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The Deep Underground Science and Engineering Laboratory

Site Independent Study

The process
The science
Infrastructure requirements
The international context

6 Principal Investigators
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(Astrophysics and Cosmology)
Eugene Beier, U. of Pennsylvania
(Particle Physics)
Hamish Robertson, U. of Washington
(Nuclear Physics)
Charles Fairhurst, U. of Minnesota
(Geology and Engineering)
Tullis C. Onstott, Princeton
(Geomicrobiology)
James Tiedje, Michigan State
(Microbiology)

DUSEL Process

Solicitation 1: Community wide study of

- Scientific roadmap: from Nuclear/Particle/Astro Physics to Geo Physics/Chemistry/Microbiology/Engineering
- Generic infrastructure requirements
- Proposal supported by all 8 sites
  - Approved by NSF (January 05)
  - PI's went to Washington 28 February to 2 March to clarify goals and time scale

Kimballton
SNOlab
WIPP
Henderson Mine
Homestake
Soudan
San Jacinto
Cascades

Solicitation 2 : Preselection of ≈3 sites

- 8 proposals submitted February 28.
- Panel late April. Decisions public by late June

⇒Solicitation 3
⇒Selection of initial site(s)
⇒MRE and Presidential Budget (09) -> 2012-2015

See www.dusel.org

Solicitation 1 Organization

6 PI's responsible for the study

in particular scientific quality/ objectivity

14 working groups + Workshops

Infrastructure requirements/management
Education and outreach

2 consultation groups

- The site consultation group (Solicitation 2 sites)
  - Endorsement of the PI's and general approach
  - Input on scientific/technical questions important to the sites
  - Competition between sites
- The initiative coordination group: major stakeholders (e.g. National Labs)
  - Coordination with other major initiatives
  - Competition between these initiatives

⇒Interim report before the Sol 2 panel meets

⇒Report directed at OMB/OSTP/Congress

cf. Quantum Universe

+Web based reports with technical facts

External review à la NRC

Workshops

Berkeley Aug 4-7

Agree about methodology and finalize Solicitation 1 proposal
First exploration of scientific themes
Start of work on infrastructure requirements
Common language for solicitation 2

Blacksburg Nov 12-13

Focus on Earth Sciences (including Geo-microbiology) and Applications
More precise definition of scientific roadmaps and generic experiments

Boulder Jan 5-7:

Further develop the science argument for DUSEL
Focus on infrastructure requirements -> Modules
Place DUSEL in international context: most unique aspects
Launch work of the working groups

Working Groups/Sites: July 05

Finalize content of report, including difficult questions
First draft of report
Reviews

Rolling out workshop in Washington Early Fall 05

Originality of the process

Community-wide Site Independent: Science first!

Multidisciplinary from the start

- Not only physics. astrophysics but Earth sciences, biology, engineering
- Internal strategy inside NSF : interest many directorates ->MRE line
- NSF=lead agency but involvement of other agencies:DOE (HEP/Nuclear, Basic Sciences) , NASA (Astrobiology), NIH, USGS + industry

Flexibility

- This is an experimental science facility, not an observatory
- Specifically adaptive strategy to take into account
  - The evolution of science
  - International environment (available facilities -e.g. SNOLAB, MegaScience coord.)
  - Budgetary realities
- Excavate as we go ≠LN Gran Sasso
- Potentially multi-sites
  - Although some advantages of a single site in terms of technical infrastructure and visibility
    - not necessary provide we have a common management (multi-campus concept)
    - variety of rock type and geological history
    - closer to various universities (important for student involvement)
- Modules that can be deployed independently (in time or space)
  - Decoupling of large detector from deep science
  - ($1B-$2B)= mega-science decision taken outside the physics community (2010)

Major Questions in Physics

What are the properties of the neutrinos?

Are neutrinos their own antiparticle?

3rd generation of neutrinoless double beta decay. (1 ton)

key ingredient in the formulation of a new ``Standard Model'', and can only be obtained by the study of

What is the remaining, and presently unknown, parameters of the neutrino mass matrix?

