



**CEMI**  
Centre for Excellence  
in Mining Innovation

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

## *Summary of Feedback*

# **Microseismicity Experimental Design Workshop**

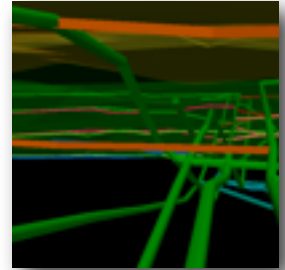
Sudbury, Ontario, Canada  
Hampton Inn  
October 29-30, 2009



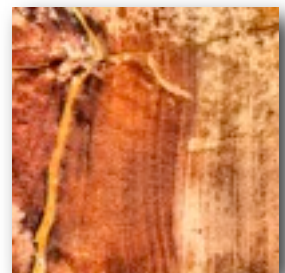
*Microseismicity*



*Geophysics*



*Modeling & mine design*



*Structural Geology*

*To provide comments and suggestions, please email [info@miningexcellence.ca](mailto:info@miningexcellence.ca).*

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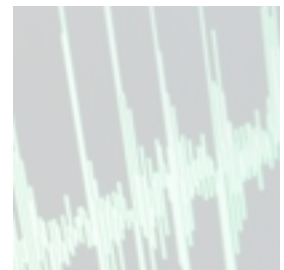
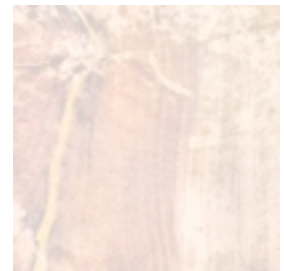
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# Introduction

## Preamble

On Thursday, October 29th – Friday, October 30th, 2009, an Experimental Design Workshop in Microseismicity for the proposed International Fault Slip Control Research Initiative (IFSCRI) was held. This workshop was one of five field-specific workshops which are to be held over the next 6-8 months, 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 million, multi-year research program.

The following document contains a summary of the feedback received during the workshop, as well as detailed feedback received from both workshop groups and individual participants. Please feel free to contact Damien Duff at [dduff@miningexcellence.ca](mailto:dduff@miningexcellence.ca) should you have additional information to add to this collection of feedback.

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**Research/Knowledge Gaps were identified in the following areas:****1. Data collection/ Integration**

- a. Integrated data and source models of expected ground behaviour (geology, seismic, numerical models, time element, differential tomography ( $\Delta(V_s, V_p, Q...)/\Delta t$ ) need development
- b. Definition of the constitutive parameters (e.g. E (modulus),  $\sigma$  (stress);  $\phi$  (Friction), Rate state, full wave field, etc)

**2. Understanding of Excavation Vulnerabilities (mining-induced and in situ)**

- a. Why are there weak and strong faults? Do we understand the mechanisms of brittle fault structures?
- b. Why are some faults seismic and others aseismic and do we need a better understanding of static and dynamic friction issues?
- c. Opening response – how does an opening perform? (Differential changes, deformation, different scales)

**3. Testing/Instrumentation**

- a. Need more sensors to collect the data we need

**We must focus our research efforts upon:****2. Data Collection / Integration**

- a. 3D ground characterization and ongoing monitoring
- b. Making better use of sensors and ensuring optimal instrument layouts:

**3. Developing our networks and people**

- a. Collaborate across disciplines E.g. natural earthquake, tunneling community, geothermal,
- b. Establish university-based group research group/consortium in Canada
- c. Facilitate open standard for data treatment (workflow and distribution)

**3. Technology Development**

- a. Find a common platform/ "standardization" for capturing and integrating data
- b. Miniaturization of instrumentation (including developing cheap strain instrumentation) with communications capability

**The Experimental Design must incorporate the following features:****1. Test site properties**

- a. Start with single site and add additional sites in series (as may be needed)
- b. Need to be seismically active at reasonable frequency- One > Mag. 2 event per year / High likelihood magnitude 3 within a year.
- c. Not likely to shut down within the program time span or due to temporary variations in commodity prices
- d. "Easy" long-term access to site- at large geographic scale as well as at a mine-scale

**2. Experimental Design:**

- a. Needs a 3D/4D model for test site being used
- b. Real time mining data capture and processing capability – mining ongoing throughout the experiment
- c. Alignment between production needs and research needs (Arrays and instrumentation should not impede production)

**3. Data Collection / Integration**

- a. Geophysical properties logging- observation of subtle waveform changes, radar, seismic tomography....
- b. Multiple sensor arrays (better monitoring and greater cost effectiveness) and nesting new sensors within existing network
- c. Bulk strain measurement in multiple orientations
- d. Allow access to raw (unprocessed) full waveform continuous real time data by researchers

**STRATEGIC QUESTION #4 | *What are the Resources Required? (Team & Funding)***

**4**

***The program must incorporate a range of interdisciplinary team members:***

**1. Disciplines**

- a. Physicists and applied mathematicians are perhaps the most crucial

**2. Organizations**

- a. Academic Institutions International Government research agencies- NIOSH; CANMET; CSIR; CSIRO; Nuclear Waste risk management; CMIC
- b. Mining Companies- Codelco; BHP; AngloGold; DeBeers; LKAB; Harmony Gold; Goldfields; Agnico Eagle; GoldCorp; Barrick

**3. Team Mix**

- a. Cross-disciplinary teams (academia, industry, government)
- b. Heavily youth- biased. ≥ 60% - both PhD and MSc- level “build it and they will come”
- c. Participants from Canada/US/Australia/South Africa, etc
- d. Lobbyist - David Suzuki figurehead (PR)
- e. Rated scientists – funding requirements

**Potential Suggested Leads**

- a. Some names suggested such as - Paul Young, Yves Potvin, Wilson Blake and others,
- b. Communication and lobbying capability are important.

