Table of Geobiology and Geoscience Questions/Experiments from S-1 and their feasibility in DUSEL-Cascades.

Part A. Geobiology Science Questions.

S-1 Geobiology Science Questions	Rating#	Location in facility (refers to design in proposal)	Comments
How deeply does life extend into the Earth?	***	Drilling Bay #1, Stage II & Stage III. Sample processing in drilling Bay #2 or Stage II Geolab.	Deep boreholes from Stage II or Stage III are workable. Significant probability of encountering higher geothermal gradient at depth. Colonization of once sterile system?
What fuels the deep biosphere?	***	Successively in Stages I, II, & III with short, angled drilling when fractures encountered. Processing in Geolab.	Ideal site due to convergent margin location and possibility of higher geogas flux.
How does the interplay between biology and geology shape the subsurface?	**	Largely accomplished in Stage I during excavation. Opportunistic in Stages II and III.	Biological impact on fracture surfaces and shear zones possibly significant.
What are subsurface genomes telling us?	***	In all Stages, including drilling and sampling from the surface. Sample processing in Geolab or in surface facilities.	Fluids in fractures in deeper parts of Mt Stuart Batholith may have been isolated for ~50Ma. Anticipate simple, unique community genomes.

Did life on the earth's surface originate underground?	*	Stage II angle drilling to encounter wall rocks with higher permeability (Drilling Bay #I).	Originally sterile environment may enable evaluation of microbial transport and survival
Is there life in the subsurface as we don't know it?	**	Stage II Drilling Bay #1 or 2, horizontal drilling to compare low vs. highest permeability zones.	Conventionally oligotrophic environment of a granitic batholith is potentially a good place to look.

Rating of feasibility of addressing question in DUSEL-Cascades. 3 stars: highest rating, DUSEL Cascades site fully answers scientific question. 2 stars: Question can be addressed in DUSEL Cascades but with some limitations. 1 star: Question can be addressed but with significant limitations.

Part B. S-1 Geo-Science and Geo-Engineering Research Recommendations.

S-1 Geo-Science and Geo-Engineering Document Section	Rating[#]	Location in facility (refers to design in proposal)	Comments
5.1.1 Surface and Near-Field Geophysics	***	Stage I, Stage II, Stage III. Multiple locations operated out of Geolab, Stage I.	Excellent surface access. Length of Pioneer Tunnel offers linear sensor distribution. Focus on fracture properties
5.1.2 Borehole Geophysics	***	Key location between Stage I and Stage II; Stage II and Stage III. All deep boreholes and "look ahead holes for all excavations. Data recording at Geolab Stage I.	Detection of chemical and physical impacts along fractures or contacts high scientific value
5.1.3 Regional Geophysics, Seismic Arrays	***	Stage I Entire Facility plus special to-be-designed tunnel or borehole for extending aperture. Stage II and III developed based on Stage I results.	Initial array set up for monitoring slow earthquakes on the Cascadia Subduction Zone.
5.1.3 Regional Geophysics, Electromagnetic Soundings	***	Large-scale vertical loop antennae would be constructed between Stages I and II or in a surface to Stage I borehole.	Potential to detect crustal structure of the Cascadia Subduction Zone. Closely coupled with slow earthquake detection
5.1.4 Geophysical Proxy Methods in General	***	Stress measurement throughout the facility, continuously monitored and recorded; Similar approach to conventional EM soundings	Linkage of stress measurement/EM soundings to near-surface hydrologic observations such as moisture content or snow pack.
5.1.5 Geophysics and Safety	***	Application of data collected as part of 5.1.X above to enhance safety throughout the facility	DUSEL will enable more routine application of geophysics to underground structure safety

