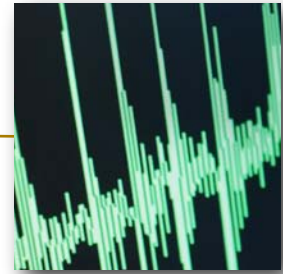




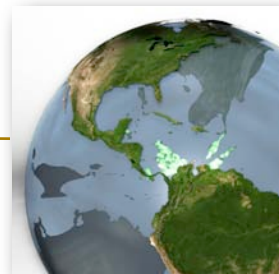
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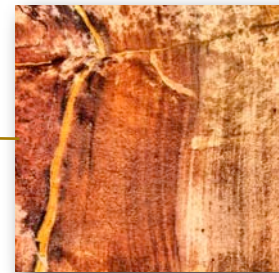
*One of a series of workshops in support of the development of the
International Fault Slip Control Research Initiative (IFSCRI)*



Microseismicity



Geophysics

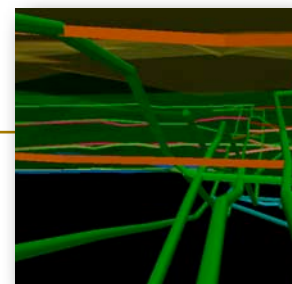


Structural Geology

Summary of Feedback

Leaders' Workshop

Toronto, Ontario, Canada
Golder Associates and Delta Chelsea
June 2-3, 2010



Modeling & Mine Design

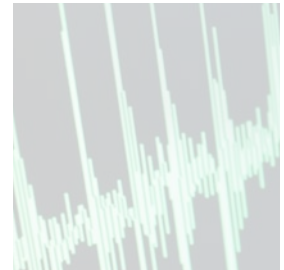
Acknowledgements

Thank you to all workshop participants for your contributions and continued guidance as we move forward with this exciting initiative.

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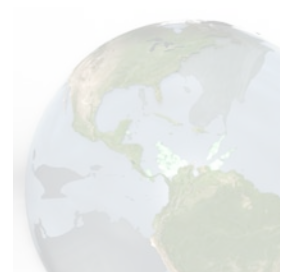
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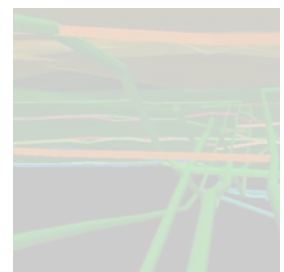
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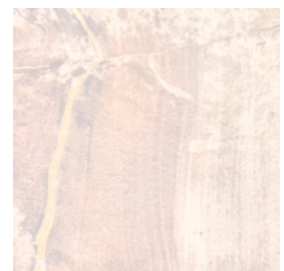
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Introduction

Preamble

On June 2-3, 2010, the Leaders' Workshop for the proposed International Fault Slip Control Research Initiative (IFSCRI) was held. This workshop was designed to review the outcomes of the previous four technical area-specific workshops, each one with the purpose of brainstorming exciting and relevant research and technology projects needed to better understand the fault slip problem in underground mines within the context of a ~\$20-50 million, multi-year research program. Further, this workshop would identify the fundamental science questions to form the basis of ongoing research as well as to select a sustainable test site at which to carry out the research.

The following document contains a summary of the feedback received during the workshop, as well as detailed feedback received following the workshop. Please feel free to contact Damien Duff at dduff@miningexcellence.ca should you have additional information to add to this feedback document.



(From left to right) | Back row: Dave Counter, Richard Smith, Benoit Valley, Ross Ward | Second Row: Toivo Wanne, Maurice Dusseault, Keith Bullock, Doug Morrison, Steve McKinnon, Mark Diederichs, Peter Kaiser | Third row: Brad Simser, Doug Goldsack, Jane Djivré, Nigel Smith, Denis Thibodeau, Ming Cai, Fernando Vieira | Front row: Bernd Milkereit, Greg Cooper, Louis Martin, Doug Schmitt, Damien Duff, John Hadjigeorgiou, and Derek Elsworth.

Missing from photo: Shannon Katary

Agenda

Workshop Moderator: Damien Duff (CEMI)

Day 1 – June 2nd, 2010

Location: [Golder Associates Ltd.](#)

141 Adelaide Street West, Suite 1220 (12th floor), Toronto, Ontario, Canada M5H 3L5

1300-1330: Introductions and overview of workshop purpose. Summary of progress and **accomplishments** to date

- Coffee and Snacks available upon arrival

1330-1530: **Administrative matters** related to ensuring the success of the IFSCRI initiative

1. *The SNO and Dusel experience- lessons to be learned*
2. *Strategic Governance issues*
3. *Stakeholder buy-in strategy, including companies, universities, international?*
4. *Need for panel of senior scientists/scientific advisory board*
5. *Discussion of IFSCRI funding requirements and appropriate funding strategy- Phase 1 and Phase 2*

1530-1545: PM Break (Coffee and Snacks)

1545-1945: Discussion of test site suitability criteria and **selection of preferred test site.**

1. *Will include detailed VRL reviews of Kidd Creek and Creighton mines (2 hours each)*

1800-1900: Working Dinner

Day 2 – June 3rd, 2010

Location: [Delta Chelsea Hotel](#) – Seymour Room (2nd floor)

33 Gerrard Street West, Toronto, ON, Canada M5G 1Z4

0800-0830: Continental Breakfast

1000-1015: AM Break (Coffee and Snacks)

1200-1300: Working Lunch

0830-1430: Presentation by team leaders and discussion by all of **the basic science challenges**, opportunities and research needs within each technical focus area- ~ 1 hour each.

1. *Geophysical Monitoring and Instrumentation*
2. *Rock Characterization*
3. *Mine Stiffness*
4. *Risk Engineering*
5. *Rock Support*

1400-1415: PM Break (Coffee and Snacks)

1430-1500: Review of **Cross disciplinary opportunities** and any new ideas

1515-1700: **Action plan** for the future:

1. *Strategy for Phase 1 contemplated work*
 - *Evaluation of options for test site design and performance of required pre-engineering work*
 - *Funding application writing team*
 - *University/company engagement/buy-in*
 - *Collection of baseline technical data at the suggested test site and testing of potential equipment packages*
2. *Summary/Wrap-up*

Key Points | Summary

Action Items

1. Complete and submit focus area white papers by June 11th and highlight 10 key research opportunities with 3-5 critical ones
2. Check back with industry
3. Come back to this group (on group basis or individually) looking for detailed follow-up input
4. Leaders to help create awareness among academic colleagues (departmental and cross-departmental) about IFSCRI
5. Need 2-3 key writers to assist with fall funding applications.

Key findings from the review of Kidd Creek Mine and Creighton Mine 3D Models “Their sustainability as potential Test Sites”

Kidd Creek Mine as a Potential Test Site:

- Interest from rock characterization group in area between 68L and 75 and potentially below 75L and to 82L.
- There are 27 geotechnical holes available on 22.5 degree arcs through a fault plane (from somewhere in mine) for which there is complete core coverage (stored indoors). MD specifically interested.
- Geophysics team interested in area below 82L and specifically below 90L. Could do what they need to do there.
- Rock support team sees advantages in the lower part of the mine
- Mine stiffness team sees advantages in ensuring that effects of active mining are monitored by geophysics group- particularly where fault slip and damage is occurring?

Creighton Mine as a Potential Test Site:

- Interest by all teams in hanging wall area below about 60L. Significant seismicity there which is unexplained.
- Perfect if there was a drift driven straight out into the hanging wall (MD) which could be mapped and characterized and compared with boreholes and looked at in context of known seismicity.
- The crotch of the pant leg zone (460 zone) could also be favourable and has SMCK's vote.
- Again there are good opportunities from a geophysical standpoint.

Key findings from review of Kidd Creek and Creighton 3D Models

- Rock support and mine stiffness team see advantages in the HW part of the mine.
- Mine stiffness team particularly like the capability to link findings with earlier research re: seismicity time links and seismic plane maps.
- Proximity to SNOLAB and the possibility that boreholes could be drilled from nearby as well and info channelled to office/data collection room there and routed to surface?
- Talking with Nigel later indicates that this is a possibility for consideration as is the chance that we could have access to office/shower and other SNOLAB-related facilities.
 - Will be giving his superiors and fellow directors a “heads up”

IFSCRI Key Research Objectives

Identified by Technical Teams

Geophysical Monitoring and Instrumentation

- Investigate petrophysical proxies for stress (seismic, conductivity, dielectric, magnetic etc)
- Evaluate controlled broadband sensor arrays
- Design 3D/4D acquisition system and evaluate suitability/effectiveness for active and passive monitoring
- Derive a 4D stress volume (x, y, z, t)

Rock Mass and Fault System Characterization

- Establish a geomechanically and behaviourally relevant classification approach for faults and fault systems
- Develop approaches for handling discrete and distributed uncertainty related to genetic model choice and component variability within fault systems
- Improve and justify best practice for rock/fault system characterization, balancing modelling needs with logistical considerations (how much is enough?)
- Link characterization with requirements of physically meaningful modelling

Mine Stiffness and Failure Sensitivity of Structures

- Understand mine stiffness and its impact on fault slip as well as on fault propagation
- Perform tests which shed light on the mechanisms of energy release
- Improve our understanding of how to control energy release from fault slip in underground mines
- Provide experimental observations useful for future mine design tool development

Identified by Technical Teams

Dynamic Rock Support

- Understand fault-slip rockburst damage to underground excavations through investigations of:
 - Damage mechanism
 - Damage severity
 - Documentation of rockburst damage
 - Definition of rockburst support design parameters
- Perform field and potential lab testing of rock support systems

Engineering Risk

- Determine if risk can be quantified
- Engineer a means to specifically identify and mitigate risk in fault slip environments
- Develop a cohesive means of communicating risk
- Document findings and recommendations in a guidebook of best risk management practices

Day 1 Proceedings

The following is a collection of feedback received during the workshop, and includes key points made by each presenter as well as the discussion which ensued.

Discussion of Administrative matters related to ensuring the success of the IFSCRI initiative

- *The SNO and Dusel experience- lessons to be learned*
- *Strategic Governance issues*
- *Stakeholder buy-in strategy, including companies, universities, international?*
- *Need for panel of senior scientists/scientific advisory board*
- *Discussion of IFSCRI funding requirements and appropriate funding strategy- Phase 1 and Phase 2*

Key Issues - Critical Success Factors:

1. Decide whether we are a Project or a Facility- what is the Vision?
 - a. Are we a single-science question which sunsets after the project is completed or
 - b. Are we a facility with a much longer lifespan?
2. Overarching drivers for governments are: the innovation agenda; Canadian competitiveness and Canadian ``bang for the buck``
3. Broader impacts must be demonstrable for engineering department directorates also
4. Maintaining management independence (of facilities, (and projects))
5. A clear IP structure and direction is necessary
6. Access to results MOU needed (Henderson failure linked to this)
7. Plan for early wins and maintain a core of high profile projects with different delivery times
 - a. Keep the project pipeline full
8. Having an appropriate governance structure in place from the outset is critical
9. A project advisory board (technical issues) is important- keep small!