**Funding**

- a. IODP & ICDP paid for holes to be drilled
  - o ICDP will fund up to \$1 million anywhere in the world and faster than the IODP and fund international workshops
- b. Industry in-kind, facilities, time, cash
- c. NRF South Africa- Steve Spottiswoode is a “rated scientist”,
- d. European Community Framework (with LKAB Sweden)

***What are the potential obstacles to success?*****1. Getting the people wrong**

- a. Leadership
- b. Researchers and PMs do not have appropriate skill sets
- c. Management failure or lack of management board, management redundancy
- d. Not publishing research
- e. IP in working with universities may be an issue

**2. Overall Plan**

- a. Test site management does not support plan -poor alignment in research and site production goals
- b. No short term results
- c. Selected site not economically secure (need 5 yr written commitment)
- d. No seismicity to monitor

**3. Funding**

- a. Fail to engage government support
- b. Fail to engage corporate sponsorship

***We should keep the following in mind in moving forward:*****People**

- a. Ensure there's an advisor (from SNO) on the project Steering Committee
- b. Need a spin doctor, a "translator"
- c. Industry and researchers need to establish terms and objectives that work for both sides

**Overall Plan**

- a. Provide enough lead time
  - i. Adopt a stage/toll gate approach to the project management
- b. Plan for early quality – not quantity
- c. Project must be scoped at right level so that agencies see their policy objectives reflected in it
- d. Need "white paper" outlining academic goals of project.

**Data Collection / Integration**

- a. All data should be open, raw and accessible to all participants

**Funding**

- a. Need someone who will track and push the proposals

**PR / Economy**

- a. Create user group sessions, paper presentations, e.g. at CMI
- b. Find a mechanism for international participants to buy into this

**DETAILED GROUP FEEDBACK  
(and additional comments) RECEIVED**

*(Arranged by order of strategic questions and group number).*

**GROUP #1**

1. Understanding what are the appropriate preventative measures, particularly at the mine design phase. Seismic data, in particular, could be utilized better
2. Multiple experimental test sites are warranted and we also need to integrate relevant datasets (geology, seismic, mining, geophysics etc) much better.
3. Need to develop a better understanding of overall system behaviour and be able to integrate seismic and numerical models
4. Need to understand excavation vulnerabilities and have better source models of expected ground behaviour
5. We don't properly understand static and dynamic friction issues.

**GROUP #2**

1. **What are the fundamental problems?**
  - a. Integration of microseismic data collection strategy to the definition of the differential tomography related to 3D seismic structures – it's a far field question
  - b. Use of all data
  - c. Weakness in interpretation of data, capture the full wave field
  - d. Opportunities to do tomography for attenuation, not dependent on velocity
  - e. Can we use seismic and tomography and time change
  - f. "differential tomography"  $\Delta(V_s, V_p, Q...)/\Delta t$
  - g. Opening response – how does an opening perform? Measure differential changes to better understand – measure deformation \*\* huge gap \*\* and at different scales
  - h. Need to develop cheap strain instrumentation
  - i. Blast monitoring with accelerometers at the explosion and examine the tunnel response, particle motion, but you need to put in more sensors to capture it. Gap is data integration and using amongst the two groups (blast monitoring and seismicity)
  - j. In situ stress is an issue, numerical modeling is assuming far field, and it's not, identify stress before you get there
  - k. Ground support is an issue
2. **Maybe microseismic monitoring is not the right tool for this problem;**
  - a. The gap is that we cannot identify the location of critical structures geometrically, geographically, geomechanically!
3. **Do we truly understand the failure mechanisms of brittle fault structures?**
  - a. We are using the microseismic idea in a very narrow way, but it is very rich in potential and could be used in other ways.

**GROUP #3**

1. **Characterization/Imaging**
  - a. Boundary Conditions; Initial Conditions- time element incorporated
  - b. Constitutive parameters, E (modulus),  $\sigma$  (stress);  $\phi$  (Friction), Rate state?
2. **Process Understanding**
  - a. Why are there weak and strong faults?
  - b. Why are some seismic and others aseismic?
3. **Engineering/Mitigation**
  - a. Optimal geometry for  $\Sigma M= 1$

**Guiding Questions**

*What problems are other "active fault" initiatives around the world working on and how do we ensure we structure ours to stand out, to address the research gaps that still exist? What are those gaps?*

*What are the fundamental applied seismicity problems which still exist within the context of understanding and controlling fault slip that we should be addressing with this proposed initiative?*