θ_{13}

What is the hierarchy of masses?

Is there significant violation of the CP symmetry among the neutrinos?

Do protons decay?

The lifetime for proton decay is a hallmark of theories beyond the Standard Model. Strong dependence on theory may allow a spectacular discovery!

These questions relate immediately to

- the completion of our understanding of particle and nuclear physics
- the mystery of matter-antimatter asymmetry

Surprises very likely!

Major Questions in Astrophysics

What is the nature of the dark matter in the universe?

Is it comprised of weakly interacting massive particles (WIMPs) of a type not presently known, but predicted by theories such as Supersymmetry?

.

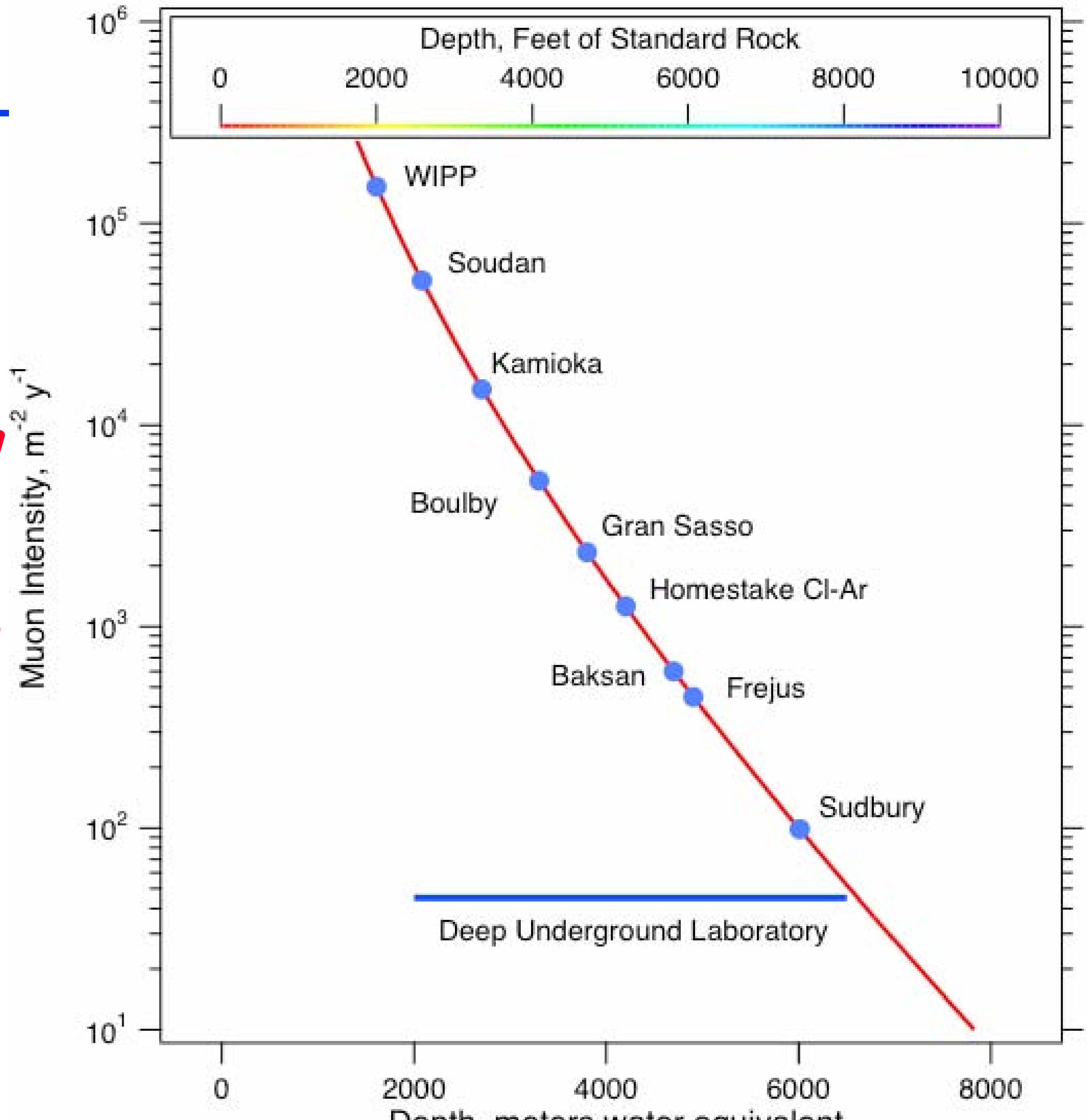
What is the low-energy spectrum of neutrinos from the sun?

Solar neutrinos have been important in providing new information not only about the sun but also about the fundamental properties of neutrinos.

+ Important by-products

- Neutrinos from Supernovae: Long term enterprise for galactic SN!
- Underground accelerator (cf. Luna)
  -> Nuclear cross sections important for astrophysics and cosmology

Rare process Physics needs low cosmic-ray rates



Geoscience: The Ever Changing Earth

Processes taking place in fractured rock masses

- Dependence on the physical dimensions and time scale involved.
- *in situ* investigation of the Hydro-Thermal-Mechanical-Chemical-Biological (HTBCB) interactions at work:
  - through observations not possible from the surface
  - experimentation where we act directly on the rock.
- This understanding is critical for a number of problems of great scientific and societal importance
  - ground water flow
  - transport of foreign substances
  - energetic slip on faults and fractures.

Approach the conditions prevalent in the regions where earthquakes naturally occur

help us answer questions such as

- What are the detailed processes involved in the Earth crust and tectonic plates motions?
- What controls the onset and propagation of seismic slip on a fault?
- Can earthquake slips be predicted and how can they be controlled?

Requires A deep laboratory, with long term access

Which rock? Initially any kind would be interesting
Eventually igneous and sedimentary (+salt)

Subsurface Engineering

Mastery of the rock

What are the limits to large excavations at depth?

- petroleum boreholes: 10km Ø 10cm
- deepest mine shafts: 4km Ø 5m
- DUSEL experimental areas: 10-60m at a depth between 1 and 3km

Much experience will be gained through the instrumentation and long term monitoring of such cavities

Technologies to modify characteristics e.g. in order to improve recovery

go beyond hydrofracture, role of biotechnologies

Transparent Earth

Can progress in geophysical sensing and computing methods be applied to make the earth "transparent", i.e. to "see" real time processes ?

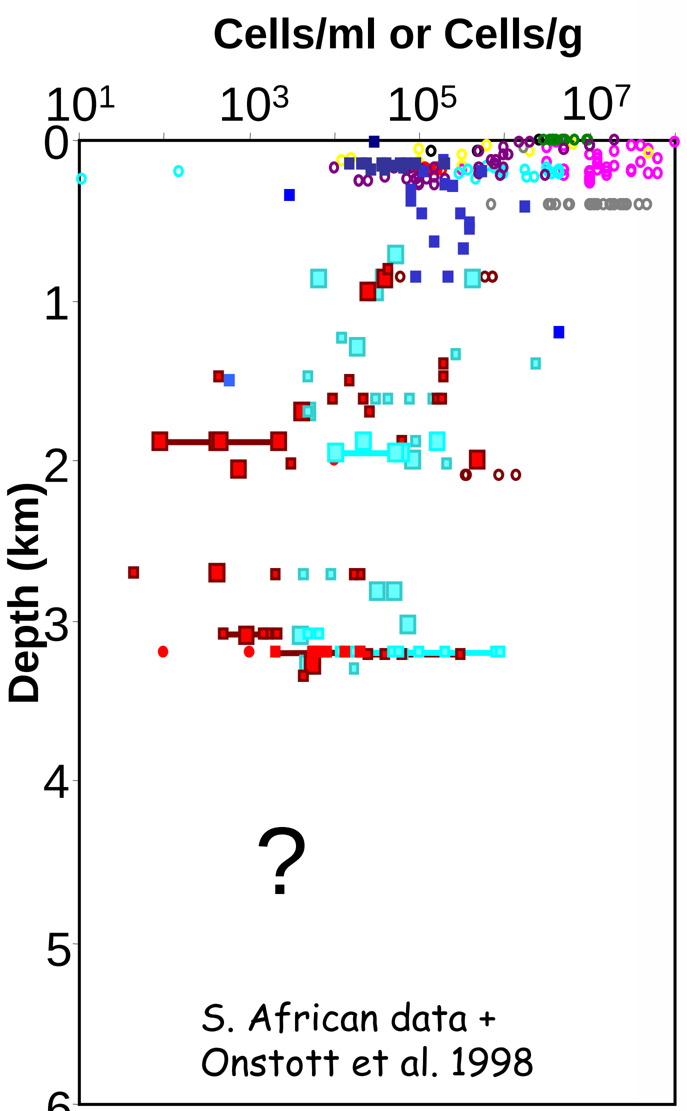
Remote sensing methods tested/calibrated by mining back

