Crust and Lithosphere

• Our Charge
  – description of scientific problems
  – importance for broader society
  – importance of the topics within Earth and other sciences
  – existing and required resources for fundamental advancements
Crust and Lithosphere

• The Overriding Theme
  – Stewardship of Earth by Assessing Hazards, Discovering Resources, and Understanding Continental Evolution
Problem 1) The Role of Fluids in Earth Processes

- **Key questions:**
  - What is the fluid cycle of the Earth at all scales?
  - How do we know fluid is there?
  - How do seismic waves propagate in multiphase materials?
  - How does fluid relate to the spectrum of deformation (earthquakes, ETS, creep, etc.)?
  - What is the magma plumbing system and how does it evolve?
  - How do fluids respond to tectonic processes?
Problem 1) The Role of Fluids in Earth Processes

• *Societal Impact*
  – Monitoring groundwater resources (3-D and 4-D)
  – Petroleum resource exploration (improving methods to promote/enhance hydrocarbon extraction)
  – Carbon sequestration
  – Geothermal energy and connections to magma migration
  – Volcanic hazards (differentiating between explosive and non explosive eruptive systems by examining plumbing structure and composition)
Problem 2) Understanding the Earthquake Cycle

- **Key questions**
  - How do tectonic and other Earth processes influence the earthquake cycle?
  - What is different for intraplate earthquakes?
  - What happens right before an earthquake?
  - What are the temporal variations in Earth structure that relate to seismogenesis?
Problem 2) Understanding the Earthquake Cycle

• *Societal Impact*
  – Temporal monitoring of earthquake hazards to move towards forecasting
  – Assessing potential sites for nuclear power
Problem 3) Linking Rheology, Deformation and Tectonics

- *Key questions:*
  - What is the structure of faults systems (particularly the deep part)?
  - How do fault systems evolve over short and long time scales?
  - Where is the deformation, either seismic or aseismic, now and in the past?
Problem 3) Linking Rheology, Deformation and Tectonics

• Key questions:
  – What is the nature of the lithosphere-asthenosphere boundary and how does it evolve through time?
  – What is the rheology of middle and lower crust and how variable is it?
  – What is the coupling of plate motions with mantle flow?
Problem 3) Linking Rheology, Deformation and Tectonics

- **Societal Impact**
  - Earthquake hazards
  - Better understanding of landscape evolution
Problem 4) Evolution of Continents

- **Key questions:**
  - How do continents grow?
  - How is the crust and lithosphere created and destroyed?
  - What is the nature of the continental crust mantle boundary and how does it evolve through time?
  - What causes mountain uplift?
  - What are the earth processes that cause resources and mineral deposits?
Problem 4) Evolution of Continents

• Societal Impact
  – Exploration for ore deposits
  – Societal wonder about what created the material they live on
  – Help people to discover the subsurface the way they now investigate the surface via google earth
Additional Problems

• We need to determine or estimate a 3D earth model to deterministically predict path effects on ground motions to high enough fidelity for engineered structures and for precise nuclear monitoring.

• To better characterize normal and anomalous in the Earth’s crust, we need more uniform mapping of its structure.

• Seismology can lead the transition from providing technologies for exploration of nonrenewable resources to technologies for exploration of cleaner energy sources.
Importance to Earth and other sciences

- *Earth and other sciences:*
  - hydrology
  - economic geology
  - volcanology, geochemistry, petrology
  - tectonics and structural geology
  - mineral physics
  - rock mechanics
  - fluid mechanics
  - structural engineering
  - biology at depth
Importance to Earth and other sciences

• *Importance:*
  – In situ measurements of physical properties in difficult or impossible to access parts of the Earth
  – Surficial geologic techniques tell us about area, 3-D velocity structure can tell us about volumetric distribution
  – 4-D examinations of how Earth structure evolves over time is needed to better connect it to the broader spectrum of Earth processes
Existing and Needed Resources

- **Data Recording**
  - More: sensors, coverage, channels
  - Cheaper seismometers/OBS/arrays
  - All receivers should be (at least) 3 component
  - Hybrid passive/active surveys (4D results)
  - The “Perfect” seismometer: Zero mass, zero power, infinite band, real-time telemetry, biodegradable
  - Integrated sensor observatories (seismometer, strainmeter, tiltmeter, barometer, ect.)
  - Applications to planetary seismology
Existing and Needed Resources

• Datasets
  – Database and dataset preservation from industry and other sources (i.e., industry data mining)
  – Model standards, not just common data formats
  – Balance between active and passive techniques

• Alternatives to traditional seismometry
  – Space-based (i.e., INSAR)
  – Ground and near ground-based (i.e., laser-based, radar-based, optical interferometry)
Existing and Needed Resources

• *Improved analysis methods*
  – Complete 3D wave methods
  – Multiple scattering approaches
  – Bridging the gap between region and global modeling
  – Integration of very different datasets
Existing and Needed Resources

- **Facilities**
  - Databases (storage, integration, interpretation; quicker access)
  - Source facility (to complement receiver facility)
  - Computing (e.g., full wavefield analyses)
Existing and Needed Resources

• **Education and Collaboration**
  – Training future generations for stewardship of Earth
  – Deeper connections with elementary/junior high/high school sciences
  – University-industry partnerships
  – Enhanced international collaborations
Existing and Needed Resources

• **Funding**
  – Need to generate new funding models with non-traditional partnerships
  – Federal (NSF, DoD, DoE, FEMA, NASA)
  – Industry (natural resources)
  – Foundations