Education in Underground Science and Engineering in the United States: A Report from a Workshop

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Table of Contents

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Executive Summary

The profession and status of rock mechanics is at a point of transition, and those engaged in it and related disciplines need be to be prepared to meet the challenge of new opportunities. A critical element in this transition will be changes in rock mechanics education.

Background

This transition was the underlying premise in convening a workshop on rock mechanics education. Thirty-two academic and industry practitioners assembled in San Francisco in June 2008 to discuss the current status of the profession, to examine the education process and institutional support for the profession, and to determine what changes mean to the rock mechanics community. The report that follows documents those discussions, records the finding and conclusions, and summarizes the recommendations that resulted from the discussions.

Nature of transition

To understand new opportunities, it is important to characterize the past and current status of rock mechanics as a discipline and as an organizational entity. The first fundamental observation is that the status of the discipline is closely aligned with the boom and bust cycle of the industries that it serves. As mining and hydrocarbon extraction have flourished or floundered in the world economy, so also has the rock mechanics discipline and the institutions that make up its infrastructure. Likewise, education in rock mechanics will expand or contract with health of the industries and the demand for global growth that drives it.

While the rock mechanics community has performed a valued service in research, training and preparation of practitioners, and has contributed needed knowledge to a range of applications and projects, the community has been characterized as small, tightknit, somewhat less recognized when submerged into broader-based disciplines, and with its institutional underpinnings in relative decline. There are relatively few universities with limited numbers of students and modest numbers of faculty. What there is in rock mechanics education is good, but the numbers are limited.

Because of the increased demands, this education status will change. The need for new exploration of energy sources, the need for nuclear sites and hazardous waste disposal, and the need for understanding and prediction of geohazards – all taken together represent increased awareness of the dependence on rock mechanics as a discipline, and therefore the need for enhanced education in rock mechanics. The demand for quality students, taught by experienced teachers, and changes for both research in academic realms and practice in the applied settings of industry and government will make changes to education inevitable.

Response by the rock mechanics community

The issue then is how to predict and manage the changes to rock mechanics education. As a result of the workshop, some of the recommendations cover a broad spectrum of considerations:

- Ways to ensure rock mechanics will gain recognition and status as an educational discipline.
- Calls for the creation of a new educational infrastructure and expanded professional development; such ideas as a consortium of rock mechanics universities, a focused center of excellence, and explicit linkages to existing international counterpart organizations are keys to a transition.
- Explicit consideration of how strong partnerships with industries that recognize the need for enhanced rock mechanics and its education can provide mutual benefits to the rock mechanic community and to industry.
- Finally, the importance that rock mechanics should plan for and the capture of the benefits that would arise from the on-going and evolving relationship to the proposed Deep Underground Science and Engineering Laboratory (DUSEL) are addressed.

The bottom line is that rock mechanics and its educational activities are faced with a transition, and one outcome of the workshop is a call to prepare for that transition.

Introduction and Overview

The question of whether education in rock mechanics is sufficient, adequate, and robust enough to satisfy the research and development agendas of the discipline and to meet the changing needs for professionals in industry and government was the rationale for the workshop. Thirty-two participants attended a one-day session in San Francisco on June 28, 2008 to consider that question.

The primary issues addressed were:

- What is the overall state of rock mechanic education in the U.S.?
- What changes in education and organizations supporting that education can be anticipated?
- How should those in the rock mechanics community organize to address these anticipated changes?
- What are the particular implications and opportunities that arise from the planned DUSEL project?

The following report summarizes four presentations at the workshop on the state of education, the view from private industry, and the critical role that DUSEL may play in the future development of the rock mechanics discipline.

Next, the workshop attendees tackled four topics for discussion. The format for discussions – termed "point/counterpoint" – was a presentation by "provocateurs," then group consideration of the topic.

The closing section summarizes the workshop's findings, conclusions, and recommendations on actions that could be taken to further not only rock mechanics education, but to contribute to the advancement and promotion of the discipline.

There are two appendices to the report. The first is the agenda for the workshop, and the second is a list of attendees.

Summary Presentations

Presentation by Charles Fairhurst: "Education in Underground Science and Engineering in the United States: One View of U.S. Rock Mechanics Education Today"

<u>Historic foundations</u> In order to understand where rock mechanics is headed as a discipline and where the opportunity lies, it is important to recall the history of rock mechanics, as well as the education related to the discipline. Some of the highlights include:

- Our timeline could date from immediately following World War II, an era marked by the growth of industrial economies and the increased demands of economic development. Such growth had lagged worldwide during the Depression and was spurred by the recovery following the War.
- Major mining and civil construction activities were illustrated by the following major projects -- all requiring an interest and knowledge of rock mechanics:
  --Deep mines (S. Africa and India/rockbursts);
  --Coal mines (Europe/subsidence, ground control);
  --Mining (USA, BuMines/ground control, stress determination, blasting);
  --Tunnels (Europe/ Alps-NATM);
  --Tunnel boring machines (USA/ Robbins-Oahe, 1954);
  --Large dams (Europe, Asia);
  --Petroleum (USA /Drilling tools; hydraulic fracturing, 1949);
  --Underground nuclear testing (UK, USA, USSR); and
  --Nuclear waste isolation (USA, Europe).

One of the initial efforts to organize the engineering and science communities to deal with such events was the convening of the US Rock Mechanics Symposium in 1956. This session, presided over by Lute J. Parkinson, Colorado School of Mines and stemming in part as an outgrowth of the drilling and blasting symposia (UMN), convened by E.P. Pfleider and Howard L. Hartman (Penn. State Univ.), pointed out not only the increasing interest in the subject matter of rock mechanics but also the necessity of exploring the knowledge, building the numbers of trained practitioners, and organizing the professional and academic discipline.

