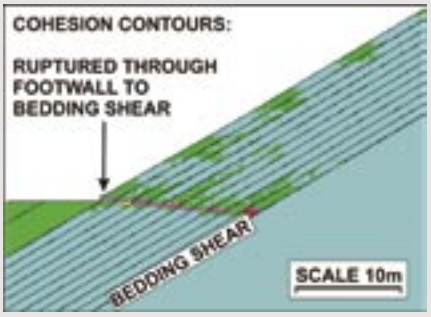


Figure 6

After this progressive rupture takes place, the weakened toe can no longer support the weight of the footwall and sliding begins under the force of gravity alone. The steep dip of the footwall (30°) compared to the friction angle of the bedding shear (15°) allowed the failure to continue quickly once toe restraint was removed.

Stress measurements

The ratio of maximum horizontal stress to vertical stress is often not known and must be assumed from measurements at other sites. Initial modelling used stress measurements from the Roxby Downs mine, some 150 km to the west of Leigh Creek.

The assumed pre-mining stress field predicted substantial stress-induced uplift of the pit floor and footwall, which is resisted by the weathered layer and dragline dumps (Figure 7). There is evidence in the field to support this modelling prediction, including slight uplift, lateral cracking, oversteepening and overhanging of the base of the weathered layer. However the modelling prediction of uplift appeared to be excessive.

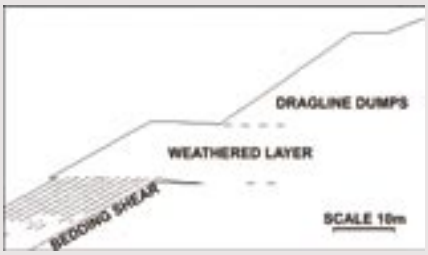


Figure 7

Stress measurements were then carried out of the current stress field and were back-calculated to the pre-mining stress field. This indicated that the maximum horizontal stress direction was significantly different than was previously assumed. Using the new stress field predicted uplift that was more consistent with field observations while the failure mechanism remained unchanged.

Modelling with the measured stress field provided confidence in the failure mechanism predictions and the parameters used in the model.

Predictions for future mining

The numerical model was able to explain the failure in terms of mining-induced stress, which was not possible using other methods of analysis. However, of greater value is the ability of the model to be adapted to future mining cuts so that it can be used for design.

The Upper Series pit was to be deepened along strike to the west. Bedding shears continue beneath the footwall in the remainder of the Upper Series and it was found that these occurred at 5 m and 14 m deep, not at 10 m deep as in the area of the failure. The mining cut was to extend the pit deeper than the failure and therefore presented a challenge to design a stable footwall, particularly in the presence of a shallower bedding shear.

The UDEC model was adapted to the geometry of the new mining cut and was mined using the same properties that were determined from the model of the failure. The model showed that the footwall in the new mining cut would fail when the pit was about 16 m shallower than the depth of the actual failure because of the shallower bedding shear.

Stabilisation options

FOS was determined using the UDEC model and showed that mining could be safely completed by mining to a shallower floor level. However, this would result in a significant reduction in reserves and other

options were explored that aimed to improve the coal recovery.

The failure occurs because the stress response of the ground due to mining causes uplift which attempts to force the footwall upward, which in turn is resisted by its own weight.

It was found that by removing some of the footwall back to the bedding shear, the maximum principal stress in the toe would be reduced by allowing the footwall to slide on the bedding shear in response to mining-induced stress. Higher stress conditions remain deeper within the footwall due to the presence of a deeper bedding shear and this then governs the footwall stability. Figure 8 shows the type of stress-induced failure that may occur with this geometry and stress condition.

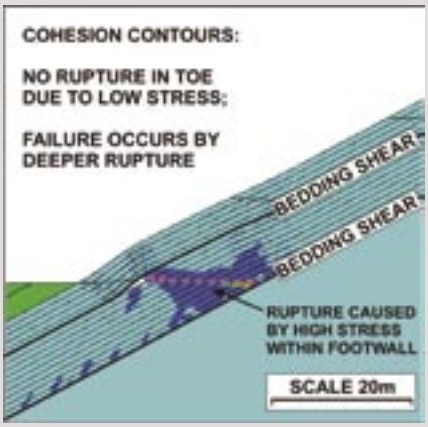


Figure 8

The UDEC model was used to determine the stability of various levels of footwall removal and coal mining to control both toe failure, and deep-seated stress-induced failure. Figure 9 shows the final footwall profile.

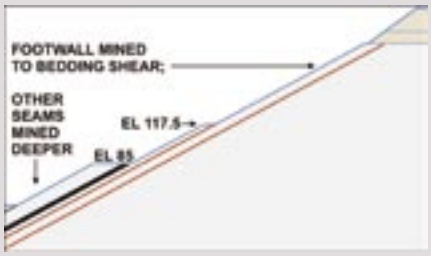


Figure 9

Monitoring

Figure 8 shows that significant toe dilation would occur during failure. The modelling also showed that very small toe dilation occurs in the early stages of rupture. To detect the onset of any such failure, the footwall was monitored during mining using Groundprobe's Slope Stability Radar system.

The critical period for footwall stability was predicted to be when coal is mined near the footwall at EL85, and radar monitoring was used during this period.

Completion of the mining cut

Mining progressed through the critical period between October 2004 and January 2005 when coal was removed down to the 85 level near the footwall (Figure 10).

Figure 10

Movements detected by the radar monitoring system ranged from 2 mm in 4 hours, to 30 mm over several days. Movement rates increased and the area of movement extended as mining progressed deeper, suggesting that the footwall was increasingly stressed and that failure may have occurred if mining extended deeper near the footwall.

No failure occurred and the mining cut is now nearing completion to its design elevation of EL50 below the buttress.

Conclusions

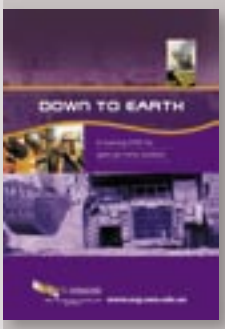
The Leigh Creek footwall failure has shown that a combination of high in-situ stress, relatively low rock strength, and unfavourable pit geometry such as a steeply dipping footwall underlain by a bedding shear, can cause stress-related failure in a shallow open cut mine.

Numerical modelling has proven successful in explaining the failure mechanism. A modified numerical model was used with the same parameters determined from the failure analysis to design the adjacent cut, which was mined successfully. Radar monitoring detected increasing dilation of the footwall toe with depth, indicating that the footwall toe was partly stressed.

Limit equilibrium methods are widely used to analyse such pit slopes. In this example, such analysis indicated that a mining depth could be achieved that was far greater than was actually possible. As open cut mines extend to greater depths, stress-related failures are likely to become more apparent and traditional analysis methods should be used with caution.

For further information contact David Lucas on David_Lucas@coffey.com.au

OPEN PIT MINE WORKERS GEOTECHNICAL HAZARD AWARENESS TRAINING DVDS



What does your workforce know about the ground hazards of open pits?

Preventing recurrence of surface mining accidents remains a top priority requiring constant vigilance and a substantial commitment from all involved in open pit mining operations.

Open pit wall failures, loose rocks rolling down slopes, ground water and stockpiling procedures are common sources of risks in Australian open cut operations. The ACG's **Unearthing Black Gold** and **Down to Earth** open pit mining geotechnical training DVDs aim to equip mine workers with the necessary skills and knowledge to assess and react to the geomechanics hazards in open pit operations. Contact the ACG for more information.

2007 INTERNATIONAL SYMPOSIUM ON

Rock Slope Stability

in Open Pit Mining and Civil Engineering

12 – 14 September 2007

Sheraton Perth Hotel, Western Australia

Slope Stability 07 co-chairs Yves Potvin, ACG, and John Read, CSIRO look forward to presenting an innovative symposium that will explore the most recent developments in the design, analysis, excavation and management of rock slopes.

Interested authors are requested to submit their abstracts to the ACG before Monday 26 February 2007 via acg@acg.uwa.edu.au.

Slope Stability 07 will take place concurrently with The AusIMM's Large Open Pit Mining Conference to be held at the same venue from 10 – 11 September 2007. Attendance at these highly regarded events will provide you with a unique opportunity to question the experts and to network with peers.

Visit www.slopestability07.com for further details.

Slope Stability 07 will examine the latest rock slope stability developments from throughout the world

Photos courtesy of Argyle Diamond Mines

Slope Monitoring Forum

A one-day pre-symposium Slope Monitoring Forum will explore the emerging monitoring technologies and, more specifically, discuss the strengths, weaknesses and applicability of:

- Digital photogrametry
- Laser
- Radar
- Seismic monitoring applied to slope stability

The forum will feature demonstrations of commercial and R & D technologies, formal presentations and discussion periods.

Paste07

go with the flow

Paste flows well

In an industry that is consistently trying to minimise its risk exposure while simultaneously driving down unit costs, the management of mine tailings has provided an ongoing concern to mine managers and owners. The current resource boom is seeing lower and lower grade deposits becoming economically viable, with the inevitable consequence that greater volumes of tailings are produced per unit of commodity recovered.

Conventional tailings management methods rely on transporting the tailings to the tailings storage facility (TSF) at a low solids content, with more than three parts water to one part solid not being unusual. The consequences of this approach have sometimes been catastrophic failures resulting in significant economic and environmental damage and even fatalities (the most recent failure of this type resulting in fatalities occurred in China in April this year). However, more common and immediate concerns include the enormous wastage of water that results, difficulties with post-closure rehabilitation and operational costs that result from having to frequently undertake earthworks to raise the height of the TSF.

In the 1970s an alternative approach was advocated by Eli Robinsky in Canada. He suggested thickening the tailings to a consistency such that no segregation of particles occurred upon deposition and no free water bled to the surface of the TSF, significantly reducing the need for water retention and management. His idea was received with interest but also scepticism and for decades was considered largely impractical. Despite this apparent lack of support, Robinsky persevered with the idea and was responsible for implementation of the first thickened tailings surface disposal site at Kidd Creek mine in Canada. The project encountered many difficulties with achieving required underflow densities consistently, but despite this, the perserverance of the mine management paid off and today the site seems to be operating as planned. More importantly, it showed that the technology was workable, if only the equipment to reliably and economically prepare and transport the thickened tailings was available. Industry developments over the past two decades have provided this equipment and many of the problems encountered by the Kidd Creek team have been overcome. There are a number of operations around the world using thickened tailings for surface deposition of tailings, with the material being handled including diamond, mineral sands, gold, alumina, lead-zinc and nickel tailings. There are upwards of a dozen operations in Australia alone that are today utilising some form of thickened tailings disposal on surface and at least a similar number of underground operations using even higher consistency material (paste tailings) for backfilling mined voids.

Contrary to only seven or eight years ago, when most tailings operators and managers were interested but sceptical about thickened tailings, commonly asking questions such as, 'but where is it working?' and very few examples were available, today things are different. There are many instances where the technology has been implemented and thoroughly evaluated. Today we have the opportunity to learn from many of these operations, providing sound arguments for future projects that are considering thickened tailings as an alternative solution to site-specific problems.

The success of some paste and thickened tailings projects provides sound arguments for projects considering this advancing technology. Photo courtesy of De Beers

Sufficient experience of operating thickened tailings sites has been gathered to begin validating some of the claimed benefits of the technology, such as reduced water and reagent usage, decreased operational costs and reduced seepage to the subsurface. Interesting experiences with the management of stormwater runoff are also available, and the increasing interest in the problems of how closing a facility built using thickened tailings (such as a central thickened discharge, or CTD) site differs from a conventional facility, provides for interesting debate.

All of these issues will be aired at the Australian Centre for Geomechanics' 10th International Seminar on Paste and Thickened Tailings that will take place in Fremantle, Western Australia in March 2007. The seminar will provide an opportunity to share successful experiences with using thickened tailings, as well as the problems that have been encountered. This will help indicate the direction that future research and development should be focussing on as the industry continues to look to drive down unit costs of tailings management while reducing the risk of harm to potentially affected communities and to the environment.

For further information about Paste07, please visit www.paste07.com.

Andy Fourie, ACG Paste07 Seminar chair

The Paste07 Seminar will explore the latest advances in the preparation, transportation and deposition of paste and thickened tailings that will be reinforced by current case studies. Photo courtesy Mt Keith Nickel Operations, BHP Billiton Nickel West

Eastern Australian Ground Control Group

Shaft Development - Design, Construction, Operation, Monitoring and Repair Technical Meeting & Site Tours

May 2007, Townsville, Queensland

Call for Papers and Presentations

The Eastern Australian Ground Control Group (EAGCG) is holding a meeting in Townsville to discuss aspects of the investigation, design, construction, operation, maintenance and monitoring of all types of vertical openings across civil and mining applications including vent shafts, haulage shafts, ore passes, crusher chambers, ore bins, sewer outfall risers, surge shafts and coffer dams.

Papers and presentations are invited from designers, shaft development contractors, mine/infrastructure operators and researchers on all aspects of vertical openings. Tours are planned to various mines accessible from Townsville.

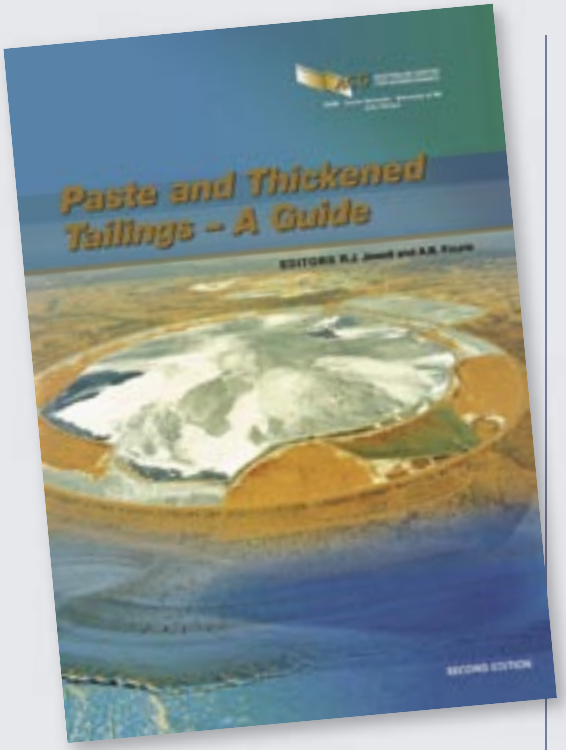
For further details, please contact:

Marnie Pascoe – president (Marnie.Pascoe@bhpbilliton.com)
Andrew Campbell – secretary (acampbell@bendigomining.com.au)

Paste and Thickened Tailings – A Guide (Second Edition)

A book review by Robert Cooke, director, Paterson and Cooke Consulting Engineers Pty Ltd, South Africa

The first edition of the Paste and Thickened Tailings Guide published by the Australian Centre for Geomechanics played an important role in helping academics and practitioners establish a common terminology and understanding in this rapidly advancing field. The second edition further builds on this by including new chapters on slurry chemistry and reagents, and a substantially expanded case studies chapter.



The Guide comprises twelve chapters, each written by internationally recognised experts, covering all aspects of paste and thickened tailings from preparation through to surface and underground disposal and mine closure. The editors note that the Guide is not a design manual and is rather intended to provide guidance and advice for professionals considering implementing a paste or thickened tailings system.

The chapter on sustainability notes that it is important to examine full life cycle costs before selecting a tailings disposal system. Apart from reduced operating and closure costs, paste and thickened tailings systems may also offer non-monetary benefits in terms of improved public perception regarding environmental and social issues. Increasingly for many operations production is limited by water availability.

A good appreciation of rheological concepts is important for understanding the key processes related to paste and thickened tailings systems: tailings dewatering, transport and disposal. The rheology chapter provides a detailed overview of these concepts and includes the suggestion that tailings disposal systems are designed to meet the rheology required for the selected disposal method.

The chapter on material characterisation notes that some tailings properties change during the preparation, transport and disposal processes: most significant of these is the change in the tailings mixture rheology. Guidelines for relevant measurements for characterising the tailings for each of these processes are presented. The author warns that beach slope angles determined from laboratory flume tests should be treated with caution as there is no accepted method yet for predicting deposition slopes from laboratory tests. The chapter concludes with a useful checklist of material properties that should be measured for the thickened tailings projects.

It may be the least accessible chapter in the Guide, but the slurry chemistry chapter deals with issues that are critical to implementing successful systems for tailings containing clay minerals. The authors describe how the colloidal properties of the clay suspensions influence the tailings rheology and behaviour during sedimentation de-watering. It is likely that future significant advances in paste and thickened tailings will be dependant on a proper understanding of slurry chemistry.

The chapter on reagents provides an interesting history of the development of flocculants and coagulants – I am pleased to finally know the difference between the terms "flocculant" and "flocculent"! Reagents are a significant cost for many paste and thickened tailings systems. The overview prepared by the authors will help designers and operators optimise reagent selection and dosage, by providing a good understanding of flocculation and coagulation mechanisms and the factors that affect reagent performance.

The chapter on thickening and filtration provides an excellent overview of thickener types and the methodologies used for sizing thickeners. They note that sizing paste thickeners is largely based on experience with similar installations. The various types of filters used to produce paste are described with the relative advantages and disadvantages of each type. Useful indicative costs are provided for thickeners and filters.

The transport chapter discusses the flow behaviour of paste and thickened tailings in pipelines. The relative advantages and limitations of centrifugal and positive displacement pumps are reviewed and the author notes that life cycle costs must be evaluated when selecting the pump type. Transport of paste by truck and conveyor is discussed although these modes are not widely used for surface tailings disposal. The chapter concludes with a review of aspects to consider when undertaking an economic evaluation or comparison of transport systems.

A balanced assessment of the advantages and disadvantages of surface disposal of paste or thickened tailings compared with conventional tailings is presented in the above ground disposal chapter. The author notes that although the concept of high density tailings disposal technology was first implemented over 30 years ago, the adoption of the technology for surface has been slow. This is ascribed to the lack of reliable methods for producing and transporting tailings. With the recent advances in these areas it is expected that implementation rate of paste and thickened tailings systems will accelerate. The chapter details considerations for design, operation and management.

The mine backfill chapter discusses the interdependence of backfill composition, underground benefits and legal compliance. This is illustrated by considering the benefits of underground paste disposal for base metal, coal, gold and platinum mines. The author reviews underground rock mechanics requirements, environmental requirements and considerations for ensuring successful paste transport. Examples of two underground paste disposal projects are presented to illustrate the application of underground paste backfill technology.

The closure chapter notes that although all mining operations have a finite life, the mining operation remnants (including the tailings storage facility) have an almost infinite life. The mining company, in consultation with local communities and authorities, must develop a suitable final closure design that meets the requirements of all stakeholders. The chapter deals with safety, stability, aesthetics, acid mine drainage, financial issues, reclamation and rehabilitation.

The Guide concludes with twelve excellent case studies for surface disposal of paste and thickened tailings. The studies cover a broad range of systems illustrating the applicability of the technology for different applications. This chapter will be extremely valuable for anyone contemplating a paste and thickened tailings system. However, the value of the case studies could be enhanced by more consistent reporting of key parameters (e.g. rheology and beach slope) and identification of key lessons learnt from the system (i.e. what did not work, how the system was improved).

In summary, the Guide makes an extremely valuable contribution to the advancement of paste and thickened tailings technology. It is a key reference for all professionals in the field.

To obtain your copy of the Paste and Thickened Tailings – A Guide (Second Edition), please contact the ACG via acg@acg.uwa.edu.au

Robert Cooke, Paterson and Cooke Consulting Engineers Pty Ltd

The ACG gratefully acknowledges the support of the publication sponsors:

Level 1 Sponsors:

- **Aran International Pty Ltd**
- **Dorr-Oliver Eimco**
- **Lightnin Africa**
- **Metago Environmental Engineers**
- **Outokumpu Technology Pty Ltd**
- **PasteThick Associates**
- **SRK Consulting**

Level 2 Sponsors:

- AMC Consultants
- AMEC Earth & Environmental
- Australian Tailings Consultants
- Coffey Mining

The Guide covers a broad range of systems illustrating the applicability of the technology for different projects

Postgraduate studentships in the field of mining backfill

The ACG, in collaboration with the School of Civil & Resource Engineering at The University of Western Australia, has secured industry sponsorship for a research programme on the geomechanics of underground backfilling. The project will focus on the application of effective stress theory to minimise the geotechnical risks associated with backfilling procedures, and the optimisation of the backfilling process in order to reduce costs. It will require laboratory testing (including the use of a geotechnical centrifuge), numerical modelling and some field work.

Entitlements include a tax-free stipend of A$30,000 for up to 3.5 years, as well as all travel, computer and study materials.

The position will suit a civil, resource or mining engineering graduate. The research project is in a completely new field within the mining industry and will provide successful candidates with a niche qualification in a rapidly expanding field. The research programme will include collaboration with researchers in Canada and there may be opportunities for exchange visits.

For more information, please contact Andy Fourie at andyf@acg.uwa.edu.au or Martin Fahey at fahey@civil.uwa.edu.au.

Is the last drop worth it?

By Ian Arbuthnot, director, Outokumpu Technology Pty Ltd

Considerable progress has been made in the last 15-20 years in developing thickeners capable of producing higher density underflows. This follows the increasing demand from the minerals industry for higher densities, which is driven by the economics of tailings disposal and some process issues.

In particular, high density tailings allow more economic disposal methods (e.g. Central Thickened Discharge (CTD), "dry stacking"), while at the same time recovering more water and hence reducing water make-up costs; whole tailings can be used where appropriate for mine backfill – which can both reduce underground mining costs and in some cases extend mine life; and in some processing applications, operating costs and/or capital equipment costs can be reduced.

We need to be reasonably clear on the definitions used. To distinguish between a "high density slurry" and "paste", a yield stress (YS) transition of 200± 25Pa has been proposed (Ref. Jewell, R.J., Fourie, A.B. and Lord, E.R. "*Paste and Thickened Tailings – A Guide*" ACG (2002)). Above this transition is paste, and below this is either a "low", "medium" or "high density" slurry. A high density slurry would be non-segregating and would still flow down a slope, and would have a YS up to about 200Pa. A paste would exceed this YS value and would generally require positive displacement (PD) pumping, and would not release a significant amount of surface water once deposited. Care still needs to be taken in using these definitions, since the YS of a thickened slurry or paste is affected by its shear history.

A "slump test" is used in some situations to describe the behaviour of a high YS slurry. This is a simple standardised test which measures the degree to which a material slumps when placed on a flat surface, and is inversely related to the YS of the material.

Further background reading material on these concepts can be found in the excellent publication "*Paste and Thickened Tailings – A Guide*", referred above. A second edition of this Guide was printed in 2006.

Applications

The main minerals processing applications where higher density thickener underflows have been used are:

Tailings disposal For above-ground surface storage, rather than the conventional tailings dam, a high density non-segregating slurry is required. Likewise for the "down-valley" style of disposal, in which the tailings material must flow, but should exhibit a planar slope in its beaching characteristics.

Mine backfill Whole (coarse and fines) or part tailings (coarse only) are used – very specific flow and strength requirements must be met by the material used. Where the whole tailings stream is used, it is generally necessary to achieve a paste consistency. This has usually been done by filtration and repulping, however, the new generation of paste thickeners offers alternatives.

Autoclave feed For autoclave leaching circuits, such as laterite nickel applications, the feed material is typically very fine and as such difficult to thicken to high density. However, the autoclave is generally an expensive item and reducing the feed volume by increasing the density is usually economically attractive. Production of paste for this application may show clear benefits.

Counter Current Decantation (CCD) applications The washing efficiency of a CCD circuit is strongly dependent on the underflow density from each thickener stage. For a selected washing efficiency, it is a matter of direct economic analysis to determine whether to opt for higher density thickening in order to reduce the number of CCD stages, i.e. whether the reduced number of thickener units offsets the increased cost of producing the required higher underflow density.

Tailings thickeners

Of the applications previously described, tailings disposal is common to most mineral treatment operations. Much effort has been expended by the major thickener manufacturers in developing thickener technology to suit the changing needs of tailings disposal systems. For either CTD or down-valley discharge, the need is for a high density slurry. Typically, the YS at the discharge point would be in the range 10-30Pa. For "dry-stacking" of tailings, usually involving the separation of coarse and fine tailings and utilisation of the coarse fractions for layering and embankment construction, the thickened fines fraction is typically thickened to a somewhat higher consistency than CTD, i.e. a YS of 30-100Pa.

Although the above YS ranges do not appear to be in, or close to, the paste regime, the shear history of the discharged material needs to be considered. If a tailings stream has to be discharged at the end of a pipeline at a YS value of 100Pa, it is quite likely that the YS in the thickener would have to exceed 200Pa, since the shearing that occurs within the pumps and tailings pipeline causes significant structural breakdown of the thickened slurry matrix, and reduction in YS. This is a function of the pump type (centrifugal or PD) and flow regime within the tailings line. The thickener requirement may be to produce paste, whereas at the disposal point the material no longer has paste consistency. However, if the required YS is say 30Pa at discharge, then a high density slurry underflow of YS ≤ 150Pa would probably suffice.

Because of the significant increase in capital and operating cost in using PD pumps, process designers usually favour installing centrifugal pumps even for quite high YS slurries. A common technique used to present a lower YS slurry to the tailings pumps is to install an underflow recirculation circuit incorporating a large centrifugal pump. This reduces the YS of the thickened material in the underflow cone of the thickener, making it more fluid

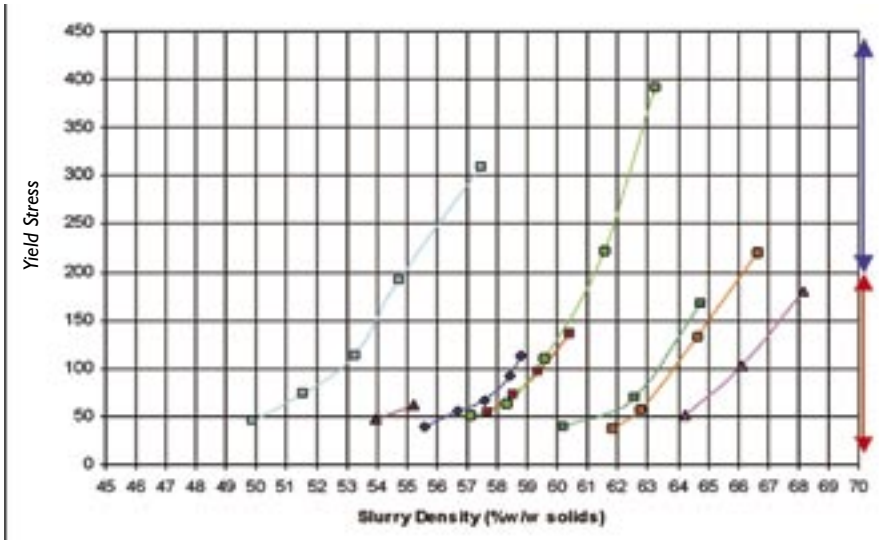


Figure 1 Yield stress vs slurry density for various copper ore blends within a single mining zone, ranging from pure oxide on the left, through various blends to primary sulphide on the right. Note that whereas the actual YS values are quite different for the differing ore blends, the "exponential" shape of the curve is common

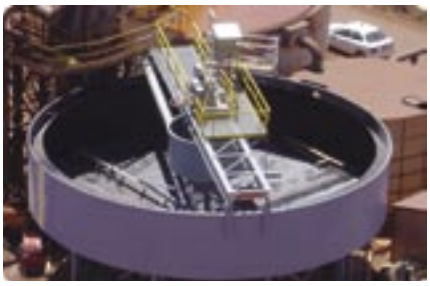
and easier to pump long distances to the tailings discharge point.

Clearly, the thickener designer can be faced with a number of differing scenarios for tailings thickening. Referring to the exponential YS–slurry density curve (see Figure 1), it is a matter of considerable interest to the designer whether the thickener is to operate in the medium density, high density, or paste regime.

To meet this challenge, Outokumpu Technology has developed three generic thickener models, namely: High rate – bed depth to 2.0m: High compression – bed depth 2.0-4.0m and Paste – bed depth 4.0-8.0m.

The illustrations show the difference in tank configuration of these three models – it should be understood that there are also differences in the rake mechanism and drive train design, notably in the torque capability of each type.

These thickener models are distinguished by the compression zone or bed depth rather than the consistency of the underflow. The underflow consistency is a product of both the thickener configuration and the material characteristics. For example, some tailings materials may be thickened to YS values of +200Pa in a high rate or high compression thickener, whereas others may need a very deep paste thickener to achieve the 200Pa level.



1. High rate thickener, low sidewall depth

2. High compression thickener, increased sidewall depth

3. Paste thickener – very deep sidewall, increased floor angle

Testwork

For a given mine site, it is quite common for mineral processors to take the view that the "highest possible" tailings consistency is required. This may lead to a quite arbitrary tailings density being specified (e.g. "70% w/w"), and the thickener manufacturer is then asked to demonstrate that they can achieve it. As ore characteristics can vary within a mining zone, the thickener manufacturer would need to be provided with an appropriate range of tailings samples and the required underflow density for each.

An alternative approach would be to firstly determine what tailings disposal methods are feasible, which will set the required "slump" or YS at the discharge point. The benefits of such an approach include avoidance of unnecessary equipment to cope with the arbitrary 70% w/w specification and an optimised thickener design which can far more accurately manage the varying ore characteristics throughout the life of the mine.

A vane rheometer, for example, can be used for YS determination on thickener test unit underflow samples. This approach of carrying out a full dynamic test on each sample, and measuring both unsheared and sheared YS on the underflow provides a high degree of confidence in the thickener configuration selected and the predicted performance.

Conclusion

Whether to thicken mineral plant tailings to the ultimate achievable density is a question that needs to be assessed carefully. Often, thickening to the absolute 'last drop' is an unnecessary exercise as determining a slurry's rheological properties is the more efficient and reliable means of delivering the required thickening result.

For further information contact Ian Arbuthnot via ian.arbuthnot@outokumpu technology.com

Ian Arbuthnot, Outokumpu Technology Pty Ltd

Regional seismic monitoring in Western Australia

By Daniel Heal, Mine Seismicity and Rockburst Risk Management project leader, ACG

There has long been anecdotal evidence of regional scale tectonic influences on seismicity and rockbursting in mines, particularly in the vicinity of Kalgoorlie, Western Australia. The ACG has undertaken a project to install regional seismic monitoring networks in WA to better understand these regional influences.

The aim of the project is to fill the monitoring gap between large seismic events recorded by the nation-wide Geoscience Australia network and mine-wide microseismic monitoring networks. This gap corresponds to seismic events in the range of +1 to +3 Richter Magnitude, events that are generally considered small by regional standards but are capable of causing catastrophic damage, injury and loss to underground mines.