*Why can we not identify the location of critical structures well in advance of mining with (micro-) seismic monitoring?*

*Do we truly understand the failure mechanisms of (brittle) fault structures and how signals change as fault zones are created?*

**GROUP #1****1. Sensors**

- a. Use of Multiple sensor types in the same hole
- b. We need to know which are the most important sensors
  - Define whether needed for far-field or near-field
  - Primary need is in the near-field
- c. Can start to gather data at exploration borehole stage
  - Some are often deep and drilled in advance of any mining
- d. Ideally the instrumentation fits in “slim holes”- 1<sup>3</sup>/<sub>4</sub> inch
- e. Take advantage of wireless technology

**2. Data**

- a. More integration of data needed
- b. Make better use of seismic data
- c. Determine what back analysis is of greatest value
- d. A common platform for data capture is needed- “standardization”!
  - Build open source into data standards
- e. Do we need additional tools to draw value from seismic data?

**3. Rock Mass Characterization**

- a. Use of active or proactive determination of rock mass properties (“source generation”)
- b. Initial characterization and monitoring of change thereafter
  - Using time lapse photography or similar?
- c. Better use of blast vibration data to monitor change
- d. Use of laser technology

**4. Networking/Technology Transfer**

- a. Take advantage of other related skills in other disciplines
  - Expand our network
- b. Need to expand capability with regard to seismicity in mining
- c. This is a critical issue for the next generation of mines/miners
- d. Need to develop a manual of seismic terms and their use

**GROUP #2**

1. **Benchmarking, HR training, energy balance, better integration of data**
2. **Expand the circle of advisors** – take a multidisciplinary approach, learn from the medical industry, to the point that we can do a “faultectomy and fault bypass by the Rock Doc”
3. **“Technology integration”** E.g. Get away from point measurements to array measurements, vertical hole 3 point sensor measurements, R&D to demonstrate new methods, new ways to use the technology, R&D to make it cheaper; “array approach”
4. **Demonstrate the utility of multi-parameter sensors** - Availability of broadband sensors that can be deployed (e.g. accelerators, tilt and strain meters).
5. **Change how data is treated, shared and used.** Potential spin off: raw data is useful to fuel research, e.g. in process mechanics (not preprocessed), opportunity to change how the mines and industry treats data, - change data workflow and distribution process, better understand and overcome the legal and geopolitical (and public relations) issues

***Guiding Questions***

*What are the greatest opportunities, or highest potential for significant advances in technology developments, from systematic data collections, or elsewhere...?*

*What substantial improvements could be made in comprehensive data integration for advances in mine design for FS control (e.g., hazard maps).*

*What are some new or upcoming advances and emerging technologies (e.g. wireless, etc.)?*

**GROUP #2 cont.**

6. **HQP and BQP** (broadly qualified people): (1) Academic - Create a supportive university-based group research group or consortium in Canada to further understand the fundamentals of seismology; (2) Industry - new definition of competence and training to include ability to work in an interdisciplinary fashion, drive operations, be able to talk to groups in different fields, “consortium in understanding deformation and induced seismicity in anthropogenic activities” => a consortium in parallel with the CEMI fault-slip initiative <=
7. **Problem is the accessibility of seismic data** – the opportunity is to make the data open, available to the practitioner and researcher
8. Take leadership in defining the problem
9. More sophisticated integration of modeling and seismicity
10. Learn from the tunneling community to learn about the wave field, changes in vector fields
11. Research more about basic mechanics of failure

**GROUP # 3**

1. **Utilize non-invasive measurements of rock mass state and behaviour**
  - a. Passive tomography
  - b. Micro earthquake sources
  - c. Non invasive stresses measured at earthquake hypocenters
  - d. Strength and rate of failure as function of time
2. **Research from mine seismology/rock mechanics** can be applied to natural earthquake studies and vice versa
3. **Use/develop wireless sacrificial tools to measure multiple parameters of interest (installed at exploration stage)**
  - a. Position
  - b. Orientation
  - c. Time
  - d. Acceleration
  - e. Tilt

**GROUP #1****1. Test site selection Criteria**

- a. Can monitor evolution of rock mass with mining
- b. Good Q; RMR
- c. Brittle faults
- d. Weak Faults
- e. Has fault slip (rock bursting) problems
  - Seismically active- One > Mag. 2 event per year
- f. Orthogonal redundancy

**2. Specific Experiment:**

- a. Water injection?
- b. Instrumented long boreholes. Measure far field stress, seismic parameters and others- ideally not within 20m of the borehole but some 100m to 500m away.

**3. Experimental Layout:**

- a. Instrument deployment that characterizes rock mass at range of scale
  - Enhances the lifespan and value of the experiment
- b. Instrument arrays ideally placed ahead of the mining front
- c. Ensure alignment between production needs and research needs
  - Arrays and instrumentation should not impeded production
- d. Multiple sensor arrays leading to better quality science and greater cost effectiveness
  - Leading to greater rock mass monitoring
- e. Geophysical Physical Properties logging- permitting observation of subtle waveform changes
- f. Controls needed to compare and measure against-
  - Active sources?
  - Boreholes, blasts?
    - What is blasting doing to the rock mass?