Further impetus resulted from a series of prominent disasters and accidents that occurred over the ensuring years, including the following:

- 1954, Prospect Point Collapse;
- Schoellkopf Power Station collapse (USA; 1 death);
- 1959, Malpasset Dam collapse (France; 420 deaths);
- 1960, Coalbrook Mine collapse (S. Africa; 437 deaths); and
- 1963, Vaiont Dam slide (Italy; 2,500 deaths).

Based on growing interest and demand for knowledge of rock mechanics, and in response to the types of disasters or accidents cited, the decision was made to form the International Society for Rock Mechanics (ISRM) in 1962. The Society's first symposium was held in 1966 in Lisbon, Portugal.

There has been continual activity in the years since, with the profession responding to a boom and bust cycle found in the mining, extractive, and petroleum industries. Greater demand for rock mechanics would be matched by increasing interest and support for rock mechanics education. In times of economic difficulty or interruption of government support, the tendency is to cut back education. On the other hand, opportunity might arise through reaction to disasters, but more likely through new demands as industries seek growth opportunities.

Current status Graduate education in rock mechanics does not have a broad base of support among institutions of higher education. For example, among the approximately 200 civil engineering departments, less than ten percent have substantial graduate programs in rock mechanics; those with geotechnical programs are mainly focused on soil mechanics. Most universities with mining departments do have rock mechanics, but those are few in number and departments tend to be small.

Another characteristic of rock mechanic education is the increasing role played by foreign-born graduate students. American technology has been in the international forefront for the last 50 years, due in significant part to major contributions by scientists and engineers from other countries that have remained in the U.S. after graduation. Many have become U.S. citizens. Similarly, there is a shortage of suitable faculty at many institutions as many senior faculty retire.

Just as the status of rock mechanics has tracked with the industries it serves, so also has the research infrastructure for rock mechanics been affected. Some of the key events over the past 50 years include:

- The South Africa Chamber of Mines (Cook, Salamon, Jeaeger) is now disbanded.
- The U.S. Bureau of Mines is now disbanded.
- The U.S. Corps of Engineers has reduced funding for rock mechanics programs.
- The U.S. Bureau of Reclamation has been downsized, due to reduction in funding.
- The Petroleum Reserve Fund provides little support for rock mechanics.
- The RANN (Rapid Excavation Research) program, established in the 1970's, is now terminated.

- While funding and therefore programmatic activity remains strong from the Department of Energy, that support has been focused less on university support and more on field R&D (as represented by Yucca Mountain).
- Currently, the NSF Geotechnical Program is almost the sole provider of support for university research.

These changes may give a negative impression of rock mechanics and its outlook, but what is also important is to recognize that in spite of these actions, rock mechanics has maintained its footing as an academic discipline and continues to hold recognition among those with an interest in the science, engineering and applied practice in the rock mechanics field; the community may be small, but it is still active and involved.

New opportunities Looking forward, the discipline is on the brink of new opportunities, and must gird itself for multiple actions on a number of fronts. Opportunity arises from the following factors:

- World population is rising 12 percent per decade.
- Global minerals (including water) and energy (hydrocarbon and some geothermal) demand is rising with world population.
- Global warming may lead to CO_2 sequestration underground.
- Underground isolation potential is now recognized for toxic and hazardous waste, for power plants, and three-dimensional urban design.
- The time scale to develop and implement 'revolutionary technology' is decades. (To illustrate this, it was pointed out that it took 50 years to move from the invention of the steam engine to the first successful experiment in Stephenson's Rocket locomotive.)
- All of these issues require improved underground technology.

Response to opportunities/recommendations In response, my recommendation is that NSF create a Center of Excellence program in Underground Earth Resource Engineering. Examples of NSF Center of Excellence themes might include:

- Transparent earth;
- Tectono-physics and in-situ stress;
- Coupled processes;
- Rock fragmentation and conditioning ('contact');
- Excavation engineering; and
- Underground isolation engineering.

The proposed Center of Excellence would be organized to stimulate creativity of university faculty. The estimated budget would be $2 million or more per year and should require 50 percent industry funding. It should be noted that the Center would complement DUSEL, which would be the location of many of the experiments. It would also feature international linkages to other underground research laboratories (URL's).

Role of DUSEL in rock mechanic education/international linkages

While there are many facets to this new era and multiple ways of meeting these needs -- all relating to rock mechanics -- perhaps the best opportunity for the discipline is found through focus on the proposed DUSEL.

As the project is proposed, there are three themes: first, in the realm of physics, (exploration into the origin of the universe); second, as relates to biology (what are the origins of life); but third, would be sustainability of life -- if this is not addressed, the first two are irrelevant.

In the realm of underground science and engineering (with emphasis on rock mechanics and engineering), the central issue is the behavior of rock in situ (not in theoretical constructs or laboratory conditions). Whereas in the past, research has been focused on mines for such analysis, DUSEL would provide a dedicated research lab for the first time in U.S. academic history.

DUSEL should focus on graduate education, to have an impact. Further, geoengineering research potential of DUSEL can be enhanced by international linkage with other URL's in different rock types; ISRM should be active in forging relationships with existing facilities depicted on the following graphic.

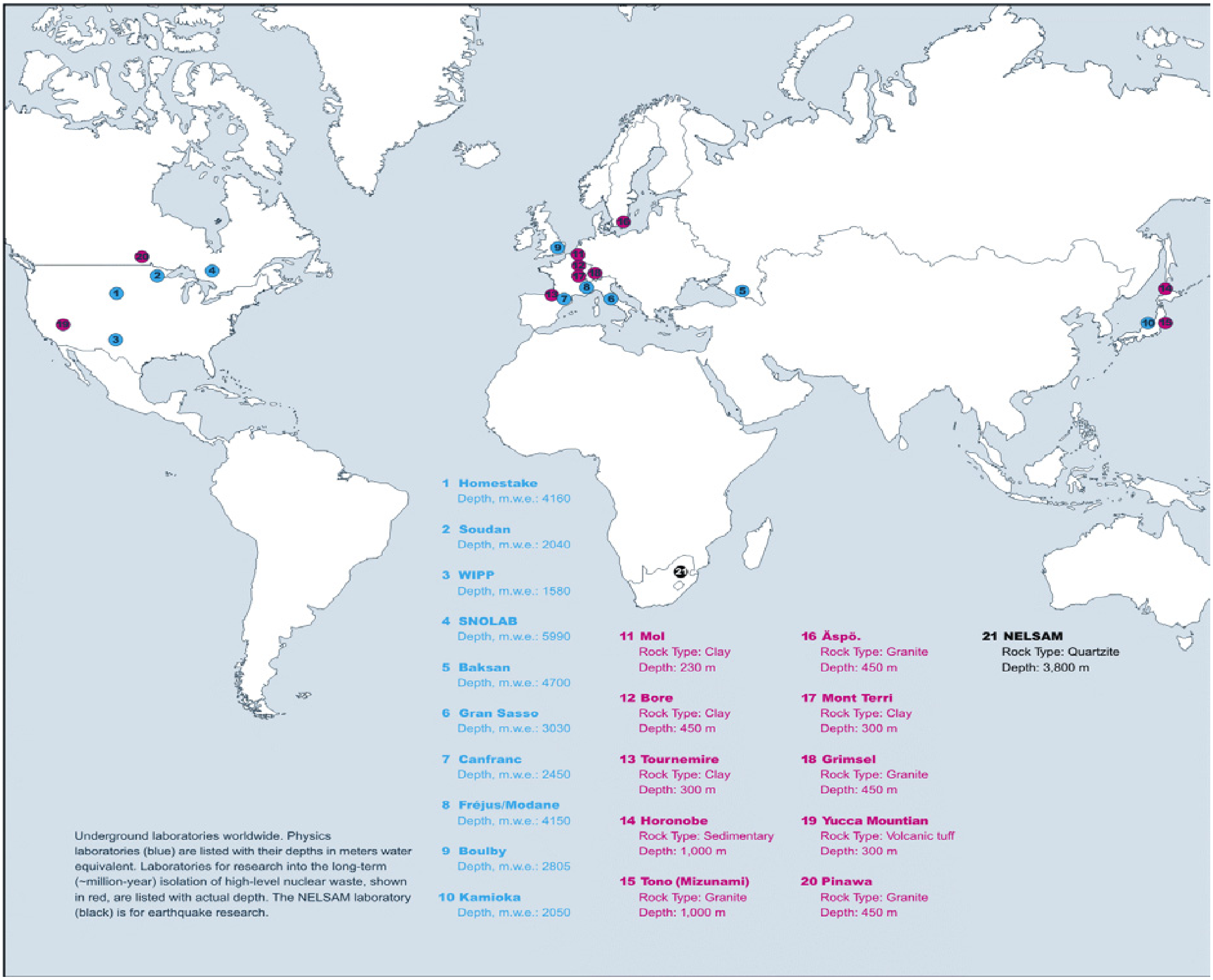

Figure 1: Location of International Underground Research Laboratories

Remarks by Richard Goodman, Professor Emeritus, University of California/Berkeley
"Thoughts on Rock Mechanics Education"

The first important thing to consider in rock mechanics education is the nature of rock mechanics. It is a discipline that will be irretrievably linked to in-situ study for research and education. While classroom learning is important, even more important is that proper education will require on-site analysis. As I observed when I served as an advisor and consultant to an underground mine in Chile and had to agree with Dr. Howard Hartman's advice that to learn rock mechanics, one must "go into the mines to learn about them." If you want to learn rock mechanics, go into the mountains.

A second important aspect of rock mechanics is that it has always been an interdisciplinary field. The history of the discipline, for example, during the 1960's to early 1970's shows that initial efforts to organize the education were based on four schools participating in mining symposia, during which the basics of rock mechanics education were carved out and specifically addressed. At that time, rock mechanics became important different disciplines. It was decided to gather a variety of disciplines under a single committee--an intersociety group with a common interest in rock mechanics. That led to the formation of the U.S. National Committee for Rock Mechanics established under the auspices of the National Research Council which led, in 1995, to the establishment of the American Rock Mechanics Association (ARMA). These founding societies included mining engineers, petroleum engineers, civil engineers, geological engineers, geophysics engineers, among others.

As an interdisciplinary field, there should be formal coursework and students must be steeped in the basics of the field. The subject matter would include mechanics, hydraulics, mathematics (statistics), geology, writing, rock physics, soil mechanics, and others. There is a long list, and it is hard to get it all in one single academic program.

A third observation is the importance of practical and applied knowledge, as well as theoretical knowledge. Graduate students not only need computer skills with advanced and specialized programs, but to be a great civil engineer, you need more than knowledge of how to solve things. You need plain facts and the more the better. We acquire those through our personal experience, and we acquire rules of thumb. The best learning comes from discovery of our own rules.

A final observation comes from the manner in which education in the U.S. differs from education elsewhere, particularly in Europe. In the US the demand for rock mechanic education maybe shaped by "push" from continued advances on the frontiers of theoretical knowledge and basic science. As the theory is advanced, so is the discipline developed. In this case, there may be a solution looking for a problem—this is the way the U.S. does it: you search for a new methodology from academic colleagues in other fields. You apply new applications to one's own field of interest.