In particular, relationship between surface measurements and subsurface deformations and stresses: important for study of the solid Earth

Great societal impact

- Large underground constructions
- Groundwater flow,
- Ore /oil recovery methods and mining/boring technology
- Contaminant transport
- Long-term isolation of hazardous and toxic wastes
- Carbon sequestration and hydrocarbon storage underground (sedimentary rock)

A recent breakthrough



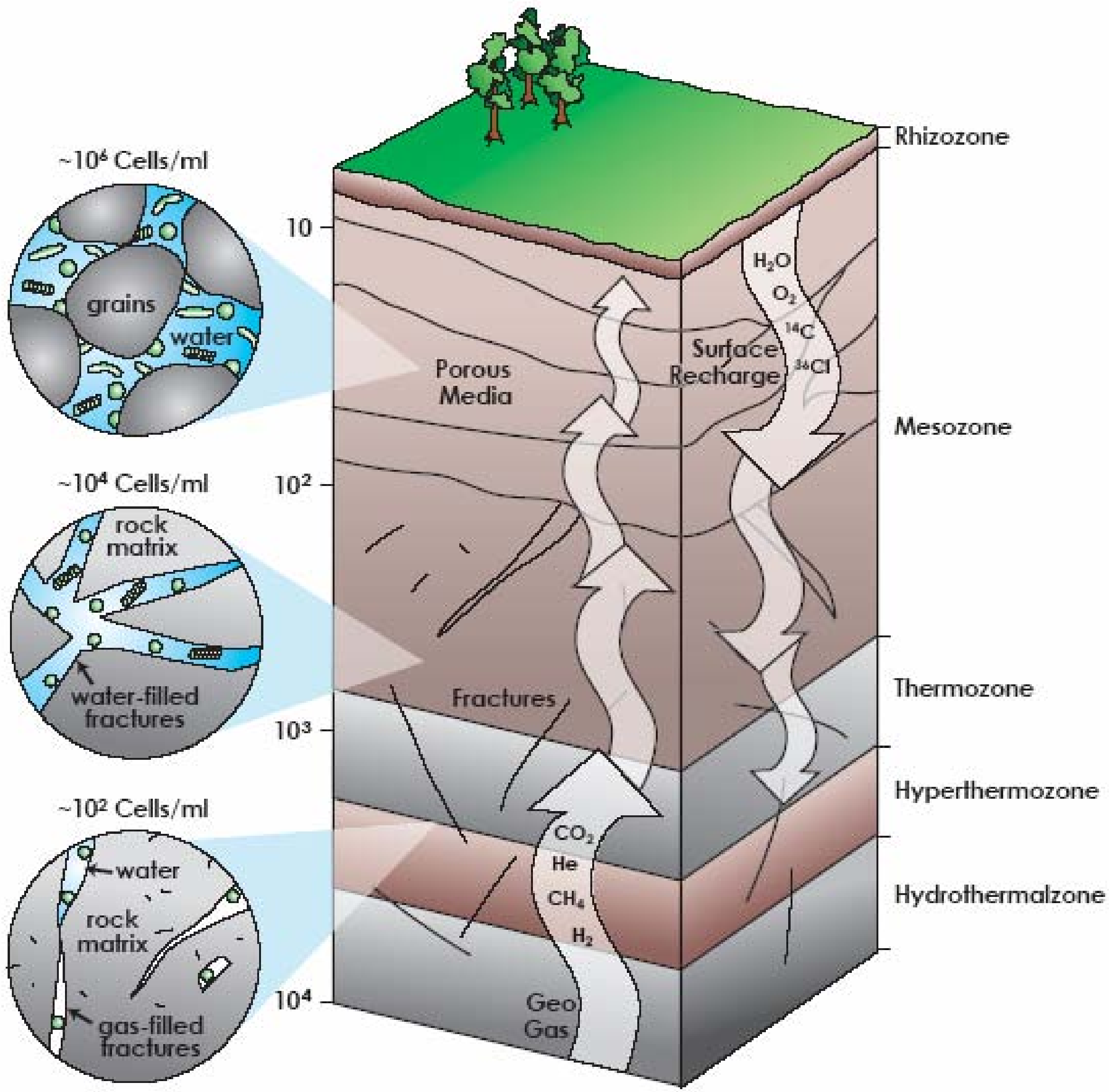


Fig. 2 of Earthlab report

Major Questions in Geomicrobiology

How does the interplay between biology and geology shape the subsurface?

Role of microbes in HTMCB

e.g. dissolution/secretions which may modify slipage or permeability

What fuels the deep biosphere?

Independent from photosynthesis?

Dependence upon geochemically generated energy sources ("geogas": H_2, CH_4, etc.).

How do such systems function, their members interact to sustain a livelihood in a hostile environment?

How deeply does life extend into the Earth?

What are the lower limit of the biosphere, imposed by temperature, pressure and energy restrictions?

=> What fraction does subsurface life represents in the biosphere?

Need for long term access as deep as possible

Current technology requires horizontal probes (negative pressure to minimize contamination)

Long term *in situ* observation and access to the walls

Deeper bores with remote observation modules

Major Questions in Biology

What can we learn on evolution and genomics?

- Isolated from the surface gene pool for very long periods of time.
- Does the deep subsurface harbor primitive life processes today?
- How different are they from microbes on the surface? A reservoir for unexpected and biotechnologically useful enzymes? Potential biotechnology and pharmaceutical applications!
- How do these microbes evolve with very low population density, extremely low metabolism rate and high longevity, no predators? Phage?

The role of the underground in the life cycle

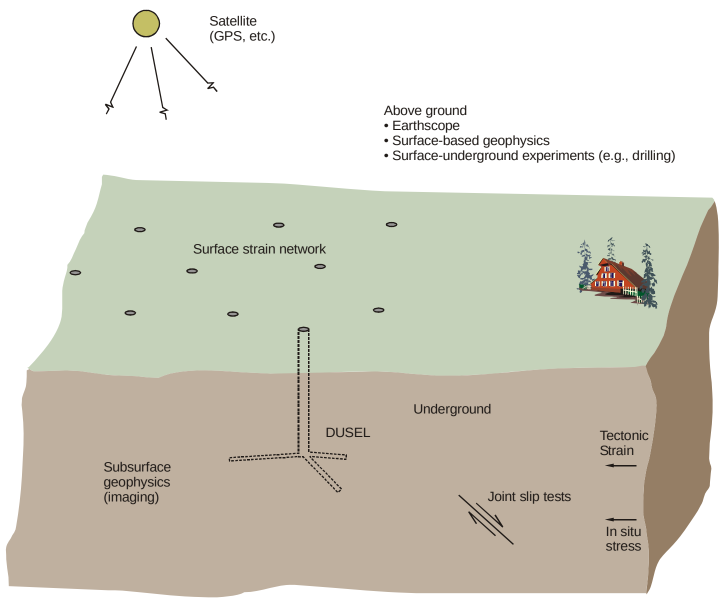
- Did life on the earth's surface come from underground?
- Can has the subsurface acted as refuge during extinctions.
- What signs of subsurface life should we search for on Mars?