Monitoring large events in mines can be technically difficult. In many cases, the events are inadequately recorded by the current mine-wide seismic systems. Problems include:

- The seismic systems are saturated by large events, meaning that the true amplitude (size) of the event is clipped and not properly recorded.
- Large seismic events are often too close to the sensors (the events are recorded in the "near-field") resulting in complex waveforms that are difficult to interpret.
- "Near-mine" events are not recorded by the current systems (they are outside the mine's array).
- Large seismic events which occur during blasting may not be recorded due to the manner in which mine-wide systems record events by "triggering".
- The current seismic systems provide no significant information about potential relations between regional tectonic seismic events and seismicity recorded in mines.

The Kalgoorlie-Kambalda regional seismic network was installed in March 2006 and currently has eight sensors operational. The network extends from Lionore's Black Swan Nickel mine in the north to Gold Fields Australia's Argo Gold mine in the south, a distance of approximately 110 km. Expansion of the network to include more sensors to the east and west of the current alignment is planned for the near future. The network is shown in Figure 1.

The Leinster regional seismic network was installed in October 2006 and consists of six sensors, with plans to include more sensors in the future. This network spans a distance of 80 km east-west and 60 km north-south. The network is shown in Figure 2.

Figure 1 Kalgoorlie-Kambalda Regional Seismic Network

Figure 2 Leinster Regional Seismic Network. Seismic locations are indicated by the red squares

There are minimal site requirements for having a sensor. Each site requires a mounting location to install the sensor at sufficient distance from any vibration sources. Bedrock is preferable although a small concrete pad can also be used (see Figure 3). A location to set up a computer and digitiser in the mine offices is also required, with power and an internet connection nearby.

Figure 3 Examples of triaxial geophones installed as part of the networks. Although mounting in bedrock is preferable (see example on the left) a small concrete pad can also be used (as shown on the right)

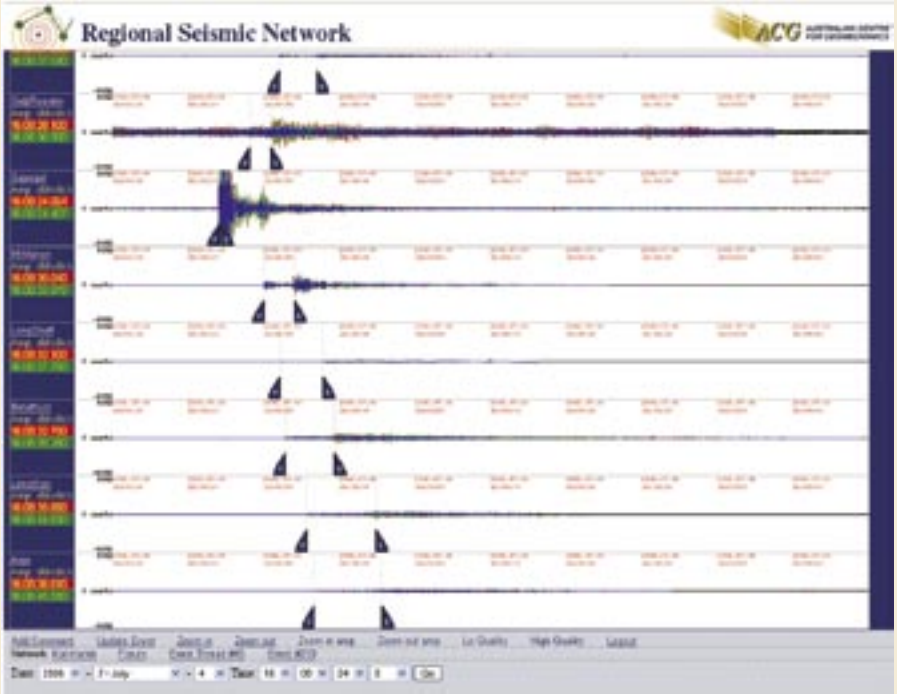


Figure 4 Screenshot from the regional seismic network website. Seismic data from all stations in the network are uploaded to the website in real-time and can be accessed by the project sponsors

A low frequency (4.5Hz) triaxial geophone at each site connects to the computer and digitiser in the mine offices. A small GPS unit is also installed at each site to synchronise time across the seismic network. Each sensor site is connected to the mine's existing computer network to upload seismic data to a website, at which project sponsors can access data from all sites in the network and process seismic events as they occur. 50Hz data is uploaded constantly to the website. High quality 200Hz triaxial data is uploaded immediately when a user makes a request on the website. An example of a seismic event recorded by the Kalgoorlie-Kambalda network is shown in Figure 4. The 3.2 Richter Magnitude event occurred to the south-east of Kalgoorlie, and is thought to have been related to a regional scale fault.

A particularly novel aspect of the regional seismic array is the "community" nature of the data collection. While individual sensors will provide useful information to each local mine, it is the combined use of several sensors that provides the research data on tectonic influences and "near-mine" events. It is hoped that this research project will result in a better understanding of the relationship between tectonic influences and seismicity in mines and possibly provide insight as to which regional scale structures may contribute to seismic hazard in mines. Such a finding would be extremely valuable for new operations planned in these areas.

We are currently seeking more mine sites in and around the existing networks to install additional stations. If you are interested in being involved in the project or would like more information, please contact Dan Heal at the ACG, dheal@acg.uwa.edu.au

Funding for this research was provided through the Mine Seismicity and Rockburst Risk Management project at the ACG. This project is financially supported by:

- The Minerals and Energy Research Institute of Western Australia (MERIWA)
- Barrick Gold of Australia
- Lionore Australia Ltd
- BHP Billiton Nickel West
- Perilya Limited
- Lightning Nickel (Independence Group)
- Kirkland Lake Gold
- Agnico-Eagle Mines Ltd
- Kalgoorlie Consolidated Gold Mines
- Beaconsfield Mine Joint Venture
- Newcrest Cadia Valley Operations (Ridgeway)
- Harmony Mt Magnet Gold
- Xstrata Copper (Kidd Mine)
- Oxiana Ltd (Golden Grove)
- Reliance Nickel P/L (Consolidated Minerals Group)
- Cosmos Nickel Project (Sir Samuel Mines)
- Gold Fields Australia

Dan Heal, ACG

Managing Seismic Risk in Mines Short Course

6 November 2007,
Novotel Perth Langley, WA

MS-RAP

The ACG will present a one-day pre-seminar (4th International Seminar on Deep and High Stress Mining) Mine Seismicity short course that will provide attendees who currently have limited knowledge of seismic monitoring with the essential information to understand the capabilities and limitations of this rapidly evolving technology.

Australian case histories will be used extensively as examples. A full demonstration of the Mine Seismicity Risk Assessment Program – MS-RAP and trial copies of the software will be made available to attendees. For more information about MS-RAP visit www.ms-rap.com.

Geotechnical engineering strategy and practical geotechnical skills training for the Newmont Australian Operations

By Michael Dunn, group geotechnical engineer, Newmont Australia Limited

In January 2005, a Geotechnical Engineering Strategy for the Australian operations of Newmont Asia Pacific was finalised (Marisett, 2005). The aim of the strategy is to provide a framework for a systematic and structured approach to addressing geotechnical issues within the Australian mining operations. The strategy was compiled in support of the Newmont vision and values.

Newmont Australia's strategy provides a structured approach to addressing geotechnical issues

This article provides a brief overview of the Geotechnical Engineering Strategy with a specific focus on the Practical Geotechnical Skills Training initiative. The strategy covers five main areas as follows:

- Ground control management plans
- Audits
- Technical support
- Development and training
- Research and development

Ground control management plan

The ground control management plan (GCMP) provides a framework for all geotechnical activities undertaken at an operation and is a fundamental part of the Newmont ground control strategy. The GCMP must be practical and provide guidance for a systematic approach to dealing with geotechnical issues.

The GCMP should be auditable and as such a standardised approach and format have been developed. A GCMP is not a static document and will be reviewed on a regular basis.

Audits

Ground control audits will be conducted on all Australian sites on a regular basis against a standard based on the Geotechnical Engineering Strategy. The audits will be coordinated by Technical Services (Perth, Western Australia) and the audit team will include a geotechnical engineer from another site to foster cross-pollination. The audit protocol is based on the Newmont "5-Star" system to ensure consistency and an emphasis on tracking improvements on a site rather than comparisons with other sites.

Technical support

A shortage of experienced geotechnical engineers within the Australian mining industry has resulted in the development of a technical support philosophy. This entails having site based geotechnical engineers supported by a core of experienced geotechnical engineers based in the Technical Services office.

The role of the Technical Services geotechnical engineers is to mentor and guide site personnel as well as providing technical input into mining studies and projects. The allocation of resources is based on issues identified during audits and technical reviews and is an interactive re-iterative process with the mine sites.

To foster information sharing and develop a team approach, geotechnical workshops have been introduced. This forum allows site and Perth based geotechnical engineers to get together and discuss common issues and develop strategies going forward.

Research and development

Newmont is committed to sponsoring innovative research that can have a positive impact on both safety and production. Research and development proposals are evaluated on the basis of their technical merits as well as their potential to develop and encourage people entering the mining profession.

Development and training

Development and training is an important aspect of the geotechnical engineering strategy. This is not confined to geotechnical engineers and includes

Newmont Australia is committed to sponsoring innovative research

other players in the mining process as it is felt that improved geotechnical skills across the board will have a positive impact on the business in terms of safety and mine design. A training matrix has been compiled outlining the requirements for various occupations and covers the following aspects:

- Basic geotechnical theory
- Specialised training
- Ground awareness training
- Practical geotechnical skills training

Training in basic geotechnical theory and specialised aspects such as numerical modelling will be achieved through commercially available industry courses and, when required, specially commissioned courses. Ground awareness training will be conducted through the various mine site training centres with input from geotechnical engineers and industry developed training material. This will be supplemented with local input relating to ground conditions and the mining methods. In addition, considerable effort has gone into the development of three key Practical Geotechnical Skills Training courses and an overview follows.

Practical geotechnical skills training

A series of three practical geotechnical skills training courses were developed in collaboration with the Australian Centre for Geomechanics. These courses are targeted at geotechnical specialists, geologists and engineers based on sites. The objective is for the course participants to gain an understanding of geotechnical issues applicable to their field of expertise. It is envisaged that this will result in improved mine design with a positive impact on both safety and production.

Initial development of the courses was undertaken followed by a pilot series presented at the Newmont Tanami Operations. This allowed for the three courses to be fine tuned and finalised based on the response from attendees. Each course is designed to be a stand-alone allowing the individual courses to be presented when required.