5.2.1 Coupled Processes: Microbial life, Heat flow, Rock deformation, Reactive chemistry, Engineering in the subsurface	***	The site is highly amenable to coupled process experiments in which a perturbtion is introduced into the rock mass (e.g. stimulation of microbial growth by addition of an electron donor) and response of coupled parameters observed.	The relatively uniform nature of the Mount Stuart Batholith locally, provides an ideal host for these types of experiments because rock-mass heterogeneity is limited.
5.2.1 Coupled Processes: Oil and Gas Flow and Transport Processes, Natural gas storage		Not applicable to DUSEL-Cascades	Fractured crystalline rock is largely inappropriate for study of petroleum migration and accumulation.
5.2.1 Coupled Processes: Fractured rock and fluids	***	Coupled processes involving fractured rock and fluids would be studied in an extension off the Geolab, Stage I. Subsequent experiments in Stage II would be based on results from Stage I.	DUSEL-Cascades is ideally suited to answer the questions posed in 5.2.1 relating to fracture geometry, transport properties, scaling, solute transport, stress pressure, T coupling, chemical reaction/particles, multiple fluid phases, and natural transients.
5.2.2 Geochemistry: Isotopic Geochemistry, Radiogenic Isotopic Studies, Environmental Geochemistry and Mineralogy, Importance of Colloidal Element Transport	***	Long and short-term experiments could be done in a variety of configurations adjacent to the Stage I Geolab, between planned rooms in Stage I and between Stage I and Stage II or Stage II and Stage III.	Colloidal transport experiments would be particularly effective and could be done in conjunction with hydrology tracer and flow tests. Radiogenic isotope studies could be synergistically linked to geobiology sampling.

5.2.2 Geochemistry: Sulfide Weathering, Sulfur Isotopic Studies, and Acid Mine Drainage.	*	Limited applicability at DUSEL-Cascades. Proposed S-1 studies would be done on samples collected throughout the facility.	Sulfide weathering and sulfur isotopic studies could be done on small amounts of sulfide present in the Mount Stuart granitic rocks. No acid mine drainage is present at DUSEL-Cascades.
5.2.3 Regional and Ore Deposit Geology	***	The proposed digital mine mapping and information technology approach would be performed throughout the facility and closely linked to, experiments, room use, and deformation studies.	DUSEL-Cascades will collaborate closely with active mining districts in the Idaho Panhandle to ensure an effective real-world outlet for trained personnel and new mine mapping technology.
5.2.4 Groundwater Research at DUSEL: Groundwater Recharge, Groundwater Storage and Aquifer Sustainability, Paleohydrology, Deep Fractures, Flow in Deep Fractures, Contaminant Cleanup, Fundamental Scale Effects, Well Testing Verification.	***	Groundwater research will be fully integrated into the construction and operation of DUSEL-Cascades. All facets of 5.2.5 research can be performed at DUSEL-Cascades in a fractured-rock medium. Recharge from the surface to Stage I depths, fundamental scale effects, and flow in deep fractures between Stage I and Stage II are particularly productive experiments.	Contaminant clean up studies would be limited to benign surrogates for contaminant compounds.
5.2.5 Mechanics of Rock Mass Deformation: Dynamic Slip on a Stressed Fault	***	To enable the dynamic slip experiment at DUSEL-Cascades, we would perform such an experiment on a large joint system, or small fault initially to ensure that ground accelerations generated would not adversely impact the	However, we propose horizontal drilling toward the batholith margin to find an appropriate fault or joint system. The Chiwakum Schist is

		facility and other on-going experiments. Location of an appropriate a joint system is not currently known.	closer to Stage II rooms than Stage I, so this experiment may be more efficiently performed as part of Stage I.
5.2.5 Mechanics of Rock Mass Deformation: In-Situ Stress Distribution in Heterogeneous Rock	***	Heterogeneities in the Mount Stuart Batholith occur predominantly as variations in fracture abundance and orientation. This experiment could be done efficiently as part of the excavation of Stage I Geolab or other room and extended based on value of initial results.	The focus on stress variations associated with fracture properties in otherwise reasonably uniform rock will simplify interpretation.
Engineering the Earth ***5.3.1 Dynamic Phenomena***	***	Rock response to blasting and other excavation processes will be monitored throughout the facility.	
5.3.2 Design of Large Underground Cavities at Depth	***	The rock quality at DUSEL-Cascades provided an exceptional opportunity for successful design, excavation, and operation of very large underground cavities such as would be needed for UNO. Proposed depth is same as Stage I.	The uniform nature of granitic materials the Mount Stuart Batholith provides for optimal information on fracture behavior and minimal cost for large a structure. Implementation of the proposed design in figure 11 is highly feasible.
5.3.3 Recovery of Hydrocarbons and Geothermal Energy	*	Granitic rocks of the Mount Stuart Batholith are inappropriate for hydrocarbon production experiments. However, geothermal energy experiments involving extraction of heat from hydrofracture-enhanced rocks are ideal. Such experiments would be done adjacent to the Geolab in Stage I or II and	The nature of fractures in otherwise homogeneous granitic rock provides an ideal test bed for geothermal energy recovery experiments.

		could be linked to other experiments such as tracer experiments and dynamic slip on a stressed fault.	
6.0 EXAMPLES OF GEOSCIENCE AND GEOENGINEERING EXPERIMENTS AT DUSEL			
6.1 Characterization Experiments — "Unperturbed" Block (Fracture Detection and Mechanical Hydro/Chemical Coupling)	***	Envisioned size of 10X10X10 meters would be performed adjacent to the Geolab (Stage I) and at similar locations for Stage II (and Stage III if scientific questions remained). Stage II and III offer the opportunity to include metamorphic rock schist).	This experiment combines multiple experiments described above. See for example, 5.2.2. Focus would be on fractured crystalline rock and systems.
6.2 Experiments on Stress Determination, its Variability over Scale of 10 ~100 m and Correlation with Structure.	***	This experiment could be performed throughout the facility, closely coupled to facility construction. An early opportunity to do this experiment including both granite and schist would be to perform it across the contact between schist and granite in side alcove or tunnels.	Correlation with structure associated with the granite-schist contact could also be performed at greater depth in Stages II and III.
6.3 A Perturbed Block (Pillar) Experiment to Study the Failure of Rock	***	This experiment could be efficiently performed during destructive examination of the large block in 6.1. Alternatively, smaller scale experiments could be performed during room excavation.	Slowing of excavation of a room would be necessary if this experiment was performed during construction.
6.4 Mechanics of Fracture Growth and Scale Effects in Rock Fracturing	***	Rock fracturing experiments could be done at progressive depths during construction at all three stages, including hydrofracture between Stage I and Stage II followed by examination during shaft excavation. Experiments would include In situ Stress Characterization, Fracture Propagation Experiments, Fracture Network Experiments, and Pressure-Displacement	Performing these experiments at small scale can be done prior to and as part of room excavation. These experiments will be fully integrated the experiments described earlier in this table and below (6.6).

		Coupling Experiments.	
6.5 Experiments in Very Deep Boreholes	***	Very deep boreholes would be drilled from Stage II or Stage III. A minimum of two drilling bays (Drilling Bay #1 and #2) are planned for Stage II.	All research conducted in Very Deep Boreholes will be carefully coordinated to maximize scientific return for investment. For example, once deep microbiology sampling and experiments are completed at depth, hydrofracturing experiments could be performed in the same borehole
6.6 Experiments during Construction	***	Experiments directly related to tunnel and room construction including, Scale Effects in Tunnel Stability, Explosives and Blasting Research, and Mechanical Excavation of Tunnels will be fully integrated into DUSEL-Cascades. We plan a base level, standard set of geoscience and geobiology data to be collected during construction. This data collection will be designed to have minimal impact on construction while obtaining the optimal amount of scientific and engineering information available only from newly mined openings.	As noted above, some specific DUSEL-Cascades Geoscience experiments the planned base-level information can be done as part of construction. This will require careful planning to minimize impacts to construction schedule. Explicit trade off's will be needed to ensure that any construction delays are justified by the value of scientific results.
Geoscience Research Specific to the DUSEL-Cascades Location and Geology			
Detection and analysis of slow earthquakes on the Cascadia Subduction Zone.	***	The location of DUSEL-Cascades above the Cascadia subduction zone means that the facility is uniquely situated to address slow earthquakes (low	This experiment will be a long-term monitoring project in which an orthogonal seismic

		frequency non-volcanic tremor) associated with "aseismic" slip on the down-dip portion of the subduction zone.	array is constructed underground to maximize the detection of slow earthquakes.
Direct testing of hypotheses regarding crustal sections for the Cordilleran accretionary complex.	***	Bob Miller, Scott Paterson, Lawford Anderson and others have develop crustal sections for the Cascades Core Complex. Deep drilling from DUSEL-Cascades for geobiology will enable direct evaluation testing of these crustal sections.	Results will help resolve key questions about the accretionary tectonic history of western North America.
Mountain hydrology	***	The topography of the DUSEL-Cascades Site provides opportunity to assess surface-to-depth hydrology (see section 4.2.4 above) in a mountainous region.	Currently hydrologic flow lines and fluxes in mountainous terrane is poorly understood. DUSEL-Cascade will include special monitoring approaches to address recharge and subsurface flow in such environments.

Rating of feasibility of addressing research recommentation in DUSEL-Cascades. 3 stars: highest rating, DUSEL Cascades site can fully address the recommendation. 2 stars: recommendation can be addressed in DUSEL-Cascades but with some limitations. 1 star: Question can be addressed but with significant limitations. No star: Research Recommendation cannot be addressed in DUSEL-Cascades, usually because of rock-type.