The second approach is the European approach, where there is a problem looking for a solution. You run into a problem that currently lacks a thorough solution or has incomplete solutions. You then conduct basic experiments to develop a fundamental solution, and then try to generalize to common principles based on the applied experience. This is an industrial approach. Because it is rooted in applied practice, there is the possibility for an enormous trickle-down of funding.

In the final analysis, the two approaches complement one another. The problem with the "theory first" approach is that it may be more difficult to fund, and with limited numbers of teachers and students, may be underfunded or constrained by the limited number of students engaged in the discipline. On the other hand, the "application driven" approach may find more support from industry and may lead to more opportunity for students, but it will still need to contribute to the body of knowledge of the rock mechanic discipline.

Given the current state of the economy and the increasing demand from industry for professionals knowledgeable about rock mechanics, there may be more rewards and opportunities coming from more emphasis on the applied knowledge as characterized in the European approach.

Presentation: Sarah Wilson, Jacobs Associates
"Industry Perspective"

My presentation is intended to reflect upon rock mechanics from the perspective of the engineering profession and the construction and mining industries.

First, we recognize that rock mechanics in itself is not well-established, but more commonly we find that knowledge and those skills embedded in related engineering disciplines; civil, mining, and petroleum engineering are the most prominent.

Even though rock mechanics is not specifically identified, there are areas of analysis and investigation that cross all those disciplines. There is the need, among other uses, for:

- Rock mass characterization;
- Analysis of ground behavior;
- Evacuation sequencing;
- Rock support design; and
- Evacuation monitoring.

These may be found in engineering projects of all types.

With regard to rock mechanic education, training for civil engineering should include knowledge of rock mechanics in (1) drawing and specifications for construction projects, (2) structural engineering, and (3) effective communication between contractors and owners.

One observation is that in civil engineering, jobs are commonly awarded to the low bidder. Because of this, even though there may be recognized risks in projects from rock mechanic considerations, the dilemma is that some bidders will choose to ignore or downplay such concerns in order to be price-competitive.

Another observation is that over the recent past, rock mechanic education has not been well-recognized or established, and the numbers of both students and faculty may be shrinking. However, opportunities for rock mechanics and thus enhanced need for education come with the growing needs in the mining and petroleum industries. Given the increasing opportunities from resource development, energy considerations, and other reasons underlying growth in those sectors, there should be a renewed interest in rock mechanics.

A final comment should be directed to the DUSEL initiative. This appears to be an opportunity to conduct research and develop new technology in a low-risk environment. Civil engineers, in particular, would benefit from this initiative. Furthermore, private industry, recognizing the value of a DUSEL initiative, would be concerned that as plans are formulated, that they would miss out and not participate fully in the opportunity.

Presentation: Derek Elsworth, Pennsylvania State University
"Opportunities for Education and Research in Science and Engineering at DUSEL"

One of the critical initiatives that will affect rock mechanics education is the Deep Underground Science and Engineering Laboratory (DUSEL), now in the planning stages at the former mining operation at Homestake, South Dakota. Since this project is so central to much academic, research, and organizational aspects of not only rock mechanics but of other disciplines as well, it is important to explore how it relates to the future of our profession.

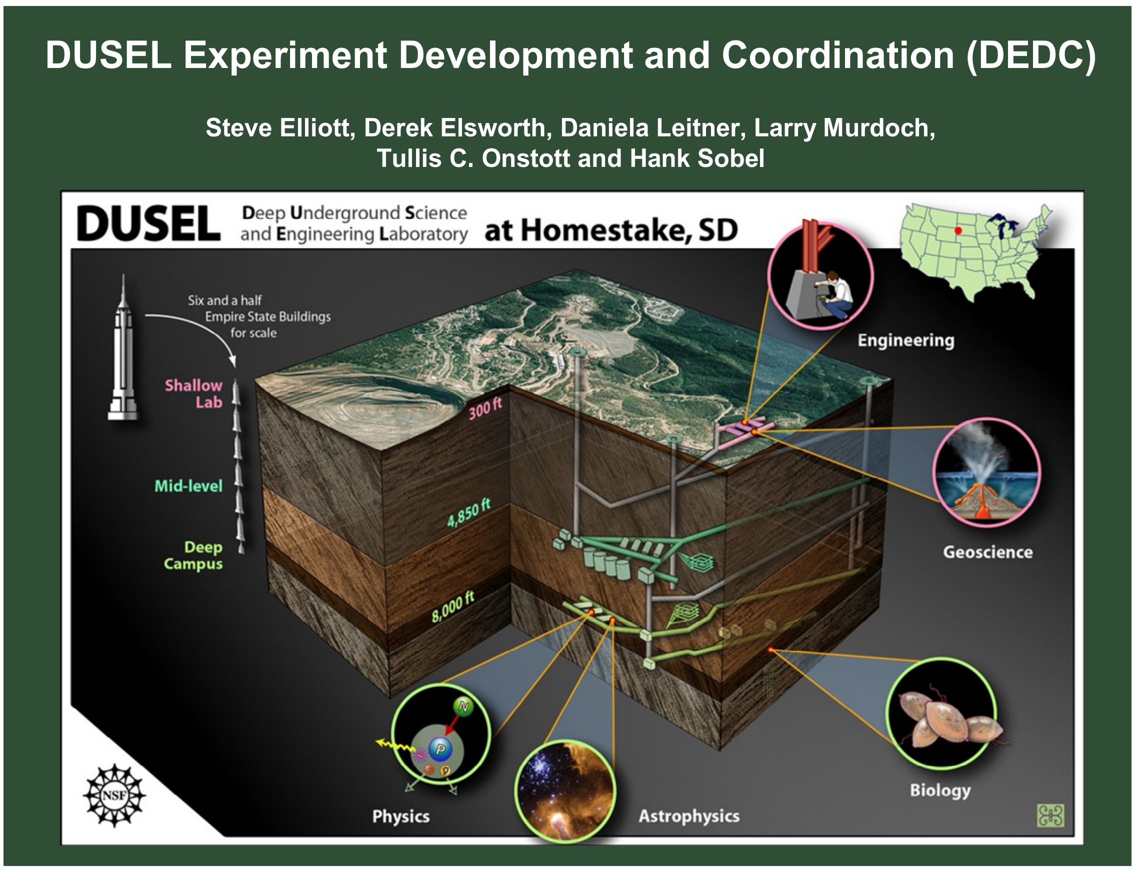

Figure 2: Overview of DUSEL Project

<u>DUSEL Attributes</u> Many of the key features of DUSEL are illustrated in the graphic above. Because much of that is widely known, the focus of this presentation will be on geoengineering, geoscience, and rock mechanics. Some of the key attributes that will found with this initiative are:

- DUSEL will represent an important facility with unparalleled attributes:
    - Long-term uninterrupted access to the site; this will permit analysis of long-term response of structures and active processes;

    - Access to unusual depth for important initiatives in deep science (physics and bioscience, but also for examination of rock conditions at varying depths); and
    - Broad access to a large volume of rock (scale effects and transparent Earth).
- A facility for world-class science and engineering science in:
    - Physics and astrophysics; and
    - Sub-surface science and engineering.
- Important societal impacts:
    - Construction;
    - Energy and sustainability;
    - Resource recovery and sustainability; and
    - Natural hazards.

Focus on rock mechanics (geo-engineering) The focus of this summary is on how DUSEL relates to geoscience and engineering, particularly as it sets a framework for rock mechanics education.

Therefore, while the objective for DUSEL is to explore basic issues in physics, astrophysics and cosmology and to probe the origins and limits of life on this planet, the particular opportunities for rock mechanics and geoengineering that arise from DUSEL include:

- Resource recovery;
- Petroleum and natural gas recovery;
- In-situ mining;
- Enhanced geothermal systems;
- Potable water supply;
- Mining hydrology;
- Waste containment/disposal:
    - Deep waste injection;
    - Nuclear waste disposal;
    - CO2 sequestration;
    - Cryogenic storage/petroleum/gas;
- Site restoration:
    - Aquifer remediation;
- Underground construction:
    - Civil infrastructure;
    - Mining;
    - Underground space; and
    - Secure structures.

Particular advantages for such exploration found with DUSEL include:

- 4D--Experiments within a block of rock (~km-scale) at depth and at *in situ* temperature and stress;
- Access to fluids and gas with minimal contamination for molecular studies;

- Capabilities to examine behavior and to characterize rock at multiple scales; and
- Proximal access to clean laboratory, fabrication facilities and unique technologies.

<u>Preparation by rock mechanic community</u> Even during the planning phases for DUSEL, there has been some preliminary attention paid to the research and educational agendas that might be undertaken at the site. Among those topics (and principal investigators) that are being explored for possible development at DUSEL, once it begins operations, are the following:

- Ambient rock deformation processes: Herb Wang, University of Wisconsin;
- Ambient flow, transport, diversity, activity and evolution: David Boutt, University of Massachusetts;
- Induced rock deformation processes: Leonid Germanovich, Georgia Tech;
- Induced flow, transport, diversity, activity and evolution: Eric Sonnenthal, LBNL;
- Underground construction and environment: Charles Fairhurst/Joe Labuz, University of Minnesota;
- CO2 sequestration: Joe Wang, LBNL;
- Resource extraction: Jean-Claude Roegiers, University of Oklahoma;
- Subsurface imaging and sensing: Steve Glaser, UC Berkeley;
- Ultra-deep biological observatory: Tom Kieft, New Mexico Tech; and
- Baseline characterization and monitoring: Steve Martel, University of Hawaii.

In addition, there are other topics of interest that might be included in the research and educational agenda for DUSEL, Interest in the following could be further developed in the coming months and years: Low background counting and effects of ionizing radiation on biological systems; geoneutrinos; petrology, ore deposits, and structure analysis.

Point/Counterpoint Discussions

Topical Discussion of Rock Mechanics, Rock Mechanics Education, and Related Issues

Provocateurs: Herbert Einstein (Professor, MIT) and Francois Heuze (Consultant, Lawrence Livermore National Laboratory (Retired))

Is rock mechanics better taught in general, non-specialist geomechanics/geotechnical courses in civil, mining, and petroleum engineering?

The following graphic illustrates the various disciplines related to rock mechanics. It is inevitable that education in rock mechanics would both draw upon and be embedded in those related fields of academic research and teaching.