SNOLAB- Lessons learned:

- Demonstrate a clear vision of world-class research that will be undertaken
- Why is the selected site appropriate? Demonstrate unique capabilities (i.e. depth for astro-particle physics experiments, cleanliness, prior legacy, etc.)
- Develop infrastructure plan as appropriate for the science, through workshops, calls for Letters of Intent (e.g. cleanliness, services)
- Ensure clear construction of collaborations (facility and experiments)
- Ensure construction of governance model for facility (with mining company, internal structures, etc)
- Development of relationship between facility and experiments and construction of operational model
- Dissemination of benefit to funding stakeholders
- Delivery of agreements (MoU with mine, MoU with experiments, etc)
- Infrastructure delivery (not to be underestimated!)
- Experiment delivery (certainly not to be underestimated!)

Dusel- Lessons Learned:

- Define a compelling science case early as the main driver
- Develop societal/economic relevance (for this particular problem of fault slip) – implications on productivity
- Link experiments with broader community who might be interested (biologists, hydrologists,) in the science and deep access for example
- Develop a large user community but a focused governance body
- Have professional scientific bodies (NRC etc) endorse the science and include influential reports (i.e. P5 in US for physics and grand challenges)
- Get funding agencies involved – find a champion or plant a champion as a rotator (Mike Turner for DUSEL)
- Get all the stakeholders to see an advantage in this that they alone cannot accomplish

- Ensure that the site has longevity and if a mine there will be a guarantee of access and ease of access once funding from other sources has been invested
- Choose a site that minimizes the infrastructure costs in a realistic way

(P. Kaiser) Who else fits? Needs to get excited? Drivers? Champions? Are there projects of interest to the petroleum industry and others? Depends on whether the question is from perspective of a national facility versus mining-company driven project.

(D. Duff) What is the interest or benefit to others including microbiology? Are we willing to entertain their involvement and find a way for them to fit in? How about the Earthquake community?

(D. Elsworth) Have to be careful because this is an important project initiative; it is dangerous to be too eager to “sell” it and risk getting away from the core problem. E.g. model validation and technologies OK but maybe not biology.

(D. Schmitt) There could be a lot of international interest from other sectors

(D. Thibodeau) From a mine point of view, need to keep the focus. As long as it’s a mining purpose primarily. Note that it may increase your capital costs.

(D. Morrison) Even mining companies have operations from around the world, and it’s going to be Canada that needs to generate the intellectual capacity for the mining companies to transfer their knowledge around the world.

(D. Duff) Trade-off is giving other researchers access, but focus is fault slip, no question about that.

(J. Hadjigeorgiou) Must recognize do we need to bring other people in for the idea to be sellable? If we can do it on our own, don’t be too eager to bring in others. If we open it up, are we doing it honestly, because we see value with them participating? Is it strategic? If so, ensure they will see and receive value.

How do we get industry to buy in and what is the value for universities?

- Have the science ministers visit the SNO to access additional circles of govt or get through a different way
- Industry engagement should be easy because fault slip is an industry problem
- Universities: Academics driver = the science; Institutions: reputation and spotlight
- Focus on HQP and technology development

Who is to lead, and how to get others on board?

- SNOLAB has moved from the project to the facility stage and therefore away from the academics to a facility management team. Consequently, there is an impartiality, easier to select projects based on relevance to the facility itself.
- Industry-university buy in, show you are on the cusp of this important value that is getting a lot of attention, so exploit it. The driver is the kudos and the visibility.
- Infrastructure operating fund?
- Develop a roadmap to outline the important projects in IFSCRI.
- Need “multiple on-ramps for others to join”
- Develop an initial suite of experiments and have a continuous availability of seed funding to test the idea, and then compete for the full project funding in a competition (NSF). This reduces the risk of not having unsuccessful projects
- NASA has a policy that 1 year after data is collected, the interpreted data is available for public
- Link to stimulus type arrangements
- Need to show the value of the reputation and prestige, consider that the dollar value in itself is not that large.

(F. Vieira) Should it be a project or a facility?

(D. Elsworth) If you can accommodate the experiment in an existing infrastructure, and the project is sufficiently small enough, keep as a project, then later expand the facility to meet needs of additional projects.

(F. Vieira) Should we prepare a set of questions the fault slip project will need to answer and then talk about the facility?

GOVERNANCE

(N. Smith) - governance is mandatory to sort out before applying for funding e.g. CFI

- don't get academics involved in operating the facility infrastructure, they are not interested

(D. Elsworth) **How to change the culture?** Contact John Hudson ISRM Commission planned as an inaugural activity –N. America underground labs

Day 1 Proceedings | Review of 3D - Models

Kidd Creek Mine

(D. Counter) **Note:** In the next 6 years everything will be have been mined; with a plan to close the mine in 2018. By 2013 we should have punched through the sills and by 2014 we would have ruptured every pillar. You can probably keep a bore hole open for 6 months. Cages to 9600 level would take 45 minutes. Can drive to the bottom of the mine in about 1¹/₂ hours. Look at the south abutment between 75 and 82L. Look at north abutment between 68L and 75L. Mining will be coming up under the north abutment sill and starting to take pillar panels out and this will be a seismically hot spot.

•Does Kidd give you what you need to do the planned research in each discipline area? Where should we do our experiments?

Risk Engineering (Keith Bullock): NO, developing teams important, physical testing location is not as important for this.

Geophysics (Bernd Milkereit): YES, we want to go beyond microseismic monitoring. Need instrumented boreholes to establish long time series of stress-strain measurements and how it affects rock properties. Need to get access to boreholes where there hasn't been a lot of development yet. The deeper the better- Specifically interested in area below 82L and, in particular, below 90L- down to 96L. Could do what team needs to do there. If can identify an area of volume of 500x500 metres and put in the instrumentation, that should be fine. The hole diameters available are: lots of BQ through NQ 2 1/8" to 3 1/4" diameter holes (slim).

Rock Characterization (Mark Diederichs):

Need basically to do anything which hasn't been done yet.

POSSIBLY- two phases of work required: short term and long term. Is core available? Cores are available for POD and Exploration holes. Need series of stubs, need underground office, storage.

There's an interest from the rock characterization group in 3-4 systems of major faults located in area between 68L and 75L and potentially below 75L and to 82L. Below 75L- we could even do something early on with existing data. We need a relatively simple geometric sequence of mining and a well defined fault system.

Would need to characterize what are the differences between the faults as well as characterize the rock masses in between. Potentially would need to drill new holes also? Going down deeper also provides the opportunity to interact with the other teams and potentially share data. **Note:** there is no shotcrete either at the deeper levels. **Note:** FW development below 90L has none.

We need to look at the 3D model in detail and see what features in the model improve our ability to figure out what's going on. Below 68L in the short term and below 75L stopes in the longer term may

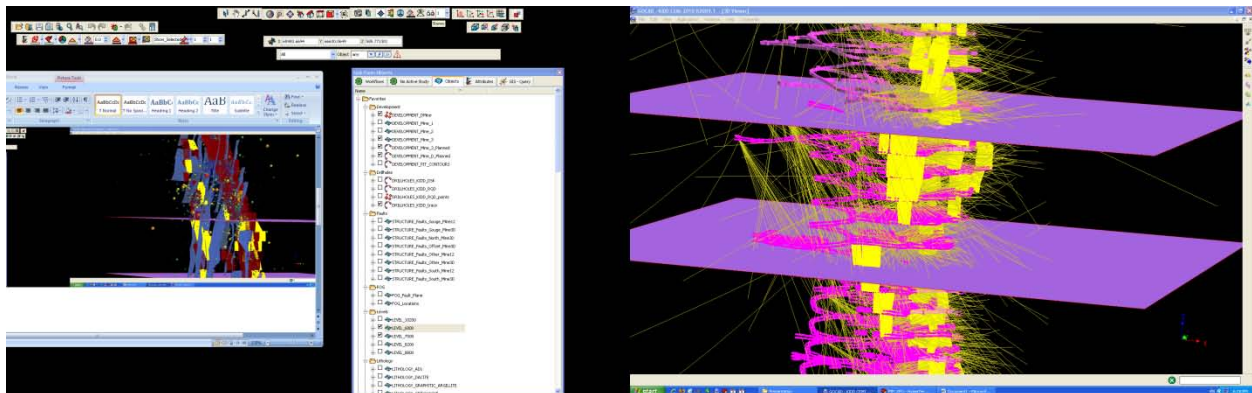
Kidd Creek Mine

do that? There is a lot of damage in that area right now though and a lot of shotcrete has been applied. Need to have the seismic system up to snuff as well.

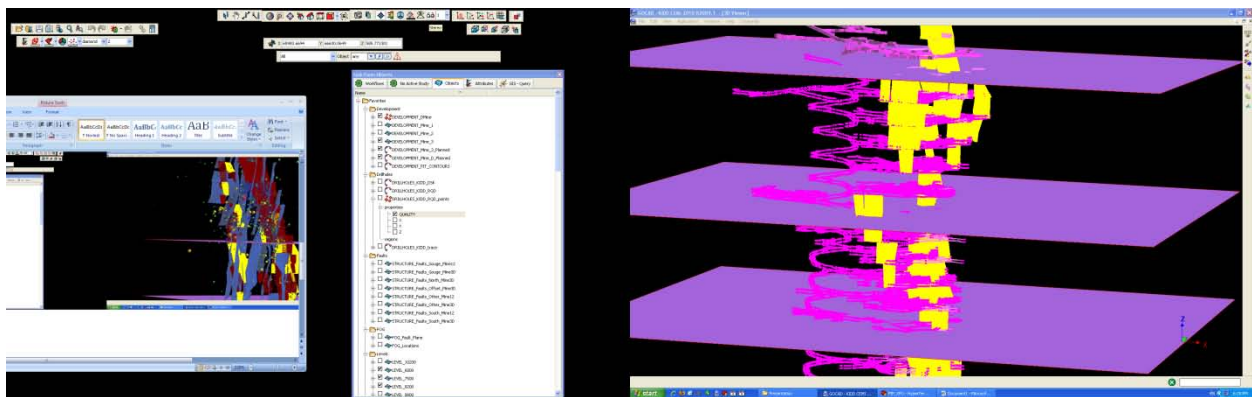
Therefore, below 75L may be more ideal since it's less damaged and shotcrete is not an issue and, further, planned mining is over the next 2 years. The longer term work would ideally be in the geophysics block- below 88L and characterize that conventionally.

Note (Dave Counter comment): There are minimum of 8 geotechnical holes per level available on 22.5 arcs through the rupture plane of the 3A fault on 5 levels for which there is complete core coverage (stored indoors). Never been sampled and stored indoors. All is NQ. Every 120 around that circle is a Geo-con stress cell- in place since July of 2009. A Paladin system is also going in on 94L in next 2 months, into a block which hasn't been mined yet.

- Rock Characterization Team specifically interested in access to these cores and related data



- For an undertaking the size of IFSCRI- we need to think about making access available rather than have to rely on what is already available. To do what we need to do we can't be doing what we've always done-sneaking around that is...



Rock support (Ming Cai):

Sees advantages in the lower part of the mine since big events will be coming. Want to find out how rock support system reacts to these events, so high risk areas are suitable. They are good for instrumentation purposes and evaluating the capacity of systems.

(J. Hadjigeorgiou) Between 68L-75L is not of value right now because of level of damage. Need to have measurements on how ground behaves- PPV etc to provide input for mine design evaluation- needs an undamaged area (PKK).

(M. Diederichs) Let's not forget that lower frequency (pre-event) seismicity- the type which produces shakedown etc. Is also one of the hazards associated with FS events. Aren't they hazardous regions therefore from a dynamic support point of view....?

(P. Kaiser) Focus has to be on pre-event control and not rock support design. Measurements can be taken which help in evaluating whether design methods work etc. and we should measure, not just ground motion and whatever complimentary measurements can be taken, but which faults, depending on their orientation may be at higher risk due to the directionality at which s or p waves are propagating, for example? Which excavations are more vulnerable because of the directionality of these waveforms? We're not just interested in ground motions but also in what the excavation surface is doing.

Mine Stiffness (Peter Kaiser):

- Mine wide seismicity and gravity driven deformation monitoring needed
- Stress change and strain change measurements needed.
- Need active mining happening so changes can be measured along faults/structures
- Shorter term work can be done where changes are happening now. Interested specifically in seeing shear displacement and stress changes monitored now.
 - and- more virgin block of ground where something will happen in 3-year term
- Short term work can mostly be done from properly oriented boreholes that likely exist right now.
- Interested in geophysical studies in areas affected by FS and damage. Repeat geophysics in those kinds of areas may be beneficial.

Day 1 Proceedings | Review of 3D - Models

Creighton Mine

Note: from an access standpoint at Creighton, there is a lot more development that is further from the ore than at Kidd (thus possibly providing an opportunity to find a place from which to conduct tests which does not interfere with production and also which affords the opportunity to drill well placed bore holes). Also, there is a surprising concentration of seismic events in the hanging wall that may present an opportunity for research purposes. From a mining standpoint there is an unusual bifurcation or “pant leg” (460 Zone area) that will present unusual challenges for managing stress distribution and thus research. Further, there is access to it that may enable us to instrument the mine levels and measure changes during mining.

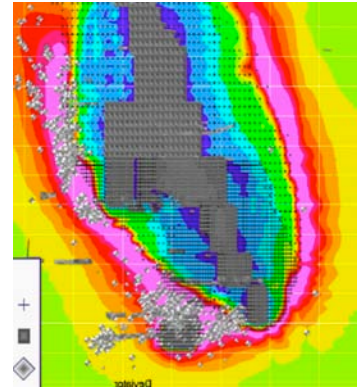
The Sudbury rock also is substantially different from that at Kidd- it’s stiff and strong compared to the “mush” at Kidd Creek. They are at opposite ends of the spectrum and thus both may present a different opportunity?

•Does Creighton give you what you need to do the planned research in each discipline area? Where should we do our experiments?

Geophysics: (Bernd Milkereit)

YES, definitely. The downward migration of stresses is interesting and looking at this from a microseismicity point of view and how it’s moving is warranted. We could also investigate the HW and neither problem areas would interfere with mining operations. Both are interesting problems. Problem of instrumenting properly perhaps?

Available boreholes? Yes, in “pant-leg” area. Squeezing may be an issue? But the next generation of sensors is cheap and cementing them in the boreholes is not an issue- we don’t care if we lose them. They’re available right now.



Rock Characterization: (Mark Diederichs)

Would like to get into HW physically. Not drilling since can’t keep holes open. Put a “Y” drift off one of stubs (in 2 different directions). Need to be able to look at structures carefully and get some seismic sensors out there.

Drift may not behave same way as a borehole because the norite has a tendency to “shard up” whereas the drift may not?

Creighton Mine

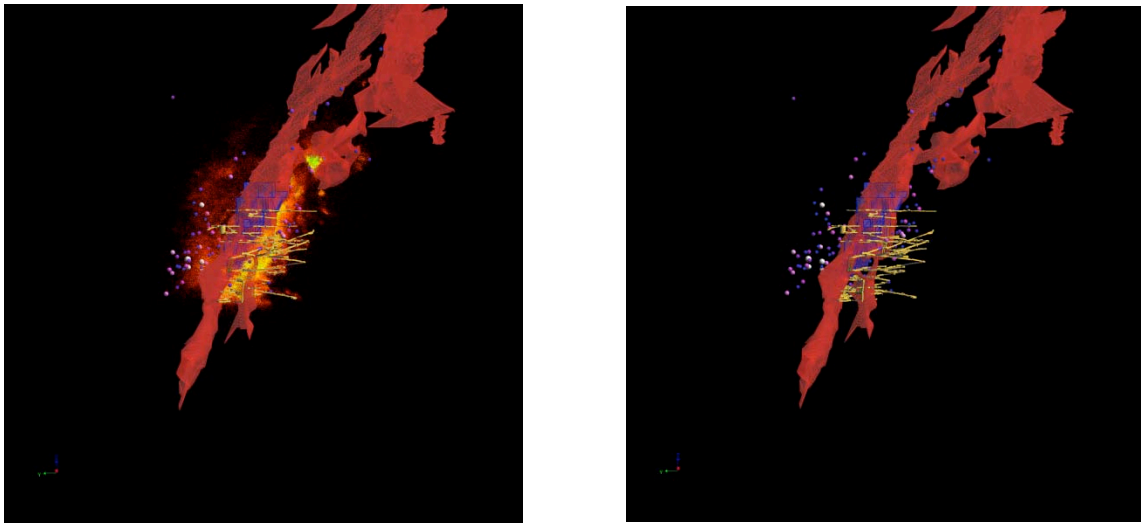
Down below is of interest too. Make sure the right data is collected and there's an interest in getting geologists to do that and ensure that everything we can collect is collected. We shouldn't be constrained by what we normally do- need to go beyond that.

Need to have somebody shadow a geologist at this mine as a minimum for now.

SMCK- the pant leg area is of specific interest- have access all around it, more access to structures. Seismicity is in HW but is unknown and will be much harder to characterize that area. Also there's a mag 4 event every few years which could just wipe everything out! The safest bet is the 460 zone area.

Further, in the HW, the seismicity is responding to more mine-scale events whereas in the 460 zone area, it's responding to events on a more "stope by stope basis" and so the changes are occurring on a scale more in line with the timescale of our planned experiment- more useful?

This is not directly about linking characterization to what is about to happen in the near future and therefore seeing those HW structures would still be very helpful. An opportunity to get something out there would be really of interest.



Views illustrating Hanging wall as well as 460 Zone general areas and associated seismicity

Mine Stiffness: (Peter Kaiser)

YES- we know that when structures intersect stopes- stuff happens. Creighton allows to answer the critical questions which are:

1. When has enough damage been done to the rock mass that faults are activated and become unstable?

2. What geophysical studies allow us to monitor how that rock mass is changing and to identify which structures are being mobilized?
 - a. Where is strain localization happening and can we measure differential straining in boreholes?

As we go deeper- we do damage way outside the area being mined which can create degrees of freedom higher up and, as we do this, we change the stiffness of the rock mass and the understanding of what is going to fail or not becomes the challenge.

The Creighton hanging wall, in particular gives us the opportunities to help answer these questions.

(M. Diederichs) An access drift there, for many reasons, would just be “huge” for this project

Rock Support: (Ming Cai)

Interested in getting into HW access.

1. Greater chance to test support system there
2. Good chance to measure strong ground motion there. Adds cost to project so money has to come from project, because mine wouldn't do that.

(B. Simser) Let's not trivialize the Mag 2's in the FW. Could measure some strong ground motions there.

(D. Thibodeau) Access to this general area- including 460 zone area takes about 1-1¹/₂ hours. The need for an underground logistics centre is underscored by this- make research more efficient.

(N. Smith) There are network services running down to SNOLAB. There is office space outside the “clean area”. There is a synergistic opportunity here perhaps?

(M. Diederichs) Establishing the underground infrastructure to support a research project of this magnitude is the starting point and the experiments will grow from that.

Day 2 Proceedings

Presentation by team leaders and discussion by all of **the basic science challenges**, opportunities and research needs within each technical focus area- ~ 1 hour each.

- *Geophysical Monitoring and Instrumentation*
- *Rock Characterization*
- *Mine Stiffness*
- *Rock Support*
- *Risk Engineering*

Geophysical Monitoring and Instrumentation

Presentation by Bernd Milkereit

Preparatory - Design Stage

3D Modeling studies, selection of borehole instrumentation for logging and monitoring definition of borehole geometries development of a strategy for multi-parameter data acquisition, data sharing, calibration, processing, inversion and visualization.

Project Initiation - Baseline Surveys

- multi-parameter well logging
- in situ stress measurements (hydraulic fracs)
- crosswell seismic and EM surveys

Long-term Continuous Monitoring

- controlled source: seismic, EM
- passive monitoring: strain, tilt, seismicity/noise, EM, magnetics

Time-Lapse Repeat Surveys

- in situ stress measurements (hydraulic fracs)
- caliper and televiewer surveys

Summary

<p>Phase 1 No specific site required</p>	<ul style="list-style-type: none"> • Investigate petrophysical proxies for stress (seismics, conductivity, dielectric, magnetic, etc.) • Evaluate controlled broadband sensor arrays • Design 3D/4D acquisition system
<p>Phase 2 At the IFSCRI site</p>	<ul style="list-style-type: none"> • Evaluate 3D/4D borehole sensor arrays for active and passive monitoring
<p>Phase 3 At the IFSCRI site 24/7 monitoring</p>	<ul style="list-style-type: none"> • Derive 4D stress volume - $s(x,y,z,t)$

Detailed Discussion:

Don't do geophysics for the sake of geophysics.

The problem is a 3D one. The only way to go is to put instruments into boreholes. The key question is: Are there any geophysical or petrophysical parameters which are sensitive to stress changes?

(B. Simser) Need to build redundancy into instrumentation plans.

(D. Thidodeau) Understanding of site conditions/parameters critical.

(B. Milkereit) This is why background measurements are necessary and why the test sites being discussed are valuable since so much of that kind of information is already available.

Microseismicity may not capture everything esp. if sensors are not broadband. There are hardly any labs left in the world capable of doing these kind of measurements- measuring changes in response to pressure.

Can we measure velocity changes in rocks due to stress in 3 and 4 dimensions is the fundamental question?

(M. Dusseault) Success story on this in granular media in the petroleum sector. Is not done in hard rock industry though.

(D. Counter) Need to look at constant source . How mechanically do it?

(B. Milkereit) JMcG worked on this problem at QU and NTC- were able to measure earth tides effects in u/g environment. Piezo-type sources will allow this.

(B. Simser) ISS are working on something similar . Was in earlier W/S.

(M. Diederichs) What are we actually trying to do- measure stress anisotropy or damage anisotropy? Both are going on. The damage needs a high frequency source but u/g can get away with lower frequency for the damage we're talking about.

(B. Milkereit) Not sure. Is in the Khz range. Want a broadband source- this is the critical thing.

(D. Schmitt) The frequencies will have to be lower for the extent of damage we're talking about.

(B. Milkereit) Resolution is not tied to how high the frequencies are but what bandwidth. Nobody is doing this kind of thing right now. Only way to measure and translate into sigma 1 and 2 is to hand over these results to other groups.

(M. Cai) Noise u/g is problem- how separate them? Can't control in lab but not u/g.

(D. Thibodeau) Problem picking up slow deformation- but let's not be constrained by what technical issues we know to exist right now - these things become problems to solve over the course of the project- [it's part of the research which may be needed]. Data of this kind is of value in u/g risk management.

(B. Simser) The anisotropy of Sudbury area rocks is significant - which could pose a problem for tests of this kind.

(M. Diederichs) Is more than just logistics and installing the equipment- will need to couple with some kind of understanding of the rock outside the immediate stress regime .

(D. Schmitt) Characterization is really important therefore.

(B. Milkereit) What is a good site? One which hasn't received that many stress effects already, then impose stress over time and watch fracture development. Tools are available on the inversion side and on the modeling side. As mining progresses, this can be taken into account in modeling for seismic wave propagation. Recent development coming from tunnel building. What are the best sensors though?

(P. Kaiser) Enhance the quality of seismic monitoring and the need for continuous source to continuously establish the velocity model? What's the gap needing to be closed?

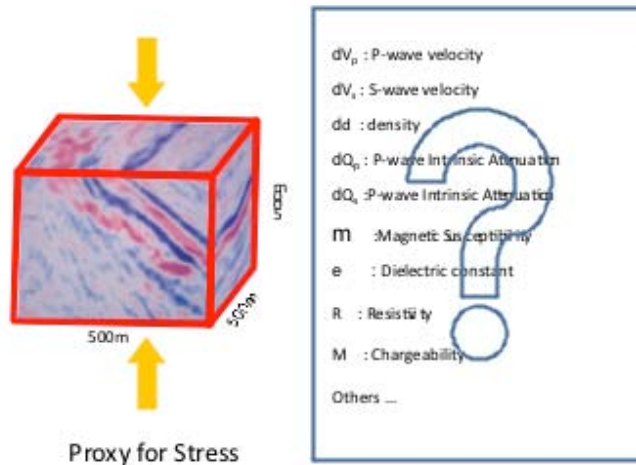
(B. Milkereit) It's not just about seismic properties. There's a whole bunch of stuff being done in Eastern Europe on other physical properties- changes, dry or wet rock conditions as a function of pressure.

(D. Schmitt) Dielectric constants in potash mines and radar are used for mapping layering and other related safety matters during mining

(M. Dusseault) Very sensitive to any physical separation .

(B. Milkereit) Point is that besides seismic there are 2-3 other techniques to be installed in boreholes which could be very helpful.

Need to get from lab scale to field scale - a denser more optimal distribution of sensors is needed based on some of the work which Kaiwen Xia has been doing at lab scale. Tiltmeter/strain meter arrays may not be available in slim-hole sizes?



(D. Thibodeau) Can it be a percussion hole?

(B. Milkereit) Really doesn't matter as long as can cement or bond sensor in the hole .

(P. Kaiser) Bore hole stability- how long need access to boreholes- minimum time in holes needed? Days only?

(D. Duff, D. Schmitt, D. Thibodeau) Casing or lining of holes possible

(D. Schmitt) Is damage around the borehole an issue? If wavelengths are long enough, is not an issue . Although [there may be] a bit of an impedance effect.

(D. Duff) But surely is a problem for other things want to measure?

(B. Milkereit) It could be but nobody has done this kind of continuous recording though and many of the sensors could/would be positioned outside the immediate damage zone- 1km, 2km levels- run like a government survey- 24-7.

(D. Thibodeau) If work fast enough, hole damage won't be critical.

(D. Morrison) Do more than one hole from same set up [thereby limiting issues associated with any one]

(B. Milkereit) Data transmission issues also important.

(D. Morrison) If looking at broadband, there's a experiment going on at Totten Mine right now in Sudbury where large volumes of data are being moved wirelessly via broadband. Data transmission issues may not be an issue, if this works out.

(N. Smith) Is this a problem- from a safety perspective- explosives etc.

(D. Thibodeau, D. Morrison) No, it's a frequency control issue

(B. Milkereit) We'll be relying on magnetic and EM time-series methods as well as multi-parameter base line surveys in part early on and these sorts of things are not being done anywhere else presently. Seismics and EM will need to be cross hole- this may be the only way we can capture things in 3D?

(D. Schmitt) Are some well-logging developments right now where the geophysical system goes down the hole near the bottom. Can be a big advantage in holes that are failing and should help get good logs.

(B. Simser) Something similar in paste fill world now.

(B. Milkereit) Control source seismics and EM systems are available which on the passive monitoring side may be useful. Same on strain and tilt meter sides.

Emerging technology is to not look for events but, monitor passively – record time series and invert the noise for velocity models. Is done for earthquake studies. Portable system available in Europe, hope to bring these in. Put in boreholes or stopes and listen. Noise is sensitive to changes in p and s wave velocity.

Are there any other effects- use opportunity- Any other effects which can be monitored with build up of stress? EM and MAG work holds promise. Photonic emission (earthquake lights) is interesting? Been discussed in earthquake community for 50 yrs. Don't make centrepiece of this work though by any means, however.

Repeat televiewer measurements useful for repeated stress measurements. Only will work if holes are stable.

(D.Schmitt) Hydrofrac tests done in Antarctica at 1,500m depth. Fractures induced and fluid flows measured down borehole. Monitor and gives a good measure of what minimum stress direction (and magnitude?) is. Did televiewer surveys before and after to see pre- and post- effects. 17 measurements taken with high consistency.

(P. Kaiser) 2-3 relevant things:

- Stress measurements- there are applications in the geothermal world- Francois Cornet work. Have experimented with this kind of thing.
- Have not exploited this sort of experiment on different fracture sets in mining which could help get idea of stress orientation.
- Is there anyone in the Geothermal world who would be interested in our experiment- may pay for experiments because we would have an array of sensors very close to the borehole which might provide them an opportunity? How about in the petroleum world? Has interest in hydrofracing and induced seismicity. How can we make this of interest to them which they can only do at 10km depth now....

(D. Schmitt) NSF spent \$350K to develop this experiment in Antarctica. We would be much cheaper though because we'd be closer to where we'd be doing the hydrofracturing. Had NQ and HQ tools...BQ? Have tried hydrofracturing at URL.

(P. Kaiser) But only gives part of tensor. Here we want to measure different fractures, can we activate different ones....different set of questions than at URL- in situ stress only.

(M. Dusseault) Anyone aware of International Partnership for Geothermal Technology (IPGT). Supported by DOE and agency in Australia. 6 sub-committees. Could be some synergistic opportunities?

(B. Valley) There's the Geyser project in Europe also- [which has a work package focused] on the better understanding of fault remobilization due to fluid injection? Just shut down another experiment in Basel.

(P. Kaiser) What are the conditions of these experiments- how would we interest them?

(B. Valley) Need to be able to do fluid injection experiments to be of interest to them.

(SMCK) Wondering if could use this technique to help with ground characterization because also have seismic array laid out and thus have option to listen to fracture propagation [created through fluid injection]. Therefore, could technically do moment tensor inversion and map where fracture would propagate to. Don't use for just stress measurement but start with existing fractures and perhaps try to figure out where they propagate to. This may be another way to explore fault or fracture network in ground in a way you couldn't do by drilling?

On negative side - if play around with stresses too much in this way, we are modifying stresses in test volume and that's a down side.

(M. Dusseault) Hottest thing in energy industry is stimulating low permeability argillites using staged hydraulic fracturing . Aspect is permeability dilation on fractures under right conditions and is attracting a lot of research money. Is there anything in petroleum industry for us? Mark Zoback work?

(D. Schmitt) Should be opportunity but hard to be sure?

(B. Milkereit) Right now is brute force approach mostly. Higher pressure, more injection, trying to keep fractures open. Monitoring is not state of the art. Are not even taking geology into account. Constant velocity background is all that interests them. Don't even take velocity changes into account

(M. Dusseault) Convince that community that the science which could come out of our approach would help them and perhaps point out how they can change their approach. Therefore, there's a case to have them involved?

(B. Milkereit) ESG is on both sides right now. Drawback is that ESG multi-array system is too large diameter to put in our boreholes. The issue with putting in mines is the insurance! Who is in the hook if the tool is lost? We would be taking on a lot of risk.

(B. Milkereit) Geology matters! Need a good reference before doing surveys- where to put sensors. Controlled source surveys need a high repeatability index and we have to be careful in selecting the

source. Need lab testing on the conductivity of rock samples early on to help firm up the idea that it changes in them as a function of stress. Most of the tools needed are currently available with some adjustments needed on the tiltmeters perhaps?

(B. Simser) We need to understand ground motion effects around excavations better. Opportunity here to put string of geophones at different distances from tunnels and look at wave effects. Won't give global picture but local picture is also important for ground support design etc.

(B. Milkereit) Work of this kind is being done with accelerometer strings for blast monitoring at GSC. A few simple boreholes with strain meters may help?

(D. Thibodeau) Other aspect- referring to work by VI at Copper Cliff- blasting near surface and tried to control ppv for house damage etc. Didn't understand why some houses getting higher ppv and thus damage. Back analysis revealed that ppv was being transferred differently along different faults and fractures. Lead to understanding of preferential channelling of ppv and rock damage.

(P. Kaiser) and the relationship to source type and orientations?

(B. Milkereit) Natural earthquake people will be interested in what we are doing because of the 3D perspective we can offer. Sets us apart from SAFOD and NELSAM.

Rock Mass and Fault System Characterization

Presentation by Mark Diederichs

Summary

- Lab needs dedicated multiple drill niches and dedicated drill teams
- Multi-use holes and hole clusters required for coring, observations, instrumentation, stress testing
- Lab need dedicated central facility underground for instrumentation junctions and primary operations (plus surface office)
- Lab may need dedicated drifts through fault zones/networks
- Main lab should be focussed on a single fault network and single mining front
- Other validation experiments on site can be run away from main area
- Need two fundamental sites (rotund and tabular)

Detailed Discussion:

This part of the project underpins everything else. Don't want to be just verifying our other indirect measurements with more indirect measurements. We have to try to understand what these faults look like and are really doing and use that to go backwards and at the exploration stage come up with a characterization and methodology and have it evolve as the mine evolves.

Some real classification of faults and fault behaviour is needed- not another GSQ or RMR or Q is necessarily needed though.

At the early stage, we need to try to understand how to deal with different models at different scales. Develop some techniques which feed into risk analysis from beginning of mine through to a stope by stope analysis scale.

Our ability to numerically model is now sophisticated but is our understanding of site characterization too immature to feed into these complex models?

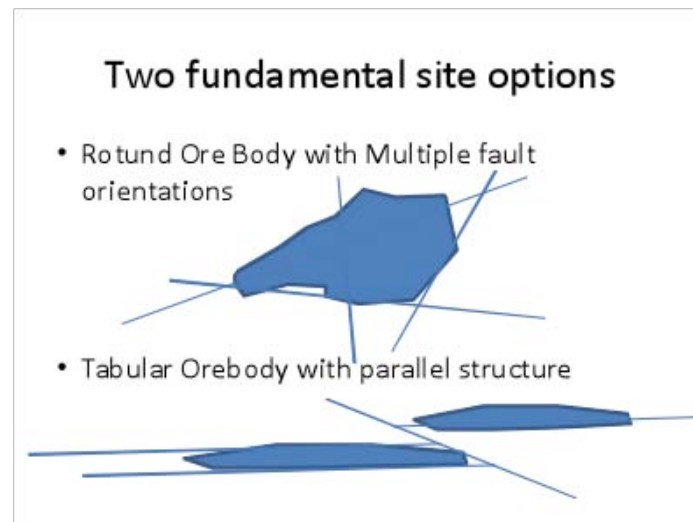
Not enough geotechnical use made of model put together at exploration stage nor at the advanced stage. Feedback loop needed where model drives the investigation and investigation refines the model and is used at the earliest stages in mine design to help drive strategic decision making.

Integration of all data is going to be important part of this and our ability to improve our models as we go is vital.

What can we do?

Primary goal is characterization framework- what can we see and measure? Fill in gaps in system... what is not there?

Virtual data collection exercise could start now. 75L stope at Kidd we looked at yesterday could provide a simple case where we could examine how little we know about fault properties. Big event could be characterization exercise tied to planned geophysical work.



Mining under either scenario will have a different impact on the faults themselves. So just don't focus on one area of one mine-Q and GSI are based on specific rock types and this are not universally applicable. So even if experiment is based at only one test site- will need to have different tests ongoing in different parts of the mine to address this.

The interaction among faults is the critical thing- we can't say that early stage faults are more burst prone than late stage ones. Different sites also present the opportunity to examine and characterize fault/fracture systems at different scales.

Ultimately want to create a system- a characterization model/database, a process- which can be applied throughout the mine life and at all scales.

The tertiary scale structures affect the initial mine stiffness and so it would be nice to get a look at this early on (direct observation) and then again later after it has been disturbed. Perhaps seismicity in mines is more due to fault/fracture interaction (and not fault slip) and so understanding things at this scale is important.

Are there standard procedures to help refine the initial genetic models? How can one use this for risk analysis purposes?

Lot more work needed to understand how to get more out of fracture generation codes. We need faults which don't slip and then release. Should we believe in them? Genetics behind the models needs work.

There's an Innovation Opportunity here: Improved fracture generation codes is an innovation need.

Do we understand what we're putting in? May be creating mine scale faults from tertiary structures- not in pristine mine environments.

(D. Counter) May be evidence of this at Kidd on 3A fault? Looked like we were creating rupture planes on pre-existing surfaces but those surfaces weren't continuous.

(M. Diederichs) Would have been really helpful to have had a chance to look at this area beforehand with the same kind of rigour. Can we thus identify areas that are likely to have that kind of event, where we can see and measure stuff?

(D. Counter) Have pre existing drill logs and new holes afterwards.

(M. Diederichs) Good start and maybe can be used as a vehicle to get going. Some work can begin now with core logs, visible exposures etc. Perhaps can shadow geologists right now? Simple fault monitoring would be helpful- especially if we knew something was going to happen. Are there simple deformation monitoring tools still available?

(B. Simser) Problem with glue on tools is the effect of bulking and stress dilation on the measurements etc.

(M. Diederichs) Direction of movement is important as well as amount of movement. Also need to tie into the geophysics- need comprehensive seismic record before getting into comprehensive characterization. We have to work with simpler stope sequences and individual faults and fault systems which are easily characterizable. Not sure how far back we need to go in, but records at Kidd or Creighton likely go back far enough.

What can be done offsite on computers? Can make a big impact without touching the ground! If models of Kidd and Creighton are as good as we have now, how much data do we need to get to that point?

Can we use these virtual datasets to create sparse/filtered data subsets to reflect what we know at various stages of the exploration/mining process? Build the structural models from that data and figure out when we come close to what we have now? Perform a blind characterization exercise [as it were]?

This is fundamental to guiding the data collection process throughout the mine life. How much do we need to know to be as correct as possible? Would guide the guidelines for site investigation throughout.

Is virtual exercise which could go ahead with datasets we have now. Next step would be to take that on to a site. How do we need to seed the fault surfaces in our models to get a valid response? Getting slip [on faults] is not enough in the models, we really need to know how it will lock up, release and respond to stress change etc. How much data/information is enough? En route to that very detailed investigations will be needed.

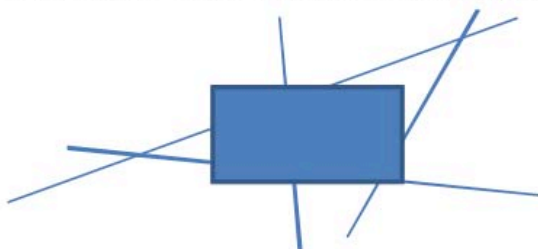
The first step is to look at simple stoping/structural situation and characterize the fault in a mine-by experiment and then try to figure out what we need to do to our model to get the right response on the fault.

Two fundamental experimental settings

- Simple Stope with single structure



- Simple Stope with a defined fault system



Combine modeling with known seismicity and basic geological groundwork to see how this all works. Then can go to bigger volumes (ultimate goal). In early stages therefore, can take on a series of simple case studies.

The notion of strength and geometric variability is going to be critical and we don't have an idea how models move..

There is an Innovation Opportunity here: We need to re-define the constitutive model for a fault system. That doesn't mean making the model, more complex. Perhaps we can do something virtually?

All of this will feed into the other experiments- geophysics, mine stiffness etc but also gets back to the notion of how much data/information we need. Can only decide what we don't need to know if we start by knowing everything and then back off data by deciding what we didn't need to know in retrospect! How much is enough??

Will need to do some fault core testing/sampling and other indirect testing? If identify fault in drift can we use local geophysics to characterize the fault surface better? Faults in our models look planar because there are location errors. But what is a typical fault shape- particularly on a 5-10m scale?

Do we use the right boundary conditions even when doing direct shear tests?

(D. Counter) We don't have a good handle on the in situ state of stress let alone the mobilized state.

(M. Diederichs) This is a huge unknown and we may need to look at earthquake community to help us. What kind of testing has been done by these folks, because this is complex issue?

At the Test Site: we will need to drill at some stage. Would be good to drill from different orientations and get multiple orientations on different structures. Define this as best we can. Start developing photo

library of difficult fault/fracture types. Also need to characterize the wall rock to allow ground truthing of everything.

(P. Kaiser) Is borehole-based work going to allow us to see the tight structures at 2,000m which could eventually cause a fault slip problem?

(M. Diederichs) Was thinking of televiewer-type direct measurement work but perhaps something could be done from geophysical side? Hairline faults may have something in them we could see? Must be some kind of signature in portable down hole geophysical surveys for even difficult to see faults?

(R. Smith) Has been a little bit of borehole GPR work. Hasn't been a lot of support for this, however. Maybe this project is the opportunity?

(P. Kaiser) Many of these structures will change during mining. Changes in stress fields will occur as a result. If we could see stress differences/changes somehow would be good? 3D stress change viewing capability could perhaps help us to see what secondary or tertiary structures are to become the problem for us –a step function opportunity in representing stress change in this way. From a mining standpoint? This would be a huge advance in mine design. If were to combine this with hydrofracing etc, there's a potential whole range of things we could do to help characterize ground, calibrate modeling etc to help with mine sequencing etc? We need to find the capability to do this sort of thing.

(M. Diederichs) Perhaps there are "tactics-scale" innovations that are needed but this whole project is exciting because of the opportunity it presents to look at all of this. Have never had the resources to be able to see what's actually happening and then compare with the capability of the tools we're using.

(M. Cai) Can we drill along faults using directional drilling techniques?

(D. Duff) Drilling option not likely effective but a geophysical tool which could see the fault from a nearby borehole could be useful?

(D. Schmitt) Resistivity tools could perhaps help?

(G. Cooper) in a big mine there are the opportunities to see faults in a lot of detail periodically

(D. Duff) Many gold mines focus on veins that are themselves faults. Provides opportunity to measure changes in fault properties as we mine. Is this an opportunity?

(M. Diederichs) Need to identify structures which are more sensitive than others to stress rotation. Characterization of structure has to be somewhat directionally-dependent. What type of fault systems will respond in different ways? What is failing and how are they failing at different times- all else being equal? Measure stresses and stress changes inside fault bounded structural blocks?

Stress change measurement tools need improvement. Deformation monitoring on faults is something we want to do. How can we better understand multi-directional vectors of movement?

(D. Thibodeau) The answer is probably multiple types of instruments.

(SMCK) We barely know what to do with the fundamental things which we collect now like: event rates, counts, energy, clustering etc. We don't get enough out of these let alone derived parameters. Focus on the most fundamental; measurements possible- with no assumptions. A lot of what comes out of seismic processing relies on making huge assumption about the source and further work could prove them wrong?

(D. Duff) Is there opportunity in the Osmos approach to measuring displacement in civil structures?

(M. Dusseault) Possibly-use twisted fibre optic cable to measure not just displacement but bending strains etc. Use more and more on geotechnical issues. Grouting in a hole is an ideal application. Use for us??

(R. Smith) Mapped changes in wing flexures using this kind of technology at Fugro.

(M. Diederichs) There are technologies out there other than the in-hole stuff- structural mapping and analysis; roughness etc.

(D. Counter) Large areas of fault surfaces exposed in Kidd pit which could be looked at with this technology?

(D. Morrison) Basic geostatistical techniques can be applied to many of our datasets to get more from them- e.g. RQD, diking etc

(M. Diederichs) There's an opportunity therefore which we could be taking advantage of- we don't get enough from what data we have.

(F. Vieira) The opportunity to combine this with geophysical data is profound.

(D. Morrison) This is a natural system and thus we probably can't ignore the fractal mathematics angle? The level of detail we're planning to look at will need it. Many of these issues are happening only on the associated tertiary and other related features, not the "big juicy faults"

(M. Diederichs) Funding for megaproject? These are smaller studies and can be funding that researchers can obtain. They just need a good verification/validation framework. Funding therefore can be in smaller chunks.

(D. Duff) Goal is to also attract those other disciplines which we won't ordinarily think of as being interested in this problem. They're hard to communicate with though and we may have to, as part of a Phase II for this project, hope we can attract them through an RFP-type process or other?

(D. Morrison) Housed in what we're doing are kernels of potential which we can get a lot more out of.

(M. Diederichs) The Geo network of excellence has provided us funding in the past at various levels. Funding has happened because of the network that the centre provides. We can be a "third party" in the room to somebody else's funding perhaps?

(J. Hadjigeorgiou) Where is the innovation? We know the questions and theories. Maybe innovation is not from us but from technology?

(M. Diederichs) Take a broad view of technology. Improving how we do things is innovation. Maybe can't sell it but can find ways to improve individual components. Is developing better constitutive models for a fault surface innovative- think it is?

(P. Kaiser) What sells in Ontario is innovation that has an economic impact. Need therefore to think about technology opportunities. Our "facility" will not get traction without it. Am biased to geophysics guys because of possible technology opportunities there but is strategic to always think about technology innovation which could help us- including developing new ones and/or re-applying re-packaging existing ones.

(M. Diederichs) Need to be careful with that because don't want the "tail wagging the dog".

(D. Morrison) Applying what others do (chaos theory, for example) to our problems represents an opportunity. It ground truths what they're doing in a way they can't.

Mine Stiffness and Mine-wide Seismicity

Presentation by Peter Kaiser

Summary

- Understand mine stiffness and its impact on fault slip as well as on fault propagation
- Perform tests which shed light on the mechanisms of energy release
- Improve our understanding of how to control energy release from fault slip in underground mines
- Provide experimental observations useful for future mine design tool development

Preface: things heard yesterday and recent ESG meeting.

When started, were clearly thinking of a facility but also looking at Canadian Rockburst research program —not a facility.

The goal is to be able to do things significantly differently from how we do now so international participation will be essential. So how do we bring these together?

Where will the funding come from? From individuals and the regular programs available but there are different elements.