The courses have a strong practical component and will be presented on site over a number of days. The theme of the courses will focus on hands-on learning allowing a small number of participants to work through real examples related to actual site conditions.

The availability of professionally developed presentation material with detailed notes for the trainer provides Newmont with the flexibility to either present the courses in-house or to outsource the course delivery to an external party. This flexibility also extends to scheduling the courses to fit in around operational constraints.

Ground support systems

The objective of this course is to develop essential skills required for the implementation of a sound ground control programme. This course reviews the requirements for ground control systems at the mine in the context of the whole mining system, including installation quality assurance, rockmass behaviour, support element expectations and anticipated changes in ground conditions. Skills acquired aid in communicating the mine's geotechnical issues with the workforce. This course is directed towards site geotechnical engineers, senior geotechnical engineers, senior mining engineers, senior mine geologists, production engineers, mine geologists, foremen and shift bosses.

Geotechnical data collection

The objective of this course is to develop essential skills required for geotechnical data collection and rockmass characterisation. The course reviews the requirements for defining geotechnical domains, data collection for geotechnical designs, and understanding pre-mining stress fields and the influence of major geological structures. Skills acquired aid in rockmass classification from data sources such as geotechnical mapping, core logging and laboratory testing. The target audience for this course are site geotechnical engineers, senior geotechnical engineers and mine geologists.

Geomechanics design

The objective of this course is to develop essential skills required to ensure geotechnical input into the mine design and planning process. The course covers aspects such as excavation design, mining methods and geotechnical considerations, stope design and pillar design and includes several practical exercises. This course would be of interest to site geotechnical engineers, senior geotechnical engineers, planning engineers and production engineers.

Concluding remarks

Considerable progress has been made in the implementation of geotechnical engineering strategy over the last 22 months. This will continue to be driven with a special focus on the development of the Technical Support model and the full scale rollout of practical geotechnical skills training during 2007. Though this process, it is envisaged that the geotechnical discipline will continue to develop within Newmont and continue to provide a valuable service in support of the business.

Acknowledgements

Thank you to Newmont for permission to publish this article. The contribution of the original developers of the strategy is also acknowledged.

Michael Dunn, Newmont Australia Ltd

Building confidence in the long-term performance of waste rock dumps following closure

by Andrew Garvie and Claire Linklater, principal consultants, SRK Consulting

Background

Waste rock dump seepage containing elevated concentrations of metals and acid is a potentially significant source of environmental impacts at mine sites. Contaminated seepage can be present at all stages of the mine life and potentially for decades or centuries following mine closure. In some cases, the onset of acid rock drainage (ARD) occurs many years after operations begin. However, a slow onset is not necessarily associated with small ARD impacts.

Screening tools for the assessment of the potential for ARD include static tests such as acid base accounting (ABA) and net acid generation (NAG) tests, and kinetic tests such as the kinetic NAG and column leach tests. While these tests provide insight to the potential for acid generation they do not always provide good insight to the controls under field conditions that dictate the rates of processes likely to lead to ARD and rates at which contaminants will be released. This becomes of particular importance when, for example, potential impacts are to be determined and the requirements for water treatment are to be established.

Important processes controlling ARD and metal leaching (ML) from a waste rock dump are:

- Oxidation of sulphidic minerals, as dictated by transport of gases within the dump and oxygen supplied from the outer surfaces to internal oxidation reaction sites.
- Movement of infiltrating pore water down through the dump, transporting acid and contaminants.
- Neutralisation reactions and secondary mineral formation within the dumps.

Depending on the dump's physical and chemical characteristics and the interplay between these different processes, contaminant loads in dump effluent will vary, both spatially and temporally.

Figure 1 shows a theoretical effluent load profile over time. Note that the load could increase gradually, only reaching its maximum value after perhaps many years of dump oxidation.

Initially the objective of those responsible for environmental management may be to determine which of the available management strategies will be most likely to prevent the load from exceeding the regulatory load. In the longer term, the objective includes the identification of control strategies, or control performance objectives for closure measures, that will ensure that post closure loadings will continue to lie below allowable regulatory loads.

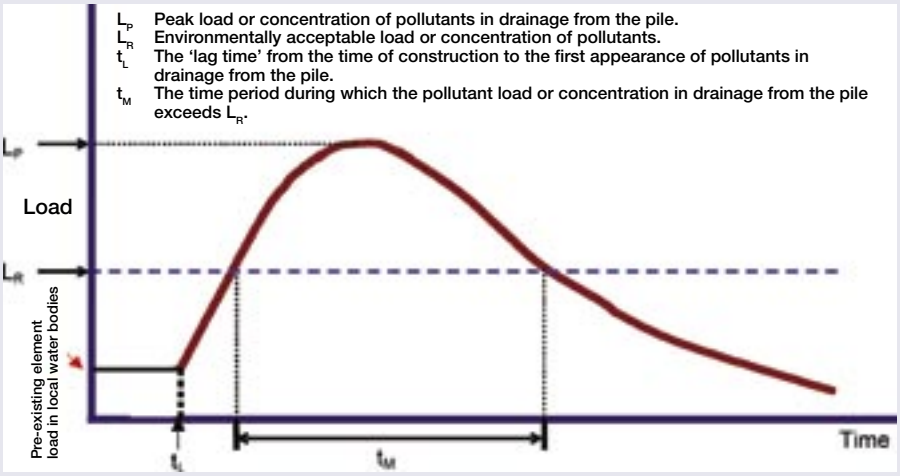


Figure 1 Theoretical load profile in effluent

The theoretical curve also shows that short-term monitoring of seepage could lead to significant underestimation of the risk posed by the dump. For example, if the operational period ceases within the lag period, clearly short-term monitoring will fail to indicate the overall potential environmental impacts. Thus, forecasting becomes critical in assessing the overall liability associated with the site. A further complicating factor is that it may take many years for the water balance of waste rock dumps to reach a steady state condition, placing further uncertainty on short-term seepage monitoring. Forecasting future effluent quality trends requires some understanding of processes occurring within the dump and the ability to project forward and estimate trends with some level of confidence.

Methods and benefits of characterising dumps

Insight into the processes taking place within a dump is gained by measuring certain attributes of the dump itself and the materials contained therein in addition to seepage monitoring. These, combined with the climatic records and dump surface properties, are used to evaluate the rates and progress of some of the key processes within the dump. In this way, improved assessments of the risks posed by waste rock dumps are possible.

Some of the key factors and the measurement techniques that are used to provide insight into the potential long-term impacts from waste rock dumps are as outlined overleaf.

Oxidation rates

Oxidation of sulphide minerals requires the presence of an oxidant. In a waste rock dump environment, the most important oxidant is oxygen (the aqueous ferric ion [Fe^{3+}] also plays a role but is often present at low concentrations). The rate of consumption of oxygen is therefore a direct indicator of the rate of oxidation of sulphide minerals.

Oxidation rates can be measured or estimated in a number of ways:

In the laboratory Depending on the equipment used and the oxidation rate the measurement time can vary from about 24 hours to several weeks. The faster techniques measure directly the rate of oxygen consumption (Intrinsic Oxidation Rate – IOR) while the slower techniques infer oxidation rates from sulphate in leachate from column leach tests (e.g. humidity column tests).

In the field Techniques include measurement of temperature profiles and/or oxygen concentration profiles. These techniques can have the advantage of capturing the behaviour of larger volumes of material. Disadvantages are that conditions within the dump are not as well constrained and this can lead to larger uncertainty in the measured value.

Pore gas composition and temperature distributions in dumps can be used as indicators of actively oxidising zones, e.g. low pore gas oxygen concentrations may indicate consumption by reacting sulphides and elevated temperatures can be a result of heat released during the oxidation reactions. Installing measurement equipment within the dump is a good way of collecting direct evidence of internal conditions. Equipment can be installed during dump construction or can be fitted in established dumps. Figure 2 illustrates an arrangement for sampling gas from within a dump and measuring temperatures at many depths. The smaller diameter outer tubes are used for gas sampling and the larger diameter PVC tube is used for lowering temperature sensors into the dump.

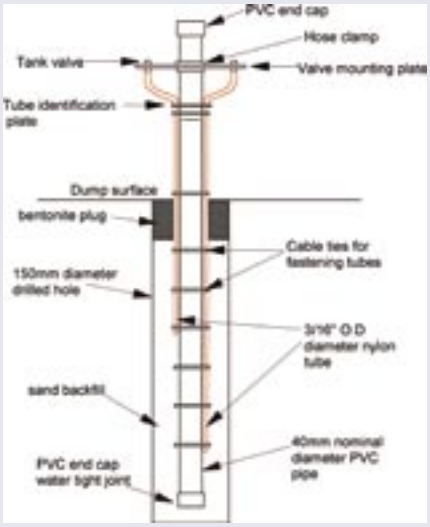


Figure 2 Installation for sampling gas and measuring temperature (schematic diagram is not to scale)

Monitoring active oxidation zones is also an effective means of evaluating the performance of dump management strategies, such as covering and encapsulation. Figure 3 shows data collected before and after emplacement of a cover.

In addition to monitoring the distribution of oxidising zones within a dump, measurement data can be used to determine dominant gas transport mechanisms (diffusion, convection or advection) and to estimate the oxidation rate of the pile.

Pore water infiltration rates and pore water chemistry

The flux of water transporting contaminants through a dump is dependent on the hydraulic properties of the dump and/or cover and the rainfall regime. Direct measurements of water fluxes are possible using lysimeters, but careful lysimeter design is required. Alternatively water fluxes have been inferred from measurements of water content, material hydraulic properties and rainfall measurements.

Lysimeters and soil moisture suction samplers can be used to collect pore water from within dumps for chemical analysis. The pore water quality can give an indication of geochemical processes taking place in the dump and can be used to guide geochemical modelling studies.

Comparison of observed water quality data with model calculations helps to calibrate the model prior to forecasting future effluent quality trends.

Geochemical models and estimating future trends

Modelling can be an extremely valuable tool when interpreting measured datasets. Using computer models, it is possible to test different ideas or the influence of parameter values to determine which processes are important in the dump. The ability of a particular model to reproduce aspects of observed dump behaviour can help to demonstrate a robust understanding of the dump. This is important when explaining to stakeholders that you understand how your dump is going to behave now and into the future.

Numerical modelling codes have been developed specifically for application to waste rock dumps. An example of such a code is SULFIDOX which can simulate the following processes:

- Oxidation of sulfides (generating heat, acid).
- Gas transport via diffusion and advection.
- Heat transport via thermal conduction and advective fluid flow.
- Infiltration of water down through the waste rock dump.
- Speciation and complexation of chemical components within the water.

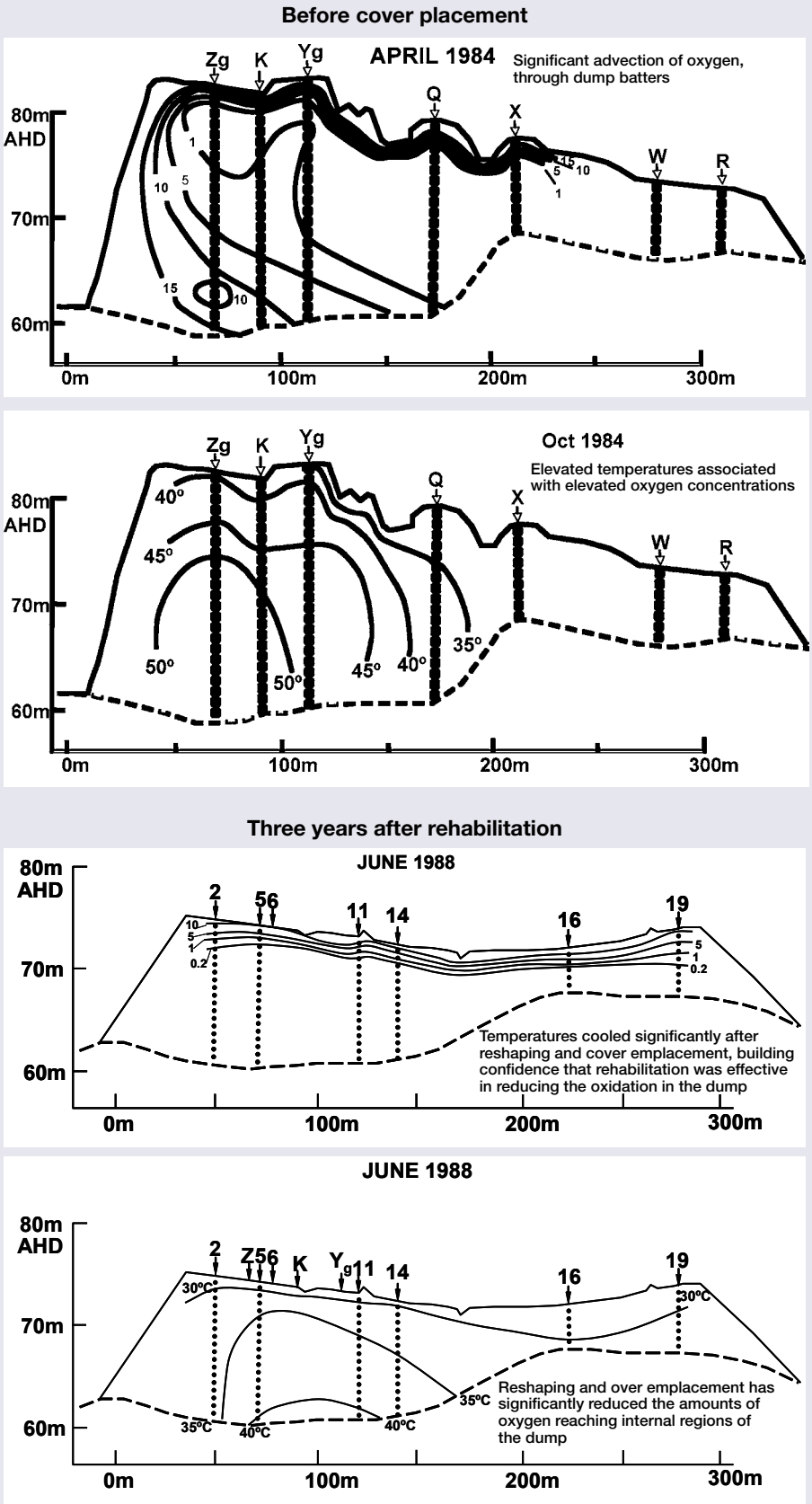


Figure 3 Oxygen and temperature distributions before and after cover emplacement (Rum Jungle minesite, Northern Territory)

- Dissolution and precipitation of minerals in the dump.
- Spatial variability within the dump, e.g. cells and/or layers of material with distinct properties.

Figure 4 shows a typical SULFIDOX output.

Models can also be used to calculate dump behaviour under conditions outside of those included in measurement programs. In this way they can be used to help differentiate between proposed remediation strategies (Figure 5). Using models it is possible to assess the effectiveness of different strategies and to make predictions regarding the future quality of effluents from the dump. Another benefit of numerical models is the ability to forecast dump behaviour over long timescales.

Conclusions

In light of increasing environmental awareness of mining companies and the accounting and reporting requirements adopted by some mining companies, understanding and quantifying the potential environmental liabilities associated with mining sites has become increasingly important. Because the processes that contribute to the development of dump seepage water quality may take many years to mature and the full environmental impacts may not occur for many years after mining ceases, it is necessary to turn to numerical modelling procedures to estimate potential future changes in water quality. These estimates can then be used to determine the requirements for closure control measures or provide direct estimates of overall liability based on establishing water treatment requirements for the site. In addition to the geochemical properties of the waste rock, numerical modelling methods however have to be cognisant of the physical processes that will dictate oxidation and metal leaching under actual field scale conditions. In many cases this requires field measurement of dump properties that are required as input to the numerical models.

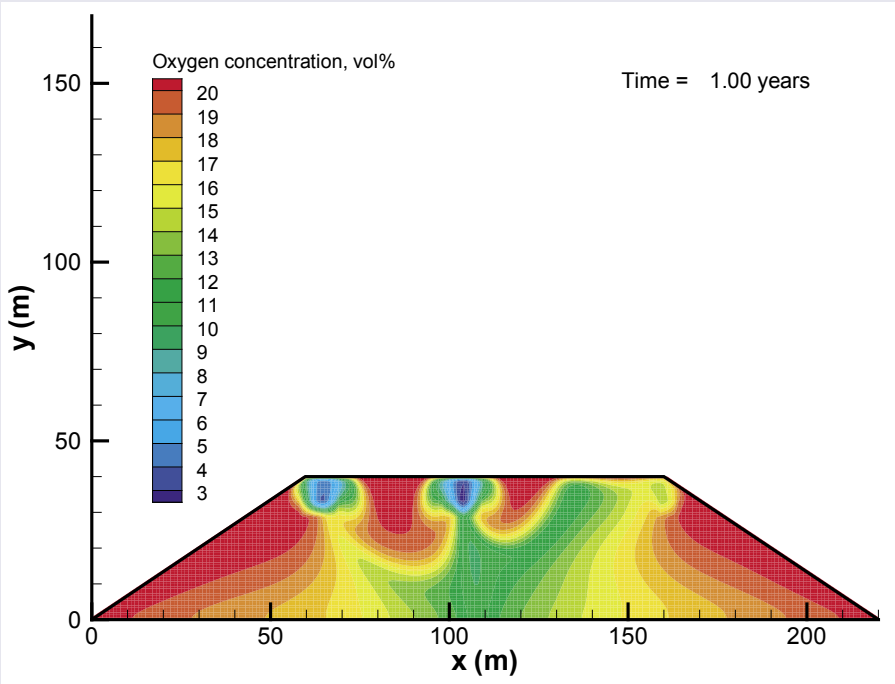


Figure 4 Simulated distribution of oxygen pore gas concentration in a dump containing 'cells' of reactive oxygen-consuming material located 5 m below the dump surface

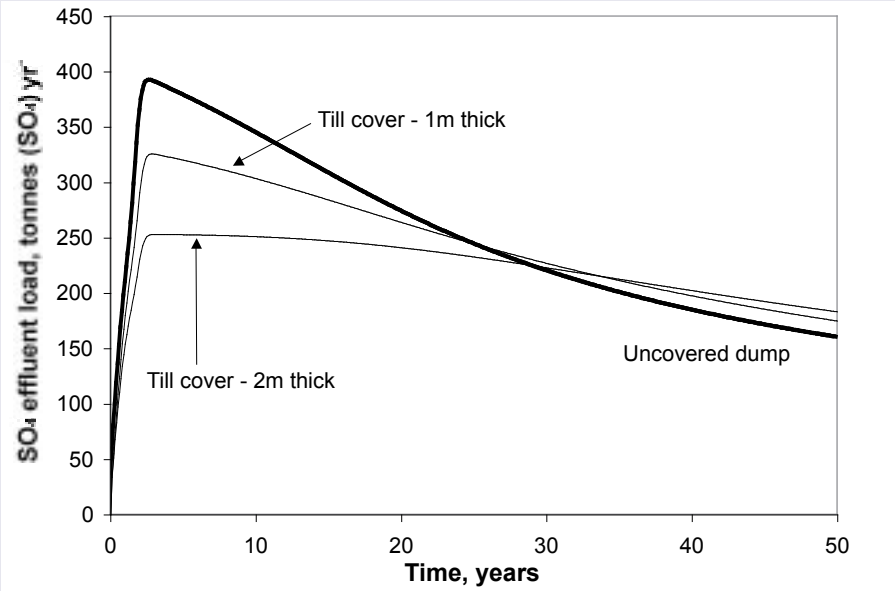


Figure 5 Calculated SO_4 loads in dump effluent, as a function of time (up to 50 years). These calculations were used to quantify the effect of emplacing different thicknesses of a cover with a low permeability to gas. In this case, the 2 m thick cover resulted in a significant reduction (around 40%) in the predicted short-term SO_4 load

A significant advantage of numerical modelling methods is that many scenarios of waste management and/or closure strategies can be evaluated rapidly to assess overall environmental impacts. The results can be used to optimise a waste rock management and closure to minimise management and closure costs as well as environmental impacts.

Andrew Garvie and Claire Linklater, SRK Consulting

First International Seminar on the Management of Rock Dumps, Stockpiles and Heap Leach Pads

4 – 7 March 2008, Perth, Western Australia

The ACG is delighted to initiate and host the First International Seminar on the Management of Rock Dumps, Stockpiles and Heap Leach Pads in Perth in March 2008. Seminar chair Andy Fourie and the ACG team look forward to presenting a seminar that will explore the recent developments in the design, operation and management of rock dumps, stockpiles and heap leach pads.