**4. Test Sites**

- a. Multiple sites recommended
  - Creighton; Kidd; Ridgeway; El Teniente; New LKAB Swedish Mine (140 new sensors employed)
- b. Risks that multiple sites will lead to fragmentation/dilution of initiative

**GROUP #2****1. Site Criteria**

- a. High likelihood magnitude 3 within a year
- b. The area of interest is highly complex, for operations, need near-field information, farfield is less relevant
- c. Need to consider proximity to extensive excavations and mining activity
- d. Identified faults that could be loaded

**Guiding Questions**

*What should be key test site selection criteria?*

*Is a test site or multiple sites beneficial?*

*From a technical standpoint? Number of boreholes needed (depth, type, etc.)*

*From a logistical one?*

*From a strategic (funding/broad wide buy-in perspective)*

*What is attractive to non-mining groups that may wish to use the site and thus contribute to advances for mining?*

*What sites are suggested as being the most appropriate from each/all perspectives?*

*What would be the experimental layout, instrumentation package (including those that need to be developed)*

*What kind of technologies are in place and also need to be developed for such an experiment?*

*What kind of data needs to be collected? What do the other four research focus area groups have to provide?*

**GROUP #2 cont.****2. Multiple Sites?**

- a. Pros: we have mines all over the world, perfect for multi-site; multiple sites mean you can do multiple case studies
- b. Cons: May lose focus if there are multiple sites

**3. Research Criteria**

- a. How do you select the research, from the fundamental knowledge gap or the practical needs end. Therefore the project needs a modelling and case study component.
- b. Minimum 4 boreholes to do a project
- c. Need regions of variable strength, and if you can capture that in one site, then one site may be sufficient, easy to achieve in Sudbury because of the various lithologies, and have depth
- d. Interested in near-field effects

**4. Research Ideas**

- a. A 3D / 4D forward modelling study to optimize data acquisition (test sensitivity, how many boreholes required, etc.) before each project starts
- b. Because mining needs to give and uptake the data quickly, need resources to be able to capture the mining process – realtime mining data capture and processing – mine-through experiment
- c. Are events scalar? Would earthquake groups be interested in smaller events?
- d. High-pressure water injection, hydrofracturing, increase understanding of how to control stress, just influencing pore pressure, with option to add thermodynamic effects
- e. Better understand how to predict and control blasting gases in the fracturing process
- f. Scott Carlisle: being proactive to create MS events is a good thing, encouraged when the guys aren't working, and a project that enables that is desirable
- g. Miniaturization of instrumentation with communications capability => government may support, if brought to table under nano (micro) technology and ICT (Information and Communication Technologies)
- h. How to measure strain over the access of a tunnel, photogrammetry, mass-measurement of tunnel deformation
  - What is attractive to non-mining groups? i.e. Geothermal people, earthquake seismologists, etc.

**GROUP #3****Single vs. multiple sites?****1. Single Site**

- a. Large amount of data with low or limited variability
- b. Multiple Sites
- c. Larger degrees of freedom
- d. Higher cost
- e. More continuity guaranteed- less susceptible to stoppages/slowdowns associated with a single site

**2. Minimum Criteria required:**

- a. Seismically active with events at a reasonable frequency
- b. "Easy" long-term access to site- at large geographic scale as well as at a mine-scale
- c. Multiple orientations preferred
- d. Database of previous events exists
- e. Nest new sensors within existing network- complimentary

**3. What kind of Technologies are in place and also need to be developed for this experiment?**

- a. Bulk strain measurement in multiple orientations
- b. Geophysics- radar, seismic tomography
- c. Data handling- ship raw full waveform continuous real time data off site with strain and other measured

**GROUP #1**

1. **Suggested disciplines are:**
  - a. Physicists and applied mathematicians
  - b. Seismologists (Large scale and induced)
  - c. Rock mechanics
  - d. Structural geology
  - e. Geophysicists
  - f. System engineers
  - g. Mining Engineers
  - h. P.R. individuals
2. **Appropriate Organizations**
  - a. Universities- UofT; Queens; Laval; Wits; ACG (Aus); Chile (PUC)
  - b. Government Agencies
  - c. USGS/GSC
  - d. International Government research agencies- NIOSH; CANMET; CSIR; CSIRO; Nuclear Waste risk management folks
  - e. Mining Companies- Codelco; BHP; AngloGold; DeBeers; LKAB; Harmony Gold; Goldfields; Agnico Eagle; GoldCorp; Barrick
  - f. Oil Companies- Suncor
  - g. Civil tunneling companies
  - h. Consultants/service providers/suppliers- ISS; ESG; Slumberger; Haliburton; SRK, Lafarge
  - i. Military!
3. **Team Mix**
  - a. Heavily youth- biased.  $\geq 60\%$
  - b. Both PhD and MSc- level
    - Academic and industry participants from Canada/US/Australia/South Africa