Within the project schedule- Phase 1 is a project (not a facility). We need to write a proposal to get \$ to do a project that gets us ready to go into Phase, II which could be a facility. On a timeline basis we need application for \$ by end of this year and then get some work done.

For the big \$, need to decide if go after a facility which will drive the design of how we get there significantly.

Let's make sure that Kidd and Creighton are not the only 2 options for test sites? Nickel Rim, for example is new, simpler (geometrically). We may need to think that if we know what the strategic questions are, is there a better place to answer them than Kidd and Creighton? Perhaps Nickel Rim (NRS)

(B. Simser) Is a good site in some ways since less than 10% extraction. Big disadvantage is don't know when we get a Mn 2 event.

(J. Hadjigeorgiou) Looks like a great case study and may be easier to sell to Xstrata? We can be more successful there...

(B. Simser) Fibre-optics at every electrical substation and thus any instrumentation program will be easy.

(P. Kaiser) Don't need to decide but NRS could be strategic to us?

(D. Duff) Risk at NRS may be getting management buy-in. May need to have something going on in a number of places to convince management.

Detailed Discussion:

From a risk engineering perspective, issue of stiffness changes which occur in the mine are drivers that create new fractures with lots of energy. It's not just about fault slip therefore. Is about fault slip and related weakness planes.

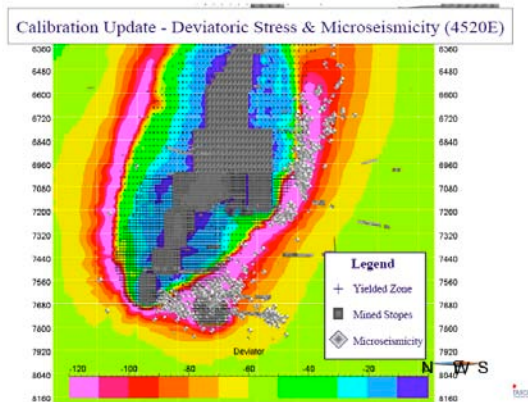
How do we create shears not measurable in boreholes during characterization?

What is the technology that goes into the facility which makes this measurement possible?

Ortlepp Shears get created across previously intact rock masses due to mining. The zone of damage is propagating as we mine and there's a field of yielded rock around the mining with concurrent seismicity. This damage represents an opportunity to solve a major problem as we go deeper.

Why are the HW events there at Creighton, however? They're there because of structure. But if we put things together and look at where de-stress zone is. If mine into the structure will create freedom for structure to mobilize then can look at damage zone as a place where a softer loading system is in place and existing structures can mobilize. In a network or system of structures, now have wedging actions (stored energy there) create Ortlepp shears thus releasing a lot of energy.

This mine, in providing access to this sort of thing represents a big opportunity.



(BM) that stress envelope is not what we see at Kidd

(DC) much softer rock mass and more continuous features which release things. Perhaps similar in the abutments? Gravity acting on system as an additional driver, would expect HW zone to be worse at Creighton?

(PKK) HW is block of rock I would like to see instrumented. How do stresses change in this volume? Have the ability to activate existing structures and create new ones and integrate inputs from other teams

as well. What is mine stiffness, how do you determine and measure it? Am not saying this is where it needs to be done but this is typical of kinds of problems stressed mines need to deal with.

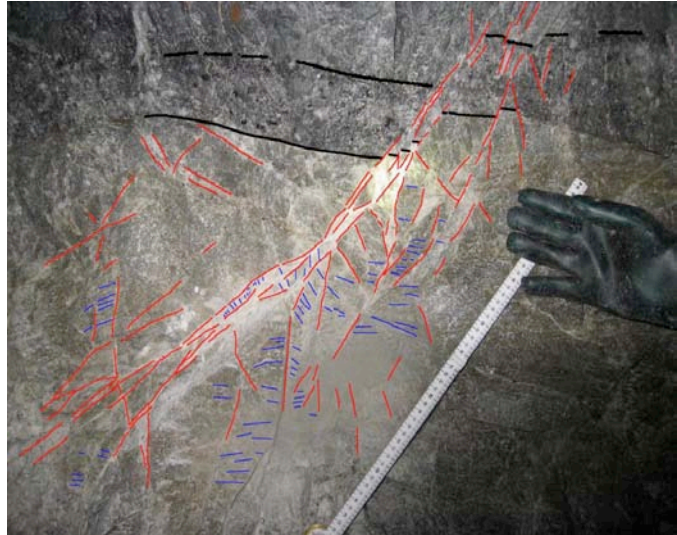
The opportunity in a deep mine is to create tensile stresses which may result in de-clamping which is much further away from where mining is happening that we would expect and this create bigger events more and more remote from the mining area.

Faults are not planar, are not continuous etc. But their characteristics can change over time. An in a stiffer environment, structures and rocks behave differently.

What are the seismic events which get created and which we detect? Source mechanism interpreted will be different for each one of these.

These active planes and how they degrade the rock mass, significantly affect mine stiffness.

We need to learn about these and how the stiffness changes and how the damage zone around an excavation influences it.



We don't understand the driving forces that create these things. We know that in a soft system things react explosively but when look at fault structures we don't understand what the drivers are.

If have a post peak behaviour of a rock and a system which is soft, there's more energy. If a stiff system, the energy consumed in breaking the rock is the same and therefore we don't have a significant seismic event.

Meaning for faults we create? Faults are being created from some pre-existing features or in a situation where mine system was still stiff. As we keep deforming the system (including by gravity) we go over peak (on stress strain curve).

If system is stiff, would go over with no significant energy release and thus no big event.

If system is soft, there will be a major event associated with the structure.

How can we integrate this [knowledge] into a mine design process and thus [help] dissipate the kinetic energy? Some opportunity if we understand how we create the structures and influence the change of stiffness for structures which are relevant.

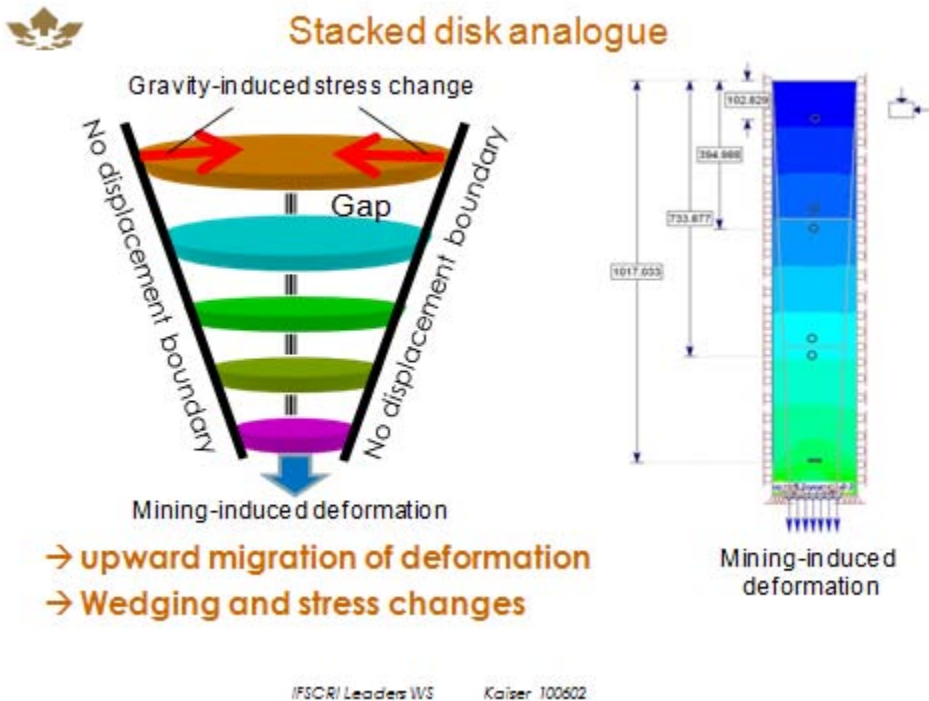
Perhaps opportunity to experiment at a mine to deal with this? Questions to be answered are; what are the conditions leading to stiff and soft systems on fault structures? We understand pillars but what is the impact of loading rate and extraction ratios? What is the impact of networks of faults?

The opportunity this experiment provides us with is to advance the state of the art in generating, activating and controlling energy release from fault structures. Gravity is a driving element, as is mining and displacement.

We need to understand also energy flow and transfer/connectivity with areas that are further away than we would conventionally assume are affected. There's no stress change there from the mining activity

but still there's activity. What is the connectivity? Analogous to situation with train cars- a change at one end can cause significant changes at the other end- and is also time dependent.

(D. Counter) Think about stiffness in global sense- boundary condition changes in one mining block relative to changes in another one.



(P. Kaiser) Is this a good representation of what's happening at Kidd? As things are allowed to move down, the effect of gravity is driving what's happening higher up.

2 major issues needing to be solved (and important in site selection process)

1. Make progress in dealing with gravity-driven processes
2. As we extract at depth there's damage and structures will become a problem when they intersect the damage zone (not just stopes as in a normal case).

These need to be addressed in engineering.

Lot of instrumentation may be needed to monitor how stress changes, displacements etc- can identify how the stiffness changes if we can combine with an understanding of how the strain changes?

Can perhaps monitor how energy is flowing as we mine. Will help to understand how things can happen at a great distance. Just tiltmeters etc is not enough. Need volumetric measurements in a monthly framework or less would be good. Links to numerical models would have to be established.

(F. Vieira) 2 questions relate to: crush type events and slip type events. The former are really gravity driven where the slip ones are not.

(P. Kaiser) Experiment needs to focus on how we're propagating through intact rock masses because much of the data is misinterpreted.

(M. Dusseault) Given right conditions- hydraulic fracturing and stress relief experiment is a definite possibility. Can we release deviatoric stress using hydraulic fracturing? Can't change clamping stress because it's an aperture issue but shear stress?...yes.

(P. Kaiser) Depends on how experiment is set up.

(D. Counter) See something similar in mining where a stope is taken and an event occurs but a subsequent stope above results in nothing but the one after that does.

(P. Kaiser) Due to propagating the zone of relaxation/damage outwards.

(F. Vieira) Experiment in SA in mid 90's looked at raising shear stress on fault plane due to injection of water. Simulated some slip but one conclusion was that to generate a MN 2 event was impossible.

(M. Dusseault) Propellant fracturing is another technology which may be relevant?

(F. Vieira) Experiment also represents an opportunity to re-examine traditional assumptions in respect of ERR and EES for example.

(P. Kaiser) Challenge is how to determine mining stiffness.

1. FS is not just about faults slipping.
2. Is also about related rupture processes and about gravity-driven processes.

Dynamic Rock Support

Presentation by Ming Cai

Is this topic relevant part of Fault Slip research or not? It's relevant because whatever we do, either planning or design side tries to avoid rock bursts. Mother Nature is complex and so something is bound to go wrong and our final line of defence is dynamic rock support.

Summary

- Develop an understanding fault-slip rockburst damage to underground excavations through investigations of:
 - Damage mechanism
 - Damage severity
 - Documentation of rockburst damage
 - Definition of rockburst support design parameters
- Field and potential lab testing of rock support systems

We have distinct objectives:

We know a lot about these things now (in literature) but there's room for improvement because of new technology available to us. Can use these in this project to assist us.