Rock dumps and material stockpiles associated with mining operations involve enormous earthmoving operations and potential challenges. Incorrectly identifying and managing these challenges may generate hazards such as sterilisation of resources due to incorrect siting, generation of acid drainage, spontaneous combustion (in coal) and instability problems, in addition to the costs involved. Ensuring that the structure will remain stable in the long-term requires accurate landform modelling and sound rehabilitation practices. "Getting it right" the first time is essential if industry is to maximise returns for any project.

Contact the ACG team for further details.

Mine closure opens new doors

More than 310 delegates convened for the First International Seminar on Mine Closure that was held in Perth, Western Australia in September 2006. The ACG initiated the first in a series of international seminars on mine closure to be held throughout the world in the coming years. The ACG with the Centre for Land Rehabilitation, The University of Western Australia was delighted to welcome the attendees that represented 17 countries. The world-first seminar placed the strongest significance on exploring the latest strategies employed to tackle the challenges of mine closure related activities. The event examined how and why operations achieve closure successfully and identified the challenging and problematic areas.

The main topics were: planning for closure, ecosystem and pedogensis, hydrology and landscapes, financing closure, landform stability, contaminant risks and off-site impacts, success criteria and social impacts. Each topic was presented by a number of authors from a variety of backgrounds that provided the audience with different perspectives and generated much discussion and interest.

Mine Closure 2006's main objective was to provide a forum for mine closure practitioners and experts to exchange views on how best to ensure that future closure of mine sites is achieved at minimum cost, whilst ensuring that future environmental and social impacts are minimised. Mark Adams from Iluka Resources paved the way for lively and interactive audience participation with an opening address entitled *Mine Closure – A Process, Not an Afterthought*. Keynote speakers included Gavin Murray, ANZ Banking Group, Ward Wilson, University of British Columbia, and David Tongway, Australian National University. The organisers were delighted to have such an experienced and varied group of presenters and their participation indicates the relevance and importance of the forementioned topics to many mining companies, research and government organisations from throughout the world.

The event was an intensive experience, from the pre-seminar O'Kane Consultants Welcome Function and pre-seminar Tailings Storage Facilities and Biology Covers Design workshops to the hotly debated "Where to From Now" forum. The programme was packed with 10 keynote addresses, 66 presentations and two parallel sessions.

Seminar chairmen, Andy Fourie (ACG) and Mark Tibbett (CLR) hope that the new ideas, strategies and emerging technologies emanating from Mine Closure 2006, Mine Closure 2007 (Chile) and Mine Closure 2008 (South Africa) will establish the agenda for future research and operational directions, ensuring the future viability of mining industry.

Mine Closure 2006 examined why and how operations achieved closure successfully

At the conclusion of Mine Closure 2008, a hardbound publication featuring chapters from invited authors drawn from the series of seminars will be produced by Fourie and Tibbett.

The Mine Closure 2006 organisers were able to present this world-first international seminar due to the generous support of its sponsors, namely, BHP Billiton (principal sponsor), GHD Pty Ltd, Ross's Auctioneers & Valuers and SKM (major sponsors).

Planning for land rehabilitation and site closure from an early stage of a mining operation is crucial

Chilean mining and the challenges of closure

By Jacques Wiertz, technical coordinator, Mine Closure 2007

Rich in natural resources and with investor-friendly policies Chile has acquired a leadership status in the international mining community. Nowadays, Chile is recognised as the "copper country" with the concentration of more than 35% of the world's copper production. Mining is the country's oldest industry that goes back as far as the arrival of the Spanish conquistadores.

Gold, silver and copper have been mined at smaller scale during past centuries in the North and Central parts of the country. Mining at a major scale commenced at the beginning of the nineteenth century with the extraction and processing of nitrate ore ("caliche" or "salitre"); a unique natural resource used to produce fertilisers. The extraction took place in the very arid Pampa, located in the North of Chile, and a great number of mining camps ("oficinas") were built in both the Iquique and Antofagasta Regions, employing over 45,000 workers at the end of the century. The production and exports exceeded two million tonnes per year. However, the discovery of a synthetic nitrate process marked the rapid decline of the industry and the closure of most of these "oficinas".

Coal in the South and iron in the North were then exploited at a major scale. Coal was extracted in underground mines at the sea border, and, in some cases, under the ocean floor as in Lota, a coal mine that was closed in the 1990s.

Large scale copper mining started a hundred years ago at El Teniente mine, located 80 km south of Santiago. Chuquicamata, Potrerillos and other big mines were then opened. The main increase in copper production occurred in the 1990s with the development of a great number of new mining projects, such as Escondida, which is currently the largest copper mining project in the world.

In the near future some of these projects will have to face the problem of closure. El Indio Gold Mine, after the suspension of all its extraction activities, has moved to a closure stage which has been approved by the environmental authorities and is presently under development. El Salvador Copper Mine of CODELCO has announced the future closure of extraction activity and started the design of an environmental and social mine closure programme.

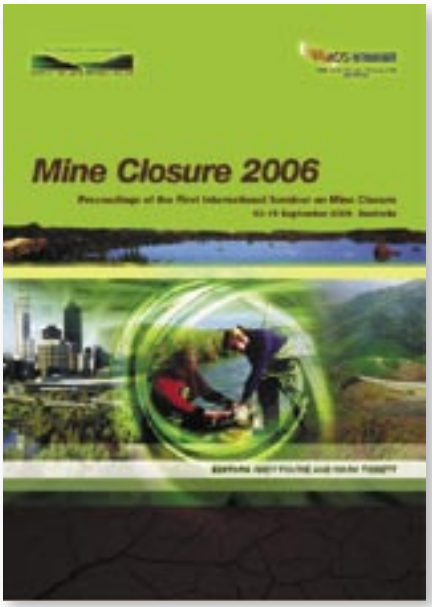
One of the main challenges of closure planning in Chile is to manage the closure of large facilities while guaranteeing long-term stability under a wide range of extreme conditions and natural hazards. In particular, the high level of seismic activity sometimes encountered means that special attention must be paid to the stability of dumps and tailings.

Chile has not yet adopted any specific environmental regulation for mine closure. However, over the past few years, several regulatory aspects have been designed and discussed amongst all the key players and will most likely be implemented in the near future.

Jacques Wiertz, technical coordinator, Mine Closure 2007

Mine Closure 2006 – Proceedings of the First International Seminar on Mine Closure

A book review by Bryan Ulrich, vice president – Nevada Operations, Knight Piésold & Co., Elko, Nevada, USA



This review is by necessity something of a paraphrasing of portions of the proceedings. Mine closure, in part or in whole, rightly deserves the undivided attention of mining companies, their consultants and their contractors in order to meet sustainability targets and to minimise negative environmental, social and economic impacts, as the project, in its post-closure years, will become the legacy we leave to our children and grandchildren.

The actual performance of mine closure, that is, nature's determination of the success of the closure, is a key deciding factor of the public's assessment of the future viability of the mining industry. Without society's consent, it may be quite difficult for the mining industry to carry on mining in many areas of the world. Thus, establishing good mine closure practices is paramount to the continued good reputation of all world-class mine operators. The back cover of the proceedings puts it very well:

> *The economical and environmentally and socially acceptable closure of mines is one of the greatest challenges facing the mining industry in this new century. Increasingly, the future approval of new operations and the continuing social licence to operate at existing operations will become contingent on a company displaying a proven track record of appropriate and successful closure of old or uneconomic mines. Although there are many examples of good closure practice, there are also many that have been unsuccessful and it is the latter that generate most public scrutiny.*
> *A consequence of this scrutiny, and the desire of mining companies to adopt best practice in mine closure, has seen a very rapid increase in the financial provisions that are being made for closure at some, as-yet undetermined date.*

It was with the recognised ongoing need to develop mine closure practices that are environmentally and socially sustainable, and are based on principles of sound planning and economics that the First International Seminar on Mine Closure was organised. The proceedings are presented in eight sections plus a plenary session. The eight sections are:

- Planning for Closure
- Ecosystem Reconstruction and Pedogenesis
- Hydrology of Post-Mining Landscapes
- Financing Closure
- Landform Stability
- Containment Risks and Off-Site Impacts
- Success Criteria
- Social Impacts

The plenary papers, while quite interesting and worthy of a thorough discussion, are not reviewed separately from the remainder of the proceedings, as they represent areas of the eight sections identified above.

Session 1: Planning for Closure. This chapter makes up the lengthiest portion of the proceedings. That is something of a statement of where the mining industry's closure attention is being paid. There are several papers describing regulatory frameworks and closure policies adopted by several mining companies. One paper underscores the importance of mine closure planning by describing how their closure manager is second only in their organisational chart to the mine's operations manager. The focus of many papers pertains to the necessity of formulating closure plans well in advance of its implementation in order to ensure there is sufficient cash flow, that necessary materials are located and strategically placed, that a fleet of mining equipment is present, with the recognition of the inherent uncertainties that may develop during a mine's life. Proper planning at the developmental stages of the mining operation can result in significant cost savings. This chapter, with contributions from over a dozen countries, contains tremendous information, much in tabular form, and also several flow diagrams explaining strategies used in various closure projects.

Section 2: Ecosystem Reconstruction and Pedogenesis. This chapter presents several interesting papers with variations around its central theme. The need for experimentation during the mine life is discussed, as is strategies for soil amending.

The economical and environmentally and socially acceptable closure of mines is one of the greatest challenges facing the mining industry in this new century. Photos courtesy of the Geological Survey of Western Australia

One paper of particular interest presents a case for setting small vertebrate colonisation as an ultimate metric against successful reclamation, as the formation of complex vegetation is typically needed for such occurrence. Another paper details the need to sow different seed varieties at different times of the year to better suit their natural emergence.

Section 3: Hydrology of Post-Mining Landscapes. This chapter presents papers on risk-based design, and the need for good modelling and field trails to ensure covers are built adequately and with regard to a broad range of conditions and occurrences.

Section 4: Financing Closure. This chapter contains papers on a variety of topics related to the financial side of mine closure work. Many papers detail various legal frameworks in place regulating closure bonds and sureties. A number of papers make reference to in-perpetuity costs, indicating the elusive nature of walk-away solutions. One interesting paper discusses how closure projects are treated quite differently than capital projects, in that their costs are typically not as well established as with capital projects, even though it is the capital projects that can be cancelled, not closure projects (one paper introduces the concept of *bankable feasibility closure design*). Significant uncertainty in the estimation of closure costs may best be dealt with using financial risk modelling.