**GROUP #2**

1. **Team**
  - a. Media
  - b. Lobbyist - David Suzuki figurehead (PR), David Simpson (IRIS)
  - c. Captain
  - d. Paul Young could be the lead
  - e. Coach
  - f. Luc Vandame,
  - g. Teams – integrated teams (academia, industry, government(CANMET) and cross-disciplinary
  - h. LITHOPROBE ex-members
  - i. Research newspaper archives to find names
  - j. Yves Potvin Australian Centre for Geomechanics
  - k. Wilson Blake, Independent Consultant, Idaho
  - l. Chris Scholtz, Lamont Doherty, Columbia University
  - m. Quebec funded a seismic network => with what university and company

***Guiding Questions******Team***

*What organizations, governments and companies must be involved and can or should show leadership and expertise in research & technological development?*

*Who are the individuals (names and affiliations) that are best qualified to undertake the needed work, lobbying, research and development, and how do we ensure their engagement?*

*Which organizations can make this happen? List areas of expertise and a specific research problem they could address as part of this initiative*

***Financial Resources***

*What resources are available in Canada and beyond? Facilities? Equipment? Cash contributions? Consortia? Government funding programs?*

*Why would anyone (in their right mind) fund such an ambitious program?*

*DO we have “culture” problem to overcome and how?*

*DO we have “culture” problem to overcome and how?*

**GROUP #2 cont.****2. Resources**

- a. CIM, CMIC
- b. ACG, CSIRO, CSIR, SME, SEG, Canadian SEG,
- c. Institut Physique du Globe de Strasbourg
- d. International Society of Rock Mechanics
- e. NEPTUNE got a major CFI grant and got good Globe & Mail coverage => how did they get such good coverage; Chris Barnes equivalent,
- f. Swiss Earthquake Department, ETH
- g. Pacific Geoscience Centre
  - IP in working with universities may be an issue,
  - Expertise to structure the research programme so that it achieves both research and commercialization

**3. Funding**

- a. IODP & ICDP paid for holes to be drilled
- b. ICDP will fund up to \$1 million anywhere in the world and faster than the IODP and fund international workshops
- c. IRIS (general seismology)
- d. Reinvest R&D tax credit
- e. Industry in-kind, facilities, time, cash
- f. Barrick, Newmont, riot into
- g. NRF (South Africa, Steve Spottiswoode is a “rated scientist”, fund students, equipment, technology)
- h. European Community Framework (with LKAB Sweden)
  - Individual countries have research agreements
  - China – Chunan Tang organized RasIM in Dalian

**GROUP #3****1. Team**

- a. University Consortia- Queens; UofT; Laurentian; Penn State; Virginia Tech; Potsdam
- b. GFZ
- c. ACG?
- d. Post Docs (and others)- “build it and they will come”
  - There’s lots of talent available

**2. Funding**

- a. Mining consortia- “give them some control of their destiny

**GROUP # 1**

1. **The people involved may not have the appropriate skill sets**
  - a. Applies to researchers involved as well as to project management
2. **The project plan may be poor**
  - a. Lots of cohesion is needed to expand the science base
  - b. Management failure risk
3. **Inability to identify suitable sources of required funding**  
Failure to excite governments. (DD Note) Project must be scoped at right level so that agencies see themselves reflected within their policy objectives
4. **Project doesn't deliver expected short or long term science advancements.** (Bernd Milkereit note earlier: early delivery of worthwhile research results is critical for a successful project of this magnitude)
5. **Test site senior management don't fully support the plan**
  - a. Poor alignment between test site production goals and research goals
6. **A management board for the project should be established** to counteract problems resulting from the departure of a single project manager (aka NELSAM)
7. **Commodity price fluctuations** could lead to miss-alignments between project plans/goals and those of a test site(s)

**GROUP #2**

1. Economically-secure site with activity guaranteed for the next 5 years with written commitment
2. Is corporate sponsorship a showstopper? Not if you can word your support appropriately and if you can find funding in parallel
3. Not being on government's priority list
4. Not finding the right leadership is one of the most important showstoppers – need a unifier and politicker and someone people like, and can work with companies and academics
5. If you have a rockburst so big it creates too much damage
6. If the overall management and funding structure is too complex
7. Not Communication and publishing works – need policy and process to encourage publications
8. Losing momentum, a year passes from now, and no proposal written
9. Need to work towards interim funding

**GROUP #3**

1. Instrument failure- also talent or analysis failure
2. There's no seismicity to measure
3. There's insufficient buy-in to the project by industry and by researchers
4. Mine economics could impact project- mine shutdown; sequence changes etc
5. IP issues
6. There's a fatality during the project which risks the project being blamed for not having predicted the problem but may also provide the mine the opportunity to flag that it's doing something about the problem
7. If major damage occurs at test site due to a ground failure, it could cut off access to instruments or to observable features as well as negatively impact researchers' desire to go back underground

***Guiding Questions***

*What are the potential showstoppers that could derail this initiative and what preventative actions must be taken immediately?*

**GROUP #1**

1. Contact a broader range of scientific participants- from all disciplines
2. The timelines for the project are too aggressive
  - a. Schedule startup for December 2010
  - b. More lead time is necessary for most people
3. Plan for early quality of results not quantity
4. A good communications plan/strategy should be developed
  - a. ~80% of it should be directed outside of this community (Sudbury)
5. Assemble a list of “do’s and don’ts from other major initiatives of this kind
6. Adopt a stage/toll gate approach to the project management
7. Ensure there’s an advisor (from SNO) on the project Steering Committee
8. Scope research needs carefully and don’t re-invent the wheel