To design a better rock support system, need to understand the demand better and also have a clear picture of the capacity of support systems which we put underground. If know these things, comes down to design methodology.

A good design requires that we put numbers to geology. We need to do this to damage severity as well and so how do we quantify the capacity of the selected rock support system in reducing the damage severity?

On the demand side- we need to understand the design parameters much better: ppv, ppa, depth of failure, bulking, ejection velocity etc. Can we define them more accurately? All are required for effective dynamic rock support design but how can we design a monitoring programs as part of this experiment to help us get them?

How do we find the weakest link in a rock support system? This can only be done in a lab-type environment. What is the maximum capacity of a system? What is the interaction between rock support systems and the ground/rock?

Presentation of Phase I and Phase II suggested approaches. (Ming's team doesn't buy-in to all of these suggestions- acknowledges his bias)

1. Literature review
2. Documentation of rockburst damage
3. Lab testing (most controversial within team) Can't simulate real rock mass.... But this project may be big enough to put resources to this and answer some important questions about SYSTEM behaviour. Where is the weakest link in a system?
4. Field testing of rock support systems- simulation of rock bursts using blasting. Can be done. Is there an opportunity for us to use LKAB's planned tests in this regard?

(D. Counter) Blasting is a problem because of the gas? What can we do to instrument existing support systems in highly susceptible, risky areas?

5. Do field monitoring (in high risk areas) and ensure that some drifts are highly instrumented- including in boreholes and on surface. At test site- we have a huge opportunity to evaluate damage to rock and support system. Like an aircraft "black box"
6. Numerical modeling to better understand the rock mass/rock support interaction. How do waves propagate and how are they magnified by various factors? Some modern tools can be used to help evaluate this and determine the influence of various inputs- geology, geometry etc.

(F. Vieira) Reference to work by Mark Helyard (spelling?)- working with Paul Young.

7. Integrate everything and develop a holistic methodology for rock support in fault slip-prone ground.

(D. Counter) Major early stage research need is to find something which can measure deformation in real time and won't get destroyed in a burst! Monitoring system has to be robust enough to withstand high ppv's, elongations etc. but sensitive enough to work.

Is there a need to excavate bolts again and look at their metallurgy or % elongation or something else?

(B. Simser) South Africans have had some success with developing a robust system.

(F. Vieira) What about the time dependency effects on rock mass behaviour? Are you looking at analyzing those in respect to seismic and dynamic response?

(M. Cai) Interested in process to some extent but more interested in after effects.

(B. Simser) Don't agree. The capacity of even dynamic support elements changes over time due to various ground motions etc. This is important to consider.

(M. Cai) Right - we need to understand the remaining capacity of a bolt.

(D. Thibodeau) In Ontario, have to ensure support system is still effective. How can we do this?

(F. Vieira) Is there a technology opportunity here- a way to investigate the integrity of an installed support system is needed...

(M. Diederichs) There are TBM-boring machines now operating, or being contemplated for civil projects in the Andes and elsewhere (Alps, China) at 2,500m depth, where bursting is happening in the walls which is sufficient to buckle the gripper pistons on the TBM. If there was a way for us to somehow help address that sort of ground support issue through this project we could get ourselves a lot of international buy-in. The hits they're getting is similar to what we're talking about here. Is this an opportunity?

(D. Morrison) Is there commercially available equipment to do a laser scan of a tunnel repeatedly? Affords opportunity to examine amount of expansion related to amount of damage behind the TBM.

(Several people) Yes. Is still cumbersome but this is a good application and may be applicable in our situation.

(M. Diederichs) Can get down to 0.5mm precision but accuracy? Certainly 5-10mm.

(F. Vieira) The shear impact on support capacity is very relevant. Is there an opportunity to research how we are losing capacity on support systems through dynamic shear loading mechanisms? Where does the blast impact on support fit in to this project? Potentially triggering of fault slip...whose analyzing this?

(D. Duff) that would be within Ming's project, presumably? Flip me an email if want to expand on this requirement.

Presentation by Keith Bullock

Core question: Can we categorize risk more effectively in order to be able to mitigate it through the mining life cycle?

Summary

- Determine if risk can be quantified.
- Engineer a means to specifically identify and mitigate risk in fault slip environments.
- Develop a cohesive means of communicating risk.
- Document findings and recommendations in a guidebook of best risk management practices.

There's no clear understanding of what we're talking about but everyone has an opinion on what they think it is. Even over the course of the last day and a half there have been some different things relevant to risk mentioned:

(N. Smith) "Important to consider the project from start to finish."

(K. Bullock) Highlights the importance of communication through the project to ensure continuity among the different project phases and that we're learning as we go.

(D. Counter) In reference to Mine D "once the project people left the site we abandoned shotcrete in lateral development".

(K. Bullock) Evidence that projects and operations people perceive risk completely differently and each thought that their approach was the correct one.

(M. Diederichs) "Modeling is not specifically covered but underpins everything."

(K. Bullock) Important to consider modeling and its effect on risk.

(S. McKinnon) "How much information is enough?"

(K. Bullock) Right volume of data/information can have significant impact on risks of decision making.

(M. Diederichs) "Are we measuring the right thing?"

(K. Bullock) Too much information on the wrong thing risks sending us in the wrong direction.

(D. Counter) "If we trigger a fracture does this risk setting off a major fault activity?"

(K. Bullock) Small things can create bigger problems... are we on the cusp of something?

(D. Morrison) "Minute changes in a rock mass may initiate activity- this is the definition of chaos."

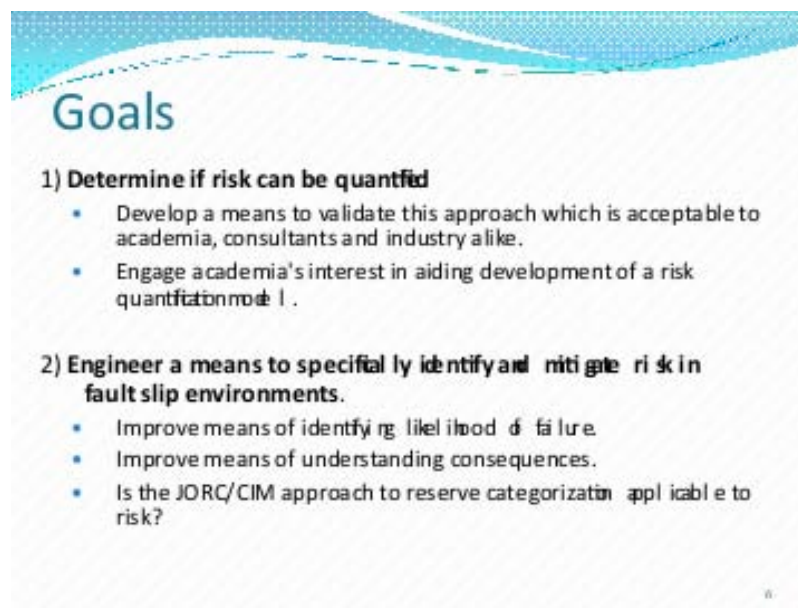
(K. Bullock) The Focus of this project is being able to quantify risk better.

(D. Counter) Have to be able to do something about risk but might have to tolerate it?

(D. Thibodeau) someone also needs to tell us how much risk is tolerable?

Overall am looking at the risk project outside IFSCRI but also trying to make sure that any lessons learned from within IFSCRI are incorporated into it. The opposite is true too.

A comprehensive means of communicating risk is absolutely needed.



Not just industry but academia and consultants are critical stakeholders in helping to do this. Need to be able to identify likelihood of failure related to fault slip. Gather the information and put in right model so that we're using it to assess risk. Consequences have to be understood better as well. This is related to understanding the mechanisms that drive these failures so that we can adopt the right approach to mitigating the risk.

We plan to:

1. Look at information from Kidd Creek - Itasca 1998 report and determine, if that was the best assessment of deep mining risk we could do at that time, in hindsight, could it have been improved? What has subsequent history taught us about the gaps in our risk assessment?
2. Use a "CONFIDENCE-BASED" approach to categorizing risk with the CIM or JORC codes as a guide. What are our current practices and see if there's a willingness to discuss risk categorization. Need a team to look at it and see if we can get any buy-in to it. Will help get some commonality across industry with respect to what we mean when we talk about risk.

3. Find opportunities to try to put codify risk numerically so that it can be better used and incorporated with other modeling parameters to help in mine design and other decision making.
4. Utilize work coming out of International Test Site experiments to determine how we might engineer to minimize negative impacts.



5. Determine which of the risk communication processes out there right now are best and develop a set of best practice guidelines. Can we learn from other industries?

(DC) Talk to Marty Hudyma at Laurentian about some work he did with the Australians- whole thing was risk-driven

(BS) ACG did a lot of work at the same time- Michele Owen (Spelling)- check it out.

(K. Bullock) Figuring a way to generalize our understanding of risk, categorize it and get it accepted across industry may not be “innovative” but having the approach adopted does represent a “step-change” nonetheless.

(D. Duff) This approach has been endorsed by Hustrilid, Stacey, Steffen, Board and others with whom we have communicated on this.

(M. Diederichs) What part of risk are we missing? Are we missing the risk costs of a lot of things related to fault slip? Are we quantifying the consequence of a fault slip event properly?. We need those hard numbers.

(D. Counter) Industry consultation plans may be coming too late in the plan as well?

(M. Diederichs) Risk assessment in railways world seems to overestimate the hazard and underestimate the consequence. Balances out perhaps but would be nice to have the right numbers on both sides of that equation.

(K. Bullock) It’s not a simple linear relationship between consequence and likelihood.

(D. Morrison) Sometimes big fault slip events don’t have serious consequences to the operation at all. Alternatively, some of the events that cause damage are not fault-slip related...

(M. Diederichs) Do we even have enough data to do a \$:magnitude relationship?

(B. Simser) No.

(M. Diederichs) Shouldn't we be working hard with industry to help them help us provide these hard numbers - even on a confidential basis?

(D. Counter) Getting the numbers right- how you quantify things is complicated.

(D. Morrison) Communication of the importance of this kind of thing is important.

(D. Duff) Mark's point is an interesting one in that it poses the question "how much risk is mine management exposing itself (or its operation) to in not trying to understand more quantitatively the costs of fault slip".

(D. Morrison) Language we're using is too specific when communicating with management. Maybe we're being too technocratic with management.

(D. Duff) Keith's confidence-based approach should address that.

(D. Morrison) Agree, it has merit (and I like it) but we need to be care that we know the "known knowns" as well as the unknown unknowns". Industry needs to understand the difference between risk and uncertainty.

(M. Diederichs) We do risk assessment research in railways industry- like this problem, those folks have difficulty providing the cost figures to us. We need to know how much an event of a certain magnitude actually cost?

(D. Duff) That had been the scope of the project which Jim Martin took on for us, But the detailed numbers weren't available, unfortunately.

(M. Diederichs) Getting them should be a focus.

(D. Morrison) Sometimes these costs are not coded in a place where they can be easily or obviously identified. The costs of fault slip may get lost in the "indirects". Need to go to activity-based costing.

(J. Hadjigeorgiou) Australians had a cost number on human life 10-12 years ago. Am not sure that some of the costs we're talking about fits in with this project. Finding the right language to communicate things is important and is somewhat level-dependent. Objective is not to "engineer risk". "Risk engineering" and "engineering risk" have different meanings to different people. We want to mitigate risk and manage it but not engineer it.