Is there dark life as we don't know it?

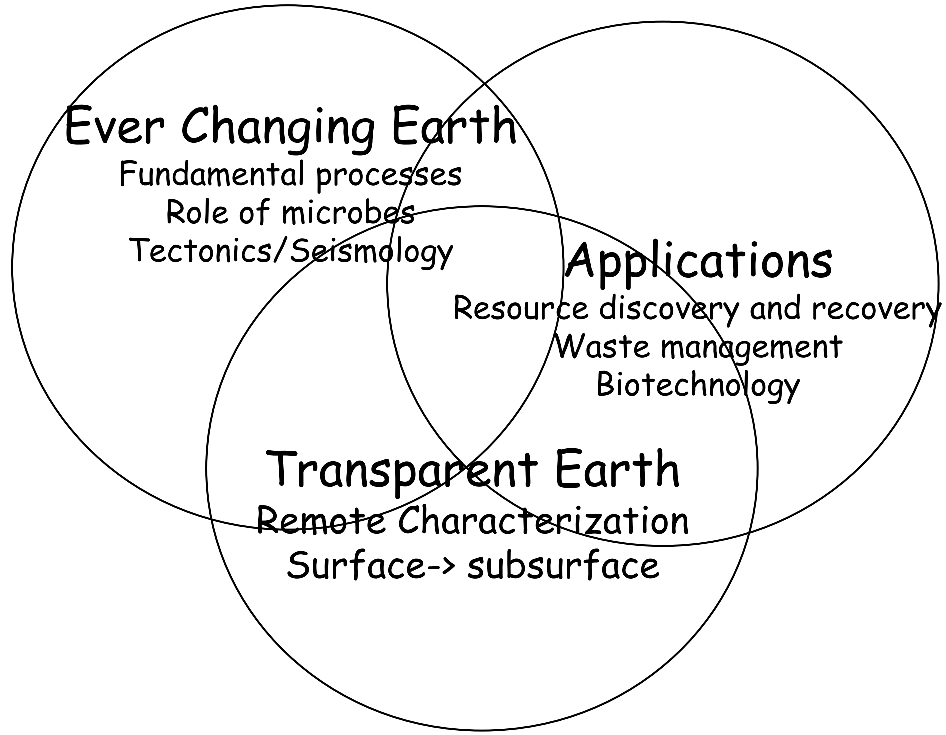
- Does unique biochemistry, e.g. non-nucleic acid based, and molecular signatures exist in isolated subsurface niches?

Same requirements as geomicrobiology
+ sequencing and DNA/protein synthetic facilities

Science-Methods-Applications



Correlation of above-ground and underground observations



Overlap is testimony of the richness of the field

Opportunity for multiple advocacy

NSF-DOE- Congress - Industry
Experts-other scientists- Public at large

Preliminary Modules

1. Very Deep: ≥6000 mwe (meters water equivalent, about the same as feet of rock):

- Double beta decay
- Solar neutrinos
- Dark matter detectors (may be 4000 mwe)
- Determine processes controlling maximum depth of subsurface biosphere and perhaps discover life not as we know it.
- Access to high ambient temperature and stress for *in situ* HTCMB experiments (as close to the seismogenic zone as possible)

UNIQUE **(apart possibly for SNOlab. See later)**

2. Intermediate depths : automatic!

- Some solar neutrinos
- Radioactive screening/prototyping
- Fabrication+ Assembly area
- Monitor and relate surface deformations and stresses to their subsurface counterparts.
- Education and outreach observation area

Answers require DUSEL (2)

3. Very Large Caverns (1Mm^3) at >2000-4000 mwe

- Proton decay
- Long-baseline neutrino physics (θ_{13}, masses, CP)

Current U.S. concept: superbeam with facility ≥ 1000-1500 km from source. However, possible rapid evolution (e.g. new beta beam idea)

- 3D +time monitoring of deformation at space and time scale intermediate between bench-tops and tectonic plates.

Approach: Maximize the rare physics impact while keeping within reasonable cost and risk.

Incentive to be deeper that Super-K

4. Very Large Block Experiments: (1Mm^3) spanning the whole depth range

- HTCMB experiments under in situ conditions in pristine environment over multiple correlation lengths with mass and energy balance.
- 'See' real-time interaction of HTCMB processes using geophysical and computational advances and mine-back to validate imaging.
- Perform sequestration studies and observe interaction with surface bio-, hydro- and atmosphere

+ common space on surface and underground

International Aspects

International Science and Engineering !

- Not only in physics and astronomy
- But also: geo sciences

(relationships with Underground Research Laboratories)

geo-microbiology is a new frontier

How to coordinate internationally to make full use of existing and planned facilities?

- Maximize the science
- Diversify instead of duplicating facilities
- We need coordination mechanisms: PANAGIC subgroup?
- We also need a reliable world wide estimation of the evolution of the demand
  - Not just a sum of the dreams
  - Evolution of the science, the community and the funding
  - How do we take into account the unexpected?

  This happened in the past with the search for proton decay and geo-microbiology!

  New facilities often unveil surprises-> new emphasis: Neutrino astronomy

The US DUSEL site independent study will attempt to start this evaluation

=>confirm (or put in perspective) the feeling of the underground community that the demand will not be met by existing facilities, because of depth, size, available space and access flexibility?

We welcome international help!

International Aspects (2)

While being fully and reliably involved in international partnerships, the U.S. naturally wants to maximize its long term competitive position.

Strategic advantage of a U.S. DUSEL

- A premier facility on U.S. soil will
  - more readily put U.S. teams at core of major projects (cf Solar Neutrinos)
  - attract the most exciting projects
  - maximize impact on training of scientists and engineers + public
- DUSEL complementary to other major U.S. initiatives
  - e.g. Earth-Scope, Secure Earth, Ocean Deep Drilling, NEON (biosphere)
- An existing underground laboratory could be a major asset in competition for proton decay/neutrino detector

What about SNOlab?

- Clearly important for the U.S. and international community in the medium range: only very deep site

  Frejus (possible extension) and Baksan also very useful at factor 50 worse μ flux
- The INCO mining company is very cooperative. Unclear however
  - Extension capability (one of the solicitation 2 proposals)
  - Difficulties with requirement of 24h-7d access, large mass cryogens?
  - Long term guaranteed access
  - Freedom of enquiry in geophysics and geobiology
- What is the overall demand?

Conclusions

A very interesting process

- Science first!
- Mutual discoveries of several communities
- Emergence of an exciting set of roadmaps

Still difficult questions

Realistic estimation of the demand
How to take into account the unexpected?
How to balance international partnerships and national interest?

Hopefully will help all efforts in the world

to equip ourselves with a complete set of underground facilities

Still a lot of work in front of us

Site Independent Goals

The best scientific case for DUSEL

The big questions
Roadmaps of class A+ experiments
Long term needs

Implementation parameters

Infrastructure requirements
⇒ Modules (set of experiments sharing same infrastructure needs)
Generic management structure
Integration of science and education and involvement of local population

International context

Place DUSEL in international context
Estimation of the space needs for next three decades
Identify strategic aspects of a U.S. facility

Deliverables by fall 05

Printed report directed at generalists

Agencies
OMB/OSTP/Congress cf. Quantum Universe

+Web based reports with technical facts

for scientists and programs monitors