**GROUP #2**

1. Need a spin doctor, a “translator”, someone who will track and push the proposals
2. Create a fault slip website with a Technical library of papers
3. Create user group sessions, paper presentations, e.g. at CMI
4. Find a mechanism for international participants to buy into this

**GROUP #3**

1. Ensure output of equal value to all member companies in the consortium
2. All data should be open and accessible to all participants
3. PI’s should have access to the “raw- unprocessed” data
  - a. CEMI will need to negotiate with industry on researchers’ behalf for this
4. Need “white paper” outlining academic goals of project because industry has to agree to allowing access to existing data as well as perhaps to sensitive data such as” grade, mining rate, etc.
5. Industry has to uphold commitments to researchers with access to test site and schedule
6. Researchers working at test site need to understand the rigidity of the mine schedule to ensure no delays etc.
  - a. E.g. the cage leaves at a specific time every day

***Guiding Questions***

*Based on what we’ve discussed:*

*What is the most important result, conclusion, next step?*

*Based on your experience with other major research initiatives of this kind*

*What are the key few most important to do things right?*

*What are the key few most important things to avoid doing?*

*What was best idea that came out of workshop, in your opinion?*

## ADDITIONAL COMMENTS

### Data Collection/Integration

- Automated Data Analysis - Not collecting data “Resolution”
  - Initial conditions, Boundary conditions, Constitutive laws
  - Problem with identifying particles and movement
  - Core – grade/tons vs geotechnical data
  - Managing all data
  - Core break at 1/5m=3 breaks/.125 m<sup>3</sup> 150 mt orebody +850 mt or 1 ?bigton? “volume of influence” -> 10 surfaces 10 g particles
    - Model?
    - Which are key?
  - We need an “all seeing eye of God” – array of sensors to measure x/y/z,  $\Delta x$ ,  $\Delta y$ ,  $\Delta z$ , temp, pressure,  $\sqrt{ib}^n$ , real time, thru rock communication – put in at exploration/development/pa.
  - BuLR deformation monitoring
  - At resolution sufficient to feed standard rm fem or displ. models to calibrate them
  - All-seeing eye of God must be in agreement with model at all times
  - Model → in time → slip → confirm by data
  - “automated” core logging (stress, condition) → “milk” core
  - “Data integration” – rock properties, state of stress, deformation, relationship between stress and strain
  - Relationship between stress, strain, fault slip or failure in near and far field as a direct result of mining (prove causality)
- 

### People

- Initiative must be university driven board → CEMI can “herd” but can’t be “private” to be credible
- Dave Gaudrea (AMIRA), Dan Heale, Yves Potvin (WRAM), Marty Hudyma (Laurentian), John Hadjigeorgio (UofT), Steve McKinnon (Queen’s), CERN, CSIO, CIS
- Completion-based JPI
- SD → proactive corp. citizen
- Board → management

### Funding

- Must be “attractive” to funding agencies
- Link to crustal seismology to become “foster child” for major government buy-in
- WSIB, FEDNOR, CDC-NIOSH, MSHA, Civil Defence, Homeland Security (Re San Andreas)
- University consortium to manage project – lead funding and subcontract to CEMI?
- Funding from mining companies and those previously listed

### Sustainability

- find a way to tie initiative into being “good corporate citizens”
- 

### Understanding excavation vulnerabilities

- We need to learn more about the physics of the seismic source. How does the slip occur, what controls it, how does a fault lock/heal, how does a major event influence the stress redistribution, etc.
- Get closer to the seismic course to increase “\*\*signal” to “noise” ratio, frequency contents, but also maintain sensors farther away to investigate properties of recorded \*\*forms.(Near-field, intermediate field, far field). And properties of the source (Homogeneous) source vs. heterogeneous, dynamic vs. kinematic model)
- To provide an engineering solution, rock mechanics must be involved/developed. Determine model constraints, define what can be independently verified from a passive seismic monitoring perspective

## ADDITIONAL COMMENTS

### Funding

- the biggest potential "show stopper" in terms of getting funding is how we answer the following question: "If we, the industry, already have large volumes of data which has not been exhaustively analyzed using current techniques, why should public funds be used to the collection of more data?"
- I can't immediately answer this question right now. One strategy to mitigate this question is to publish the data for significant events in the public domain.
- With respect to maximizing the preparation of participants, we could create a short 2-5 minutes video introduction to our participants done by yourself and/or Peter. It could be send out one week in advance of the event to get the participants thinking about the topics of interest. This video would provide some context and the questions that need to be answered at the workshop -- a homework assignment. A video would have the advantage of presenting the questions with an emphasis on the topics we are interested in. This emphasis might have otherwise been lost as subtleties and nuances in the text at a casual glance of the text descriptions.