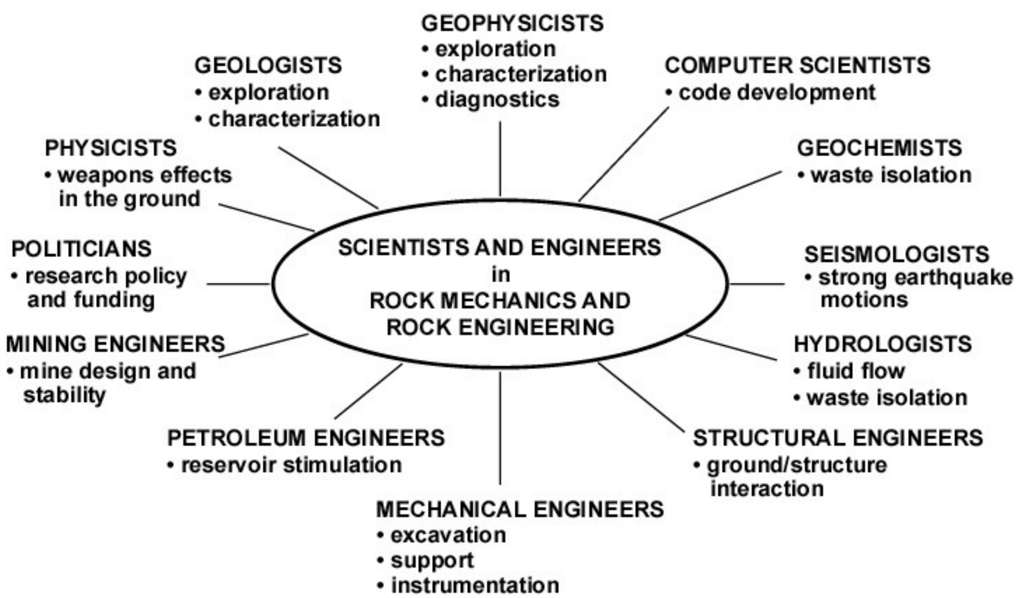

Figure 3. Multidisciplinary Interactions of Scientists and Engineers in Rock Mechanics

With regard to education in rock mechanics, the first distinction must be made between undergraduate and graduate education. The goal for undergraduate teaching in rock mechanics should be (1) to gain knowledge of the basic principles of rock mechanics, (2) to spark sufficient interest among students to encourage them carry on into graduate studies in the discipline, and (3) to build a base of informed citizens (though not technical experts) that would be aware of issues related to rock mechanics to enable them to effectively participate in public or corporate initiatives where rock mechanics would be a consideration.

On the other hand, the objectives for graduate students in rock mechanics should be (1) research and development, (2) teaching, (3) engagement in interdisciplinary studies, (4) professional development, or (5) employment in industry or government. As a subject of graduate study, rock mechanics would be oriented to increasing theoretical understandings or achieving applied advancement of the discipline.

This implies that different strategies have to be employed for these distinct purposes. For undergraduate education, a few universities might create a specific major for the study of rock mechanics. However, the more likely model for undergraduate education would be rock mechanics integrated into compatible fields of study, such as geology, civil, petroleum, or mining engineering. It was suggested that such an undergraduate course be directed at the sophomore or junior levels.

There are difficulties with an integrated model of rock mechanics education. To be successful, it will require that whatever subjects or courses with which it is combined would be receptive and compatible. If the principles of rock mechanics are not accommodated but just tolerated, the course would not be effective. Further, since many universities are reluctant to add courses, owing to limited teaching and classroom resources, rock mechanics education might be the first to be “crowded out” if cutbacks in courses must occur.

Another difficulty is that undergraduates may have minimal to no background for their first exposure to rock mechanics. Stemming from the fact that many in K-12 students do not encounter much preparation for any type of technical study, and particularly may not have taken earth science, the undergraduate course in rock mechanics may be their first exposure, and that may not be sufficient for proficiency in the course.

One commentator stated that there were no suitable textbooks for rock mechanics for the undergraduate student, and that there was only a finite supply of teachers of the discipline. According to a survey of rock mechanic teaching from 2004 (and updated in 2008), there were 43 universities in the U.S. that had a faculty member specifically identified as teaching rock mechanics. Only four universities (Penn State, Minnesota, Missouri-Rolla, and Colorado School of Mines) had five or more members teaching rock mechanics; 31 out of the 43 had one (23) or two (8) faculty members.

Finally, since quality teaching of rock mechanics entails not only classroom teaching but is best understood through examination of in situ conditions, there may be geographical or local considerations that do not allow easy opportunity for field study.

One of the factors cited for successful teaching was the necessity of well-prepared and exciting faculty; such teachers would inevitably draw interest. All agreed that use of case studies and a focus on problem solving were keys to good teaching. And demonstrating the importance of rock mechanics to energy resources, hazard forecasting, and improved employment opportunities for those versed in rock mechanics, as indicators of success, would also help to get student's attention.

Another factor cited as a characteristic of rock mechanics education is that a student majoring in the discipline would typically be open to new thinking, innovation, and creative approaches. This is attributed to the interdisciplinary nature of the discipline, the need to explore new methods of analysis and investigation, and that many of the applications in industry require problem-solving skills.

Does increased knowledge in geomechanics in general and rock engineering/science in particular have any but marginal economic, environmental and other societal impacts (e.g., construction costs, price of oil, prevention/mitigation of natural hazards, and contamination control/remediation?

Should public money be used to help advance geomechanics and rock mechanics?

The case for funding to support rock mechanics is strong. Because of the future applications that are critical to society and our economy, there is strong justification for investment in rock mechanic/geoengineering education. The benefits that accrue from that would clearly outweigh the amount of funding that would be required.

On the other hand, because of its interdisciplinary nature, rock mechanics is not represented by a strong or established advocacy group. There is not a large established base of those in the discipline that could be effectively marshaled to seek funding to support the advancement of the profession or to support education. The rock mechanics community is not well organized, and it would be difficult to compete with others seeking funding either in the private sector or from public sources.

Because of the nature of the discipline, there is a special need for public funding. First, spending on rock mechanics could easily be justified when the applications to critical social and economic needs and U.S. policy objectives are considered: energy independence, price of oil and demand for low-cost energy; new energy technologies, oil reserves and national security, and considerations in the development of nuclear, geothermal, ocean and wind energy sources. It will further be valued as it relates to offshore drilling and shale deposits, landfills, aquifers, and water supply. And knowledge of rock mechanics is essential to understanding and possible prior warnings related to geohazards such as earthquakes, landslides, or volcanic action.

