Run-of-Mine Scale Effects Experiments
(SEE)

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Science Goals: *EarthLab* and *Deep Science* state that access to the large rock volume in DUSEL permits testing of the critical-stress hypothesis that Earth's crust is generally near failure. Over its 125-year mining history, many alterations of the original stress state have taken place. How does rock mass respond to human activity? How do stress, strain and pore pressure vary in scale from borehole to tunnel to regional geology? How are stress state and strength related to geologic heterogeneity, fracture geometry, the presence of fluids, and rock anisotropy? How do the fracture network, stress state, and constitutive properties affect the stability of tunnels, shafts, wellbores, and large, room-sized excavations? DUSEL is the deepest environment in which these questions can be addressed unencumbered by competing activities. An R&D program requires the following elements: baseline site characterization, long-term monitoring, and numerical modeling.

Baseline Site Characterization The tasks needed to characterize the baseline state of the rock mass that makes up the former Homestake mine are: (a) creation of a user-friendly and web-accessible interface to the Vulcan database, (b) thorough review of the Vulcan database, drill core, and paper records to establish quantitatively, insofar as is feasible, the history of rock mass lithology, fracture geometry network in each lithology, physical, mechanical and hydraulic properties of intact rock, roughness and aperture distributions of fractures, mechanical and hydraulic properties of fractures, excavation, water seepage including hydraulic boundaries and water chemistry, rock mass deformation and stresses, and microseismicity, (c) mapping fractures three dimensionally in as much of the mine as can be accessed safely, using manual as well as state-of-the-art multimedia technology for recording walkthroughs, or possibly remotely-controlled, lighted vehicles, which permits rendering three-dimensional reconstructions, (d) obtaining rock samples to determine physical, mechanical and hydraulic properties of intact rock in a laboratory and hence to develop constitutive models for intact rock, (e) obtaining samples of fractures to determine roughness, aperture, mechanical and hydraulic properties of fractures in a laboratory and hence to develop constitutive models for fractures and (f) establishment of baseline values of stresses, tunnel dimensions, seepage including hydraulic boundaries, pore pressures, and water chemistry over a large volume of the mine.

Long-term Monitoring: Alterations of the stress state will occur in the mine from dewatering and excavating large experimental chambers. These loads act on spatial scales and at stress levels not previously available in rock engineering studies. Furthermore, DUSEL will operate for decades. Therefore, repeat measurements of the baseline values described above directly address long-standing fundamental questions about rock behavior as functions of spatial scale and time. Repeatable, long baseline and localized deformation measurements over long times are possible using fiber optic technology.

Numerical Modeling: The underlying motivation for the scientific questions is to improve geo-engineering technology and predictability in the deep underground environment. Available core data and mine records will be used to develop a geomechanical model in three-dimensions. Rock mass mechanical and hydraulic behavior show very complex anisotropic and scale-dependent properties in the presence of distinct fracture sets. Collected fracture geometry data will be used to perform three-dimensional fracture network modeling including calibration and validation. Estimated physical, mechanical and hydraulic properties of intact rock and fractures will be used to develop necessary constitutive models for intact rock and fractures. The understanding of the coupling between temperature, stress, deformation, pore pressure, geologic heterogeneity and anisotropy, rock fracture, fluid flow, fluid chemistry, and microbial life will be tested through predictive numerical models. The discontinuum and continuum numerical models needed will be significantly more complex and comprehensive than those available presently. Hence, the SEE research program includes a significant development effort in computational methods, especially upscaling methods to deal with effects of spatial scale, in close concert with the observational results. The entire SEE R&D program is to be connected to a parallel program in geophysical imaging ("What lies between the boreholes?") and microseismicity ("How and why do rock masses fail?") and hydrology ("How does water flow deep underground?").

Education and Outreach Opportunities

DUSEL is an exceptional opportunity for university, industry, and national laboratory researchers to work in partnership on problems from construction to basic geoscience and geo-engineering by occupying a single *in situ*, large-volume, underground laboratory with three-dimensional access. It provides the opportunity for experiential learning for K-12 through graduate school students within the deep earth environment where they can be in contact with the crushing weight of thousands of feet of overlying rock, the geothermal gradient, and deep underground fluid flow. It is an environment in which the coupled nature of rock response to temperature, stress, microbial life, and chemical reactions is seen as a single process. It is the environment in which the underground can be seen as a societal resource space. Students and the public will gain an appreciation of how knowledge about underground rock mass response is gained by observing researchers pose questions, conduct experiments, make observations, and analyze and interpret the results.

Interested Principals and Collaborators.

Participants in the DUSEL Workshop discussions were; Steve Martel, Herb Wang, Pinnaduwa Kulatilake, John Kemeny, Joe Wang, Steve Glaser, David Boutt, Bezalel Haimson, Steve Blair, Steve Carlson, Larry Murdoch, Christian Close, …..

***Cost and Schedules*:** The 10-year cost estimates are based primarily on personnel costs and secondarily on anticipated equipment costs.

1. Creating web-accessible, user-friendly interface to Vulcan - $200, 000/yr for 2 years.
2. Fracture mapping in mine - $120,000./yr for 2 years.
3. Baseline stress, deformation, pore pressure, water chemistry – $250,000/yr for 2 years.
4. Monitoring during dewatering, actively coupled processes experiments, and large-cavern excavation - $120,000/yr for 8 years
5. Laboratory testing of intact rock and fractures for physical, mechanical and hydraulic properties--$ 150,000/yr for 3 years
6. Numerical modeling – $150,000/yr for 8 years
7. Annual workshops – $75,000 for 10 years

TOTAL = $4.5 M

These cost estimates are very preliminary and can be refined considerably by discussion with equipment manufacturers, and with industrial groups.