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### Approach

- In my view in some of the Friday's proposals there was too little physics and too much earthquake seismology and classical rock mechanics. There is a limit to how far we can go with two-dimensional planar sources and friction being the control parameter. There is also a limit to scaling of all seismological quantities, including ground motion, with seismic moment. There is also a limit to what we can do with linear elastic and static concepts. Most what could have been achieved there is already written in a history books. *Rock mass subjected to active mining is a non-linear system which is far from equilibrium. It is not a spontaneous process, it induces stresses in the rock mass at a particular place, at a particular time and at a particular rate preventing the process of self-organization.*
- For the same reasons riding on seismic tomography may sound like an old broken record from late 80's. There needs to be element of novelty, e.g. coda wave interferometry and controlled repeatable sources, where you can get well sub 1% accuracy, ... and it sounds better.
- There are ***two sites in Australia that may interest you, and at least one in SA*** The first point is to spend as much money on research and not necessarily on drilling and on infrastructure

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### Research Gaps

- we need to extract more information from seismic data: not just location, time, magnitude of events
- need for real time differential tomography: 3D monitoring of physical properties and how they change with time
- Identifying stresses is needed but often difficult. Extensive deformation measurement should be used in parallel to stress characterization: this could help to calibrate/unify stress/strain models and seismological models.
- Near excavation effects, including wave guide effects should be investigated (similarly to the study on site amplification for surface seismic risk)

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### Research Opportunities

- development and application of sacrificial, long-term, multi-parameters (temperature, pressure, displacement, strain, acceleration, tilt...), wireless sensors. This could be used to monitor (among others) the displacement field associated with fault slip events.
- Use of high speed LIDAR techniques to capture opening geometry changes with time

## ADDITIONAL COMMENTS

### Experimental Design

- all proposed experiment should be accompanied with forward modeling in order to estimate needed sensitivity and optimize design
  - Use of active techniques vs. passive techniques: we could use water injection or other stimulation method to promote seismicity during our experiment. The idea is if we can generate the condition which produce seismicity during our experiment, we will also become better in avoiding these conditions during production mining: if one can engineer the conditions necessary to produce a magnitude xx earthquake within a given rock volume, he will also know what conditions to avoid in a actual mining sequence. Also pro-active techniques (water injection,...) could be use to pre-condition ground (release the energy) before mining actually takes place.
  - In parallel with our experiment, data mining techniques should be implemented: we may well produce so much data that we will need techniques to extract valuable information from massive database.
  - Other needs
  - mechanisms to involve international participant early on are needed
  - communication sustainability at scientific and broad-public level is critical. A project like NELSAM, whatever they actually achieved underground, is a failure because nothing was published from it (we can hardly figure out what they achieved)
- 
- One of the recent issues of EOS (Earth Observation System), the weekly newspaper of the American Geophysical Union, contains on the front page a short article about an NSF initiative to identify the 10 grand challenges for seismology at the forefront of research on Earth systems. The NSF sponsored document is published and available on line at [www.iris.edu/hq/lrmps](http://www.iris.edu/hq/lrmps). Since some of you are neither familiar with ESO nor have the time to browse through the entire material posted on the IRIS web page, I thought that it would be interesting to provide you with a very, very brief presentation of the first three challenges:
  - The first grand challenge is 'How do faults slip?' Since this was brought into discussion during our recent meeting in Sudbury, our mining colleagues may take comfort (or not?) that this still remains a study problem for the entire seismological community as well. It is further indicated that "recent observations revealed a rich spectrum of fault behavior, ranging from steady sliding with little apparent resistance to earthquakes that can slide at supersonic shear velocities (faster than the speed of the S-wave in the rocks) and that can emit shock waves that may cause exceptional damaging ground motions". It is also mentioned the fact that "only in the past decade has it been discovered that major parts of some fault systems slip repeatedly in slow events that occur surprisingly regularly, accompanied by low-amplitude seismic tremors". Among the major aspects that still need to be addressed is "the relationship between the episodic slip and tremor to major earthquakes" and "a detailed physical understanding of the nonlinear processes by which faults slip".
  - The second challenge is 'How does the near-surface environment affect natural hazards and resources?' Identifying that the location and severity of many natural hazards are strongly influenced by near-surface material processes, and acknowledging that near-surface processes affect water, energy and mineral resources, it is outlined that a detailed knowledge of the Earth's near-surface is very important for managing a sustainable environment. Thus, seismology needs to "understand how strong ground motions are produced by earthquakes and to translate this understanding into improved hazard maps". Conceptually, this is not different than what we encounter at the mine scale, where accounting for aspects specifically related to this environment is not less challenging.
  - The third and last grand challenge I would like to summarize here is 'What is the relationship between stress and strain in the lithosphere?' Well, replace lithosphere with rockmass and this is exactly what we are looking to find out in mine seismicity, correct? 'Motions and strains now can be precisely measured with satellite imaging and networks of GPS receivers, strainmeters, seismometers, and tiltmeters, but causative stress only can be can be inferred'. In order to understand the overall stress distribution and the temporally and spatially dependent rheology, the challenge is "to unraveling how some earthquakes trigger other earthquakes

## ADDITIONAL COMMENTS

thousands of kilometers away [example given].<sup>1</sup> At a different scale, this is not any different than what we attempt to do in mines, i.e., find out how large events are induced by activity carried out so remotely.

