Large Excavations in the US

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Topics

• DUSEL sites
• Site characteristics important for large excavations
• Rock engineering
• Relative importance of site characteristics
• Megaton detector feasibility

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Solicitation 2 Sites

- Cascades-Icicle Creek, WA
  - Greenfield escarpment site & nearby railroad tunnel
- Henderson Mine, Empire, CO
  - Operating molybdenum mine since mid 1970s
- Homestake Mine, Lead, SD
  - Former operating gold mine
- Kimballton Mine, Giles Co., VA
  - Limestone mine & adjacent subsurface
Solicitation 2 Sites

- San Jacinto, CA
  - Greenfield escarpment site
- Soudan Mine, Soudan, MN
  - Operating lab at former iron mine, expansion into adjacent subsurface
- SNOLAB, Sudbury, Ontario
  - Operating lab in operating nickel mine
- WIPP, Carlsbad, NM
  - Operating lab in operating low-level waste facility
Characteristics for Large Excavations

- What site characteristics are important for large excavations?
  - Depth / shielding capacity
  - Rock type / rock chemistry
  - Rock quality / In situ stress
  - Access / rock removal

- Will review each characteristic for each site

- All comments that follow are for large excavations, not DUSEL in general
# Depth / Shielding Capacity

<table>
<thead>
<tr>
<th>DUSEL Site</th>
<th>Depth / Shielding Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascade</td>
<td>Adequate</td>
</tr>
<tr>
<td>Henderson mine</td>
<td>Adequate</td>
</tr>
<tr>
<td>Homestake mine</td>
<td>Adequate</td>
</tr>
<tr>
<td>Kimballton</td>
<td>Adequate</td>
</tr>
<tr>
<td>San Jacinto</td>
<td>Adequate</td>
</tr>
<tr>
<td>Soudan</td>
<td>Adequate</td>
</tr>
<tr>
<td>SNOLAB</td>
<td>Adequate</td>
</tr>
<tr>
<td>WIPP</td>
<td>Adequate</td>
</tr>
</tbody>
</table>
## Rock Type / Rock Chemistry

<table>
<thead>
<tr>
<th>DUSEL Site</th>
<th>Rock type / chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascade</td>
<td>Igneous, insoluble</td>
</tr>
<tr>
<td>Henderson mine</td>
<td>Igneous, insoluble</td>
</tr>
<tr>
<td>Homestake mine</td>
<td>Igneous/metamorphic, insoluble</td>
</tr>
<tr>
<td>Kimballton</td>
<td>Sedimentary, insoluble</td>
</tr>
<tr>
<td>San Jacinto</td>
<td>Igneous/metasediments, insoluble</td>
</tr>
<tr>
<td>Soudan</td>
<td>Igneous/metamorphic, insoluble</td>
</tr>
<tr>
<td>SNOLAB</td>
<td>Igneous/metamorphic, insoluble</td>
</tr>
<tr>
<td>WIPP</td>
<td>Sedimentary, soluble</td>
</tr>
</tbody>
</table>
# Rock Quality / In situ Stress

Summary of available information about site rock quality.

<table>
<thead>
<tr>
<th>DUSEL Site</th>
<th>Rock quality / In situ Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascade</td>
<td>Nearby railroad tunnel</td>
</tr>
<tr>
<td>Henderson mine</td>
<td>Existing info &amp; nearby mine excavations</td>
</tr>
<tr>
<td>Homestake mine</td>
<td>Existing info &amp; nearby mine excavations</td>
</tr>
<tr>
<td>Kimballton</td>
<td>Existing info &amp; nearby mine excavations</td>
</tr>
<tr>
<td>San Jacinto</td>
<td>Some tunneling nearby</td>
</tr>
<tr>
<td>Soudan</td>
<td>Existing info &amp; existing lab caverns (different rock)</td>
</tr>
<tr>
<td>SNOLAB</td>
<td>Existing info &amp; existing lab cavern</td>
</tr>
<tr>
<td>WIPP</td>
<td>Existing info &amp; existing excavations</td>
</tr>
</tbody>
</table>

No site has sufficient experience to be sure that a megaton detector is feasible!