Section 5: Landform Stability. This chapter presents a handful of papers, largely dealing with erosion of mine waste materials and their covers, especially in regard to long-term performance. It is evident that great strides have been made recently in soil erosion modelling; those advances should be of direct benefit to good closure practices.

Section 6: Containment Risks and Off-Site Impacts. This chapter presents papers focusing on topics ranging from remote sensing and pit lake prediction models to water quality and risk assessments, and many other topics. These papers serve as very useful sources of such information.

Section 7: Success Criteria. Success criteria are measured in several ways. The authors of papers in this chapter present cases for closure success based on flora, fauna (including invertebrate population), and landscape. The success of a closure system is said to be one that can support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitat of the surrounding region.

Section 8: Social Impacts. The final chapter of the volume presents the sometimes sobering issues of the social impacts of mining on communities and populations, especially with regard to mine closure. In areas of the world where unemployment is problematic, the closing of a mine can have serious impacts on the local population. The concept of sustainable development and leaving useful infrastructure for subsequent industry are the topics of several papers.

The proceedings of the First International Seminar on Mine Closure contain a very diverse and useful collection of papers. Any serious practitioner wanting to remain current with the state-of-the-industry should consider adding this volume to their collection.

Bryan Ulrich,
Knight Piésold & Co.

GHD joins ACG

The ACG is delighted to welcome onboard GHD Pty Ltd as it newest Corporate Affiliate Member. GHD is one of Australia's largest organisations with over 4,700 employees worldwide and 77 years in operation. In Western Australia, GHD employs over 500 staff with offices in Perth, Bunbury, Geraldton, Kalgoorlie and Karratha. David Elias is Perth GHD's Geotechnical Service group manager.

"Geotechnics is a unique combination of science, experience, judgement and a passion for understanding the uniqueness and variability of ground conditions resulting from the forces of nature. It is the art of determining the properties of largely unseen and variable materials (soil, rock and groundwater) to provide infrastructure that performs as expected, at an acceptable level and cost."

"Many of our professionals are respected geotechnical leaders who represent GHD on a national international level and are pleased to add ACG to a list of committees and learned societies including Engineers Australia, ANCOLD and ICOLD."

"We at GHD believe that the ACG is growing in all areas and need to be part of that; the organisation has a positive stance in terms of research and good industry interaction. The ACG is a strong organisation in terms of mining, pit site management, tailings storage facility and in the design management industry. Overall, a strong affiliation which will be mutually beneficial for GHD and the ACG."

For more information about the ACG's Corporate Affiliate programme, please contact Josephine via acg@acg.uwa.edu.au.

David Elias, service group manager geotechnical, GHD Pty Ltd

ACG Corporate Affiliate Memberships

Tangible support for the Australian Centre for Geomechanics by industry is demonstrated by our Corporate Affiliate Memberships. The ACG currently has 14 highly valued affiliate members that receive exclusive benefits such as discounted seminar registration fees and reduced costs for the Centre's on-site training courses and products. These memberships are fundamental in assisting the Centre to play a crucial role in identifying and developing research initiatives and professional education in Australia, particularly as industry moves towards increasing the number of larger open pits and deeper underground mining operations.

ACG 2006 Corporate Affiliate Members

- AngloGold Ashanti Australia Limited
- Argyle Diamond Mines Pty Limited
- Barrick Gold of Australia Limited
- BHP Billiton Cannington
- BHP Billiton Iron Ore
- BHP Billiton Nickel West
- Coffey Mining Pty Ltd
- GHD Pty Ltd
- Golders Associates Pty Ltd
- Gold Fields Limited
- Kalgoorlie Consolidated Gold Mines Pty Limited
- Newmont Australia Limited
- PT Freeport Indonesia
- SRK Consulting

Keen to get onboard? Please call the ACG for further information.

Postgraduate studies in mining rock mechanics

The Centre is seeking postgraduate students for its Mine Seismicity and Rockburst Risk Management research project. Geologists and mining, geological, civil and resource engineers with Australian citizenship will be considered for the positions.

- Entitlements include a tax-free stipend of A$35,000 for up to 3.5 years to complete the PhD. All travel, computer and study materials are provided.

  Students will be required to conduct minesite fieldwork and data collection during the project.
- There is potential for overseas travel and data collection. Previous postgraduate students were supported to attend further education and training seminars in Australia, Canada and South Africa.
- Students will work on a range of projects related to rock mechanics and seismicity in underground hardrock mines.

This is an excellent opportunity to become a specialist in geotechnical engineering in underground mines, with involvement in real rock mechanics issues at some of WA's largest mining companies.

For more information, please contact Dan Heal at dheal@acg.uwa.edu.au

In the pipeline

Recognising the vital importance of employee training and education to improve mine safety and production performance, the ACG's training and further education platform is designed to enhance the competency, knowledge and skills base of the mining workforce.

The ACG team looks forward to launching the following geotechnical training and further education products. For more information, please contact the ACG.

Management and Safety of Tailings Storage Facilities Training DVD

Expected launch date: March 2007

This unique training DVD aims to assist operators to recognise and react to the potential hazards involved in managing and operating a tailings storage facility. Content includes:

- Risk management & geotechnical issues in tailings disposal
- Failure types – recognition of mechanisms
- Operational issues that lead to instability problems
- Recognising the importance of the water balance
- Best practice in tailings storage operation and management

Project sponsors: Barrick Gold of Australia, BHP Billiton, Newmont Australia, Rio Tinto and Worsley Alumina

Mine Seismicity and Rockbursts – Unleashing the Earth's Energy Training DVD

Expected launch date: early 2008

It is proposed that the training DVD will explain, in novice terms, the phenomenon underlying mine seismicity and rockbursts in mines. Underground mine workers will be equipped with essential knowledge to understand this hazard, including understanding the difference between natural seismicity and mine induced seismicity, what makes a mine seismically active, the pre-cursors, and how to control seismic hazards.

Project sponsors: AngloGold Ashanti Australia, Barrick Gold of Australia, Beaconsfield Mine Joint Venture, BHP Billiton, Independence Group - Lightning Nickel and Newmont Australia.

Case Studies on Deep and High Stress Mining Publication

Expected launch date: November 2007

In 2002, the ACG hosted the First International Seminar on Deep and High Stress Mining. This seminar was the first in a series of seminars held in three countries with recognised deep and/or high stress mining conditions – Australia (2002), South Africa (2003) and Canada (2006). The ACG will release a hardbound publication featuring the highest quality papers from the three seminars at the 4th International Seminar on Deep and High Stress Mining to be held in Perth in November 2007. The ACG is seeking industry sponsors for this publication.

WA Ground Control Group Update

During the last six months, the Western Australian Ground Control Group (WAGCG) held two meetings. The Kalgoorlie meeting held in July witnessed the positive revival of the group following an 18 month struggle to retain and attract new members. Richard Varden was elected as the new chairperson and Emma Kinnersly was elected as the group's secretary. The technical theme of the meeting was advances in seismisity and dynamic support with presentations by:

- Frans Basson, AMC Consultants Pty Ltd – South African perspective on seismicity
- David Gaudreau, BHP Billiton LNO – Canadian perspective on seismicity
- Daniel Heal, ACG – Mine Seismisity and Rockburst Risk Management, Phase 3
- Peter Mikula – Seismic Memory
- John Player, WASM – Dynamic Resistance Support Research

The second meeting was held in Perth in October. A presentation by Guy French, a lawyer with Phillips Fox, overviewed the legal responsibilities of the mine personnel area and the actions to be undertaken in the event of a serious incident was very well received by the group. The WACGC later joined the Australian Shotcrete Association workshop for the technical session that highlighted a number of problems associated with the shotcreting process and explored the new advances in the industry.

The next WAGCG meeting will be held in Kalgoorlie in early February. For information about the WAGCG please contact either Richard Varden via rvarden@barrick.com, or Emma Kinnersly, Emma.Kinnersly@goldfields.com.au.

ACG 2007 Event Schedule*

Title	Date	Where
Rheology Workshop	12 March 2007	Esplanade Hotel Fremantle, Perth, WA
10th International Seminar on Paste and Thickened Tailings	13-15 March 2007	Esplanade Hotel Fremantle, Perth, WA
Risk Analysis and Economic Evaluation of Mine Projects	3-5 April 2007	Mercure Hotel, Brisbane, Qld
Advanced Ground Support in Underground Mines	2-4 May 2007	Hotel Ibis, Perth, WA
Mine Water Management Seminar	12-13 June 2007	Hotel Ibis, Perth, WA
Planning for Mine Closure	14-15 June 2007	Hotel Ibis, Perth, WA
Blasting for Stable Slopes	30-31 August 2007 (t.b.c.)	Hotel Ibis, Perth, WA
Slope Monitoring Forum	11 September 2007	Sheraton Perth Hotel, Perth, WA
International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering	12-14 September 2007	Sheraton Hotel, Perth, WA
Hydraulic and Paste Backfill	5 November 2007	Novotel Langley Hotel, Perth, WA
Mine Seismicity Short Course	6 November 2007	Novotel Langley Hotel, Perth, WA
4th International Seminar on Deep and High Stress Mining	7-9 November 2007	Novotel Langley Hotel, Perth, WA
Practical Soil Mechanics in Mining	4 December 2007	Hotel Ibis, Perth, WA
Total Tailings Management	5-7 December 2007	Hotel Ibis, Perth, WA

Regional and On-Site Courses on demand throughout 2007

- **Management and Operation of Tailings Storage Facilities**
- **Ground Control at the Mine Face Training Course†**
- **Practical Rock Engineering Skills Development†**

PRE 01 Ground Control Systems, PRE 02 Rockmass Characterisation, PRE 03 Geomechanical Stope Design.

† Not available to overseas operations.

** The ACG event schedule is subject to change. For event updates, please visit www.acg.uwa.edu.au/events_and_courses.*

Festive Season wishes

The ACG team and Board of Management extend to you and your family our very best wishes for a happy and peaceful Christmas and a healthy and prosperous New Year.

We thank you for your support and encouragement during the year.

Our office will be closed from Friday 22nd December 2006 until we return on Monday 8th January 2007.

Australian Centre for Geomechanics PO Box 3296 – Broadway, Nedlands, Western Australia, AUSTRALIA 6009

Ph + 61 8 6488 3300 Fax +61 8 6488 1130 acg@acg.uwa.edu.au www.acg.uwa.edu.au