(F. Vieira) Agree. My company evaluates risk on basis of core values and it's for executives to communicate that down through the organization. Risk/uncertainty is multi-dimensional. Some of the semantics around defining risk may need to be clarified with this approach.

(M. Diederichs) Important to define what we mean. Can't mix consequences and likelihoods. Trick is to put everything in its proper bin. Just because something is not likely to happen doesn't make it not important.

(N. Smith) reputational risk is also difficult to quantify- e.g. BP at present. The natural resource industry doesn't have a great reputation.

Next Steps

Action Items

1. Complete and submit focus area white papers by June 11th and highlight 10 key research opportunities with 3-5 critical ones
2. Check back with industry
3. Come back to this group (on group basis or individually) looking for detailed follow-up input
4. Leaders to help create awareness among academic colleagues (departmental and cross-departmental) about IFSCRI
5. Need 2-3 key writers to assist with fall funding applications.

Discussions

We imagine a multiple phase process but initially a 2-phase process.

Phase I funding application needed this fall. Given that, what do we need to be doing now? Who needs to help us with that? How much money do we need?

(D. Counter) group here needs to put their top 10 list together and where they would want to do their experiments to address that list.

(D. Duff) the hope is that people modify their white paper on basis of what was heard today and that would help point at the best-suited test site. Might also help identify what early work can be done without a test site.

Need to strategize on how to take technical stuff and pull into a funding application to ORF or into an upcoming CFI application. We need feedback.

(P. Kaiser) 2-3 elements are critical:

1. Need for interdisciplinary interaction- like top 10 list
2. What is a reasonable budget to get going
 - a. How get funding?
 - i. Go after NOHFC to provide start-up funding but ORF is coming out with a call for proposals, as is CFI.

Is there opportunity here for researchers to go after early funding? We should at least be able to put an LOI together in 6 weeks to ORF surely? Everyone should think about this.

(D. Duff) How long after an LOI is submitted before approval and then have to do something serious?

(J. Djivré) At least 6 months after LOI is submitted. LOI goes in in July and full proposal at end of October. LOI is just a communication mechanism not a screening process. There's an opportunity for researchers to collaborate before the full proposal goes in.

(B. Milkereit) There's a risk with this tight a timeframe.

(P. Kaiser) Don't want to push just want everyone to be aware. Don't want to miss an opportunity just because timeline is short.

(J. Hadjigeorgiou) Should think about this strategically- going for something now and using as leverage later or waiting until we are clearer on what we want to do and then going with a complete package?

(P. Kaiser) There's a need to do some work now. Don't want to lose the interest of people just because we don't do anything in the short term. Need to move ahead with projects to help us design the big experiments. Exploratory projects- opportunities to do the base work are needed.

(F. Vieira) Trying out some existing technologies in this application would be worth doing. E.g. deformation measurements and monitoring some background noise etc at the sites would be good. A broad overarching objective for the project may still be lacking.

(D. Duff) It's hard to pass up in near term opportunities despite the fact that acting so quickly comes with some risks but we need to think strategically- we need to know when the subsequent calls for proposals from ORF or CFI might come up after those that appear imminent (in 6 weeks or so) because if they are too far into the future, we perhaps can't afford under any circumstances to miss the upcoming deadlines?

(P. Kaiser) will take 24 months. *(J. Djivré checking website in background)*

(D. Duff) Strategically important therefore to apply now, it seems. All we're on the hook for in the short term is the LOI and the only risk may be that we can't find someone to write the letter! That's no big deal.

(J. Hadjigeorgiou) When we do a proposal, we want indicate that we want this money to evaluate our 3 sites and identify the experiments from all the workshops. Should be very doable given all the feedback we've received. We have also recognized who many of the research leaders will likely be and where the test sites are. We should be able to use this to our advantage in making an early finding application and be demonstrate early wins...this is important.

(N. Smith) The flaw with this is not being able to clearly articulate what science should be done at each site. The science question really needs to be very well understood. It sounds like we're asking these agencies to fund the work needed to find out what the real science question is! The science driver was well understood at Dusel.

(D. Thibodeau) We need a good purpose statement, a CPQRT for the project and the deliverables need to be identified.

(P. Kaiser) We need to come up with a top 10 science issues. We need to write an application of some kind and we need to convince industry of the need to host us.

We will try to have 2-4 people sign up to lead interdisciplinary definition of what the project is and what the 2-3 top things are on the top 10 list and it has to come out of these workshops.

2-3 people need to help write the application and also need parallel process to find out who is interested in hosting these experiments. Have industry persons involved to ensure we are addressing industry needs.

1. Top 10 list with critical 2-3 highlighted.
2. Check in with industry to see if interested in hosting experiments
3. Write letter of intent

Critical need is determining who is prepared to take the lead with us. Also, who else do we need around the table? What are the linkages we need to make? Perhaps needs some additional people on each team to help make those connections? Three groups are more than enough to pull things together.

(J. Djivré) Notice of intent for research excellence comp. Is simple- 500 word overview is needed. Is straightforward. Requires key individuals to review it so it reflects what we plan to do. Is not binding either so can be changed before final proposal is submitted.

(D. Duff) In the event we don't submit a final proposal having already submitted an LOI- is there a risk to our credibility with ORF?

(J. Djivré) No. This often happens.

(PKK) University would have to submit proposal meaning that individuals at each of the involved universities need to determine if their institutions are behind it. CEMI can't submit an application directly. We'll deal with that when we need to. For now we need to focus on getting the application submitted and volunteers to help us write it....

(B. Milkereit) Check out website for UK-based underground deep mining research lab.

Post Workshop Comments

Brad Simser- Xstrata Nickel

1. Seismic monitoring is still the best 24/7 3D tool, rarely (if ever) gets used to its' full potential
 - upgrade array at test site, likely with tri-axial sensors, fully grouted at least 5m deep, add tilt or strain meters to same hole
 - man power – have processing type power to get good data, have seismology type power to do things like focal plane solutions (moment tensor), stress inversions...
 - suspect 200 to 500k depending on mine to get upgrade for “world” class seismic monitoring system
 - suspect ISS best technology as they have ALWAYS focused on physics and signal processing (albeit they have many demerits as well and ESG is slowly coming around...)
 - strain / tilt type measurement (Berndt is the better guy to talk to) could be very useful! Model calibration etc
 - may need some fundamental seismology – current state of the art is always mixing apples + oranges – reliable source mechanisms could separate data into apples and apples pockets
 - but might need some work to improve things like Brune model
2. Continuous seismic source for ray path tomography to compliment / enhance above
3. Need some 3D imaging techniques (geophysics) coupled with diamond drill truthing to get better 3D fault models, earlier ? 3D seismic
4. Numerical models that can simulate real undulating geometries of fault systems – may need stochastic techniques using geology fractals early and real fault models later as info comes available
5. Repeat surveys to monitor rockmass changes with mining (existing technology ok – e.g. repeat televiewer survey, repeat checks for core diskings (holes drilled into same area multiple times)
6. Mpbx, 3D closure of tunnels lidar / siro vision type stuff
7. Instrument strings around tunnels to monitor strong ground motion (wave) effects around openings (as per my previous email)
8. Instrumented ground support (smart cables, strain gages on retainment components, load cells at bolt heads...)
9. Global strain measurements – fibre optic long runs or whatever that new stuff is, strain or load in backfill... stuff like that
10. Fault instrumentation – e.g. contractometers sub parallel to fault, anchors on either side – gives very linear reading, but more than one might give you some tensors

Whatever else instrumentation people can dream up – care has to be taken to NOT confuse fracture zone dilation with fault movement.

Doug Schmitt, University of Alberta

I don't have a top 10 but, I did separate into what I see as first scientific questions, then followed by corresponding technical challenges.

Some science questions

1. What is the dependence of the various physical properties on variations in stress (strength, seismic, electrical, etc. and their anisotropies); could these be understood well enough to be proxies for stress?
2. Can the corresponding state of stress be quantitatively measured and can this be monitored with time?
3. What is the distribution of stress in a fractured or otherwise heterogeneous medium?
4. Following, how does this relate to the resultant microseismicity. Actually, in a larger scale how does this relate to deformation at both long and short time scale (we currently are not recording all we need to progress?).
5. How important is the scale of the measurement (10 m? 100 m?) (and then can borehole information be most effectively used?)
6. Can the existing micro/macro seismic information be better used? (see tech questions)
7. What are the true failure/rupture mechanisms and what might be the geophysical signature of these (seismic, EM)
8. What time dependent effects are there and what produces these?
The last two are more related to practical issues near the drifts
9. What are the effects of transient dynamic stress changes resulting from passage of waves?
10. Can damage be quantified using geophysical methods?

Technical questions - perhaps might be best to focus for a phase 1

1. What set of sensors is appropriate?
2. What should the experimental design be in terms of placement of borehole, number of sensors, etc.
3. What kind of active sources (particularly seismic) might be available.
4. What kinds of novel logging systems exist or could be adapted?

Bernd Milkereit, University of Toronto

Part 1 - Highlights

The presentation of the 3D models (and associated seismicity) for Creighton and Kidd Creek was impressive and at the same time it was an eye opener (and warning shot) for all of us designing geophysical rock mass characterization & monitoring experiments.

Clearly, the stress regimes at Kidd Creek and Creighton are different:

- at Creighton a large (homogeneous?) stress envelope pushed outward and deeper by ongoing mining activity is ideal for longterm geophysical monitoring of stress and strain;

- at Kidd Creek, the activation (or re-activation?) of specific fault structures may provide a better setting for comparison with active fault zones in the earth's crust - however, the instrumentation of boreholes for stress-strain monitoring will be much more challenging.

A new mine at the pre-production stage (such as Nickel Rim) may offer state-of-the-art infrastructure and access. However, selection of the "optimum" 500x500x500m rock volume for monitoring will be challenging - as we don't have history to guide us.

Part 2 - General Comments

The mine stiffness model (P. Kaiser) offers an excellent setting for the integration of microseismicity (energy release rate), geophysics (stress dependent changes in physical rock properties) and dynamic rock support (quantifying damage). In order to monitor stress, deformation and failure a 3D approach (concerning instrumentation) must be adopted from the onset.

Some of the emerging monitoring technology (for example, fiber optic cables with broadband strain meters, 3D borehole-to-borehole DC/IP sensors) should be field-tested for fidelity, repeatability & longevity asap.

Phase 1 (Feasibility studies and Survey design) of the IFSCRI should include:

- comprehensive physical rock property study of the proposed test site with special emphasis on stress dependencies;
- field testing of unconventional "cheap & disposable" geophysical sensor - suitable for deployment in open water-filled or cemented boreholes;
- careful design of the 24/7 multi-parameter borehole-based monitoring network (some thought must be given towards the integration of the conventional micro-seismicity collected data at the mine).

For the IFSCRI we need a better assessment of "the overall cost" associated with rockbursts and fault slip events (maybe this cost estimate should include ground control, health&safety, etc.) - but I'm not an accountant.

One of Peter Kaiser's mine stiffness figures ("going over the peak") looks like seismic velocity variations due to fracturing. While geophysics can't measure mine stiffness - monitoring seismic velocities may become a new proxy for stiffness. This is the kind of figure we will need for the "final white paper" - to show the linkage between disciplines. We should discuss this and other links when you are back from Chile.



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