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Rock Engineering 101

• Rock “material” — strong, stiff, brittle
  – Weak rock > Strong concrete
  – Strong in compression, weak in tension
  – Postpeak strength is low unless confined

• Rock “mass” — behavior controlled by discontinuities
  – Rock mass strength is 1/2 to 1/10 of rock material strength

• Discontinuities give rock masses scale effects
Rock Engineering 101

- Massive rock
  - Rock masses with few discontinuities, or
  - Excavation dimension < discontinuity spacing
Rock Engineering 101

• Jointed or “blocky” rock
  – Rock masses with moderate number of discontinuities
  – Excavation dimension > discontinuity spacing
Rock Engineering 101

• Heavily jointed rock
  – Rock masses with a large number of discontinuities
  – Excavation dimension >> discontinuity spacing
Rock Engineering 101

• Rock stresses in situ
  – Vertical stress \( \approx \) weight of overlying rock
    – \(~27\) KPa / m \( \Rightarrow 35.7\) MPa at \(1300\) m
  – Horizontal stress controlled by tectonic forces
    (builds stresses) & creep (relaxes stresses)
    – At depth, \(\sigma_v \approx \sigma_h\) unless there are active tectonic forces
Major Rock Features

• Examples
  – Geologic contacts
  – Joint swarms
  – Shears and faults

• Effects
  – Reduced rock quality
  – Reduced strength
  – Locus for rockburst / seismic activity
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Effect of Major Rock Features

[Diagram showing geological and structural features with annotations and measurements]

5% Stress Change

[Additional annotations and measurements related to geological stresses and rock mechanics]
Numerical Modeling

- Rock engineering equivalent of bridge or building structural analysis
- Develop understanding of the critical physical parameters
  - Rock characteristics
  - Rock stresses
  - Cavern shape
  - Rock support & reinforcement
- Common types
  - Continuum
  - Discontinuum
Simple example

- Continuum model FLAC 2D
- 60 x 60 x 180 meters (length not modeled)
- Curved roof & straight walls
- Depth 1300 meters
- Stresses ≈ depth
- Example rock properties
- Sequential excavation
- Rock reinforcement
- Model permits rock failure
Sequential excavation
Effect of Rock Strength

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Cablebolt Forces
Rock Mass Characterization

- **Stages**
  - Choose the best site
  - Find best location at the chosen site
  - Prove rock conditions at chosen location

- **Volume of rock necessary**

- **Technical objectives**
  - Provide design basis
  - Choose proper design and construction techniques
  - Reduce risk of differing site conditions
  - Basis for cost estimating
  - Basis for defining baseline, i.e. contractor bidding
## Access / Rock Removal

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<tr>
<th>DUSEL Site</th>
<th>Access / Rock Removal</th>
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<tbody>
<tr>
<td>Cascade</td>
<td>Horizontal access &amp; nearby railroad tunnel</td>
</tr>
<tr>
<td>Henderson mine</td>
<td>10-mile ore conveyor</td>
</tr>
<tr>
<td>Homestake mine</td>
<td>Existing shaft ore handling equipment</td>
</tr>
<tr>
<td>Kimballton</td>
<td>Inclined tunnel to surface</td>
</tr>
<tr>
<td>San Jacinto</td>
<td>Horizontal access</td>
</tr>
<tr>
<td>Soudan</td>
<td>Shaft</td>
</tr>
<tr>
<td>SNOLAB</td>
<td>Shaft &amp; underground use</td>
</tr>
<tr>
<td>WIPP</td>
<td>Shaft</td>
</tr>
</tbody>
</table>

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Conclusions about important features

• Depth / shielding capacity
  – All sites appear adequate

• Rock type / rock chemistry
  – All sites appear adequate, but salt at WIPP may be problematic (due to creep & solubility)

• Rock quality / In situ stress
  – All sites are potentially suitable, but none are guaranteed feasible

• Access / rock removal
  – All sites are potentially suitable, but horizontal access is beneficial
What is MOST important?

• Rock type / rock chemistry
  – Creep & solubility are the principal issues

• Rock quality / In situ stress
  – Commonly influences costs by a factor of 2 to 4, could make a site unfeasible

• Access / rock removal
  – Can influence costs significantly, but is very site dependent
Rock Engineering 101

• What are the implications for large cavern construction?
  – Find a site with excellent rock
  – Characterizing the rock mass is JOB ONE
  – Avoid tectonic zones & characterize in situ stresses
  – Select size, shape & orientation to minimize rock support, stress concentrations, etc.
• Soudan 2 & MINOS caverns
Cost & Risk vs. Site Investigation

- Upper Bound of Project Cost
- Lower Bound of Project Cost

Increased Site Investigation $ vs. Project Cost Range

Actual Cost

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Questions?
Concluding Remarks

• Is a megadetector feasible?  Qualified yes
• What are the qualifications?
  – Rock conditions & depth
    • Best location at the best site, not too deep
  – Enlightened funding agencies
    • Understand & manage the risks, cost uncertainties
  – Site factors
    • Rock removal, competing demands for resources
  – Contractor
    • Chosen on cost & qualifications