Second, it would be likely that public funds would be used for basic research and development. Such funds would be more difficult to find in the private sector and among corporate sponsors.

Private funding, on the other hand, should also play a role in supporting rock mechanics education. While it may be more difficult to argue for support for basic research, there is a clear case for private funding where specific problems are addressed, where practical and applied solutions are expected as a result of the funding, and where private companies benefit from having cadres of trained rock mechanics as employees.

Will the DUSEL benefit underground engineering and science? Can the knowledge gained at DUSEL be generalized? Will collaboration with other fields of study at the lab—physics, biology, geoscience—be possible and have beneficial effects?

There was consensus that DUSEL represents a great opportunity for advancing the discipline of rock mechanics. The question was more how and in what form such support for and participation in DUSEL should take place.

Rock mechanics is a small, tight-knit community. DUSEL will aid in recognition and an increase in status for the discipline and its practitioners. It will aid in collaboration. And it will lead to intellectual ferment, which, in turn, will lead to new discoveries, new methods, and techniques.

DUSEL will likely give a focal point to rock mechanics that is now scattered or lacking. It will serve both as a center of learning and a center for promoting awareness, raising issues, and building the case for both further investment and further development in rock mechanics.

Caution was expressed, however, with the recognition that the program has a very long planning and development period, and that there was need for continual attention to how rock mechanics would relate and take advantage of it.

Are rock engineering/science and geoengineering "low-tech domains" and thus not very attractive?

Many students do not see glamour or excitement in rock mechanics. They have preferences for such disciplines as computer/electrical engineering or bioengineering as trendy disciplines. The image of dirty miners is not the same as the image of clean lab coats.

A larger issue in attracting students is the financial considerations. Some students may perceive they would not make as much money in rock mechanics as in other disciplines.

One downside of this growing recognition of opportunity in the private sector is that it might cause students to not complete their studies or to not pursue advanced degrees, given the temptation to leave school for employment opportunities.

The key to attracting students will be good teaching, and techniques such as using case studies and real-world illustrations. This must be part of forming a critical mass of those engaged in the discipline.

In terms of the image of rock mechanics, it is important not to lose the historic support from NSF and to focus on it as primary sponsor; part of that will be participation in DUSEL. But that is not broad enough. It was also important to build and maintain quality relationships with industry.

Findings, Conclusions, and Recommendations

1. ARMA needs to develop a multi-part, targeted strategy for education, and segmented as follows:

- K-12;
- Undergraduate;
- Graduate; and
- Post-graduate.

Each segment should include consideration of the educational objectives, characteristics of the target audience, analysis of barriers to entry and competition, education techniques, funding sources, and a work plan with a timeframe for implementation.

2. Specific suggestions for each of these segments, to enhance general awareness, to build support, and to increase the number of academics and practitioners in the discipline, would include the following:

K-12 education:
- Where possible, organize field trips, provide summer camp exposure.
- Produce entertaining and informative videos on rock mechanics and its applications.
- Establish visitors' centers at major facilities (mines, DUSEL, etc.).
- Add specific content/information to earth science courses for high school students; provide seminars for teachers.

Undergraduate education:
- Provide core curriculum for rock mechanics, suitable for integration into engineering, geology, and related courses.
- Develop distance learning courses featuring experienced and enthusiastic teachers of rock mechanics; leverage access to the best academics and practitioners.
- Provide access to case studies, demonstration, and video highlights.

Graduate education:
- Recognize outstanding teachers; develop core courses around their teaching, promulgate via distance learning.
- Working with sponsoring companies, create work-study programs.
- Create sponsored-research opportunities with private sector.
- Create fellowships for industry practitioners to teach or do research.
- Provide clearinghouse for employment opportunities in rock mechanics and related disciplines.
- Monitor changes in H1-B visa status for impacts on participation by foreign students.

- Arrange exchange programs with foreign universities and underground research laboratories (URLs).

Post-graduate education/promotion of rock mechanics discipline:

- Develop and deliver ‘short courses” for information, maintaining state-of-the-art in theory and practice.
- Consider certification through continuing education.
- Conduct “market research” on key trends affecting rock mechanics profession (with implications for funding, employment, or research opportunities), including the following industries:
  - Petroleum and gas;
  - Nuclear power plant siting;
  - Nuclear and other waste disposal;
  - Geothermal;
  - Construction and civil engineering; and
  - Mining and extraction.

3. ARMA should support establishment of a Center of Excellence in Rock Mechanics. The Center of Excellence should be organized to promote not only rock mechanics education, but also to promote research. It should be designed to relate to counterpart international bodies with an interest in rock mechanics.

4. ARMA and/or the Center of Excellence should convene industry advisory panels with representatives from each of the industry partners listed above; one specific charge to the panels would be to identify opportunities for collaboration leading to employment and funding opportunities.

5. ARMA should make use of state-of-the-art techniques for public relations. Approaches to be considered include:

- Press releases on key events, timely news for stakeholders;
- Daily, weekly, periodic talking points to ARMA spokespersons by a “designated correspondent” on behalf of the association;
- Directed research studies and analysis, other publications sponsored by industry partners, government agencies;
- Online newsletters, news digests, and a news bureau – using social networking as means of delivery of content (Facebook, Yahoo Groups, etc.); and
- Use of social networking techniques to coordinate consistency of messaging and lobbying/information efforts.

6. ARMA should ensure active involvement during the planning and development phases of DUSEL, and maintain a lead role during operations. However, ARMA should not rely on that program as the sole focus of its education efforts. Other programs and initiatives should pursued by ARMA. The purpose would be to balance the overall ARMA effort and not to put all the eggs

in the DUSEL basket. An easy thing to do would be to assume all the education and promotional actions of ARMA should be focused on DUSEL. That would be tempting, but would not serve the long-term and broad interests of the association well.

7. ARMA should draft a strategic plan for DUSEL during the conceptual and feasibility phases as soon as possible, including role of rock mechanics, use of DUSEL space for research and education, specific action plans, lead participants, funding strategy during startup and operational phases, integrated research agenda, value of outcomes of participation to ARMA and other stakeholders

8. ARMA should be aggressive and pro-active during the development phase of DUSEL, to ensure participation and to hold a place at the table with other disciplines, sponsoring agencies, contractors, etc.

Appendix A: Agenda

Workshop on Education in Underground Science and Engineering in the United States

Westin Market Street San Francisco

June 28, 2008

Agenda

7:30 am	Registration Desk Opens for San Francisco 2008. Registration for this workshop will take place at this desk located in the pre-function area on the hotel's second floor. There is no fee for participating in this workshop.
	Presentations and General Discussion
9:30 am	Welcome, Introductions, About this Workshop and the Updated Survey of Rock Mechanics Educators in the U.S., *Peter Smeallie, Executive Director, ARMA and the ARMA Foundation; Herbert Einstein, Professor, MIT and Chair, Workshop Planning Committee*
9:50 am	One View of U.S. Rock Mechanics Education Today, *Charles Fairhurst, Professor Emeritus, University of Minnesota*
10:10 am	Thoughts on Rock Mechanics Education, *Richard Goodman, Professor Emeritus, University of California, Berkeley*
10:30 am	Discussion, *Moderated by Antonio Bobet, Professor, Purdue University*
11:00 am	Break
11:15 am	A View from Industry, *Sarah Wilson, Senior Engineer, Jacobs Associates and Vice President, ARMA*
11:30 am	The Deep Underground Science and Engineering Laboratory (DUSEL), *Derek Elsworth, Professor, Pennsylvania State University*
12:00 noon	Lunch
1:00 pm	Point/Counter Point—Provocateurs: *Herbert Einstein, Professor, MIT and Francois Heuze, Consultant and recently retired from Lawrence Livermore National Laboratory*

i. Is rock mechanics better taught in general, non-specialist geomechanics/geotechnical courses in civil, mining, and petroleum engineering?
ii. Does increased knowledge in geomechanics in general and rock engineering/science in particular have any but marginal economic, environmental and other societal impacts, e.g., construction costs, price of oil, prevention/mitigation of natural hazards, and contamination control/remediation?
iii. Will the DUSEL benefit underground engineering and science? Can knowledge gained at DUSEL be generalized? Will collaboration with other fields of study at the lab--physics, biology, geo-sciences--be possible, and, if so, have beneficial effects?
iv. Are rock engineering/science as well as geoengineering/science "low tech domains" and thus not very attractive?

1:45 Discussion, *Moderated by Antonio Bobet, Professor, Purdue University*

Analysis, Conclusions and Recommendations

2:30 pm Assess the educational infrastructure in terms of its ability to teach and the ability to attract students for underground engineering and science at the undergraduate and graduate levels. Develop recommendations for improvement [possible working groups or in plenary with moderator]

3:15 pm Report Out

3:30 pm Break

3:45 pm Recommend educational opportunities that involve DUSEL. Such opportunities may include industry-sponsored summer workshops for faculty, site visits by classes, special lectures and tours on site, and summer or semester internships for students on site. [possible working groups or in plenary with moderator]

4:30 pm Report Out

4:45 pm Wrap Up

5:00 pm Adjourn

Appendix B: Workshop Participants

Herbert H. Einstein	Professor	Massachusetts Inst. of Technology
Ahmed Abou-Sayed	President	Advantek International
Azra Nur Tutuncu		Shell Exploration & Production Co.
Antonio Bobet	Professor	Purdue University
Jami Girard Dwyer		Barrick Goldstrike
Derek Elsworth	Professor	Pennsylvania State University
Sidney J. Green		Schlumberger
William G. Pariseau	Professor	University of Utah
Sarah H. Wilson	Senior Engineer	Jacobs Associates
Jamal Rostami	Assistant Professor	Pennsylvania State University
Richard Goodman	Professor Emeritus	University of California, Berkeley
Joshua Taron	Ph.D. Candidate	Pennsylvania State University
Charles Fairhurst	Professor Emeritus	University of Minnesota
Francois E. Heuze	Rock Mechanics and Geological Engineering Consultant	
Chi Park	Geotechnical Engineer	Lachel Felice & Associates
Erik Westman	Assistant Professor	Virginia Tech
Sangyoon Min		Parsons
Ki-Bok Min	Lecturer	The University of Adelaide
Peter Smeallie	Executive Director	American Rock Mechanics Assn.
Eleanor Smeallie	Student/Rapporteur	The College of Charleston
John Tinucci	General Manager	Vector Engineering, Inc.
Yasuhiro Mitani	Faculty	Kyushu University
Ahmad Ghassemi	Associate Professor	Texas A&M University
Steven Glaser	Professor	University of California, Berkely
Bezalel C. Haimson	Professor	University of Wisconsin-Madison
Val Zimmer	Graduate Student	University of California, Berkeley
Joseph F. Labuz	Professor	University of Minnesota
Lianyang Zhang	Assistant Professor	University of Arizona
Man-chu Ronald Yeung	Associate Professor	California State Polytechnic University
Scott Kieffer	Professor	Graz University of Technology
Mary MacLaughlin	Professor	Montana Tech
Denis Labie	Sr Research Engineer	Natural Resources Canada