- Based on a series of fundamental concepts, seismology allowed us to develop and apply in mines a range of methods and techniques. These methods and techniques do provide a quantitative and reliable evaluation of various parameters. However, we still have a lot of work to do in order to find out how relevant are these parameters and whether they bear a relationship with aspects of practical / engineering interest for the mines.

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### Experimental Design

#### 1. Earthquake seismology versus Mine-induced seismology:

In spite of its longer history and undeniable achievements, Earthquake Seismology (ES) should NOT control the importance of the issues faced in Mine-Induced Seismology (MIS). In the past many techniques, concepts, conclusions, etc. have been “imported” directly from ES into MIS but this has not been always a positive contribution. The fact of the matter is that working in MIS is more likely to help scientists of ES greatly in answering their questions. The opposite is not necessarily true. Therefore, I would recommend that, before adopting them, we examine carefully all the assumptions, hypothesis, etc coming from ES.

#### 2. Connection to other branches of science:

I believe it is beneficial to seek the participation of scientists in other branches of science in this experiment. The NELSAM experiment has sometimes been referred to as a “bio-seismicity” experiment. The IFSCRI can largely benefit from collaboration with scientists and engineers that may have issues that may be resolved by the present project. It may be useful to find such issues and see how the present project can help address them.

#### 3. Seeking in kind contribution from other organizations:

A related point is to identify organizations that may be able to contribute to this project by providing equipment, service, equipment, etc. in kind.

## APPENDIX

### Summary of Presentations

#### Global Fault Slip Control Developments and the Dusel Research Project

The opening session followed invited presentations by Bernd Milkereit on global active fault drilling initiatives- primarily falling under the auspices of either the ICDP- Intercontinental Drilling Program or the IODP- International Ocean Drilling Program- and by Derek Elsworth on the Dusel Research Project- located at the old Homestake Mine in Lead, South Dakota. In each case, usually more than one funding agency was involved.

Bernd placed each of several active fault drilling initiatives worldwide within their geological research context. The relevance of most relate to nuclear waste disposal, tunneling and computational seismology, exploration and reservoir geophysics and pure scientific drilling-related issues. Active fault drilling also provides a critical insight into time dependent processes due to episodic earthquakes. This capability is not provided by static experiments

#### Lessons learned

- The repeatability of geophysical sources- unreliability over the duration of the experiment
- The longevity of sensors- corrosion issues etc
- The performance of strain meters
- There are a limited number of 3D rock characterization parameters which have been monitored over time.

Of the international initiatives looked at with some possible relevance to CEMI's IFSCRI, SAFOD (US); TCDP (Taiwan); CRL (Greece); NELSAM (South Africa) were considered the most relevant.

NELSAM perhaps has the most potential overlap or potential for duplication with IFSCRI but risks appear low since that initiative appears to have potentially failed (although some publications are still coming out from Japanese seismologists) because one of the PI's- Zev Reeches' health has failed and because of administrative problems. Tim Jordan is the other PI. Further, all boreholes drilled into the Pretorius Fault as part of the initiative were very short (40-60m). IFSCR's will likely be long holes. The scheduled end of the project was September 09 and that was overshot, apparently.

The NELSAM site- at Deltona? Mine (formerly Western Deeps) also had huge accessibility and thus logistical problems. Further, air quality and high working temperature issues were not helpful to researchers. There are currently 2 ISS experiments being contemplated with Anglo Gold in SA. They are being mine-driven. Further, there is little conflict with Freiberg test mine plans in Germany.

**Conclusion: NELSAM does not pose a threat to IFSCRI**

Derek Elsworth, in reference to DUSEL, pointed out that that initiative is being largely driven by the particle physics community. Further, the physicists are extremely well organized and have a process in place whereby the physicists rally together as a community and then get broad endorsement from their highest professional body which, in turn, facilitates funding agency appeal and buy-in.

The science falls into Biology, Geoscience and Engineering/BioEngineering bins.

Steve Spottiswoode provided an introduction to identifying the research gaps associated with fault slip control research. Steve felt the "gaps" question could be approached from the following perspectives:

- **Amount of seismicity**
  - Are there ways of lowering event magnitude or, alternatively, lowering the effect
- **Looking at the resulting strong ground motion**
  - Can near-tunnel effects of the source (fault slip) and the damage (effect) be examined more closely and can the reason for localization be determined? Wave guide effects...

- **Timing and avoidance**
  - Measurements are needed to verify models and the ground 3D physical properties need to be better understood
  - The linkage between models and the 3D characteristics of the ground, as well as the ground behaviour (rupture, seismic) response need better understanding.
  - More measurement and understanding of regional and mine-wide deformation needed.
    - Is it on single or multiple structures?
- **Support conditions**
  - Static and dynamic

Fundamental gaps relate to seismologist's knowledge gaps around the fracture healing process; the repeatability of events; slip and rupture processes and whether seismicity tools can provide the information needed to address the fault-slip question.

We need to establish the link between microseismicity/seismicity monitoring and the rock mass response:

- How and where are structures just ahead of or far from mine openings moving
- A 3D volume experiment is needed



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