Stress, Strain, and Rheology

1. What is the state of stress on active faults and how does it vary in space and time?

    - Stress transfer due to quasi-static elastic vs dynamic elastic, viscoelastic, poroelastic and …
    - How do mantle convection processes load lithospheric faults?

2. Are the observed stochastic characteristics (GR, Omori, Bath, etc.) of earthquakes due to material/geometric heterogeneity or to non-linear dynamics?
    - geologically inherited structure, such as fault roughness, preserved fluids, non-planar fault geometry?

3. What are the constitutive laws of faults and surrounding crust that give rise to observed behavior including slow and fast slip?
    - Role of pore-fluids and thermal weakening processes.

4. What is the rheology of the crust and mantle, and how do fault systems evolve with time?
    - How are new faults initiated, how do fault systems evolve, ho are faults reactivated?
    - What determines the interplay between localized and distributed, "off-fault" deformation?

5. Can we develop comprehensive models of strain accumulation consistent with geodesy, paleoseismology, laboratory constraints c rheology, and long term evolution of landforms?
    - What are the loading processes for intraplate earthquakes?
    - How does strain partitioning into different fault types depend c loading and rheology?

NSF Long Range Science Plan for Seismology

Science integration bullets

1. Imaging the state of stress, monitoring the loading of fault and volcanic systems, and finding a physical, quantitative description of fault system behavior
2. Understanding the rheological transition between brittle and ductile deformation in the context of how mantle convection couples into catastrophic deformation processes in fault and volcanic systems (the process of strain localization).

Key figures

1. Ambient noise based, transient fault monitoring work (before/after Parkfield)
2. Fault scarp -> fault surface -> zoom in picture on small scale
3. Strain accumulation map (based on PBO?)
4. Comparison of hazard, seismicity, and strain-rate maps
5. Geodetic flow around Tibet
6. Coulomb stress figure from Chino 2008 event
7. Dynamically triggered earthquake figure
8. ETS and GPS correlation
9. Laterally variable stress drop plots from Peter Shearer
10. Post-seismic transients in Mexico

Science questions

6. **Stress.** What is the state of stress on active faults and how does it vary in space and time, and how does it relate to geologically inherited structure, such as fault roughness, preserved fluids, geometry? Are there differences in stress drop depending, e.g., on faulting mechanism or other observables? What are the agents of stress transfer: dynamic or static elastic, volcanic, mantle flow? What is the role of laterally varying tractions due to mantle flow on fault loading? Are the observed stochastic characteristics (GR, Omori, Bath, etc.) of earthquakes due to material/geometric heterogeneity or to non-linear dynamics?

7. **Short-term rheology**. What are the constitutive laws of faults that give rise to slow and fast slip? How are constitutive, e.g. friction, laws affected by temperature and fluids, throughout the seismic cycle? What is the role of effective stress, what is the permeability of the lithosphere, and how does it evolve with time? How are new fault systems initiated, how do fault systems propagate, how

are old ones reactivated, and systems abandoned? What determines the interplay between localized and distributed, “off-fault” deformation?

8.
9. **Long-term rheology**. What is the time-dependent rheology of the crust and mantle, and how do fault systems evolve with time? What is the downward continuation of strain localization in fault systems? How can rheology be inferred from field and lab observations, including seismic signals (e.g. Moho depth, anisotropy, vP/vS, seismicity) when embedded in geodynamic modeling? (Notes: For upper mantle group: Upper and deep mantle temperature/composition imaging and inferences on rheology. Lithosphere-asthenosphere boundary, plate driving forces. For deep mantle group: What is the dynamically relevant viscosity of the outer core?)
10.
11. **Interaction models**. Can we develop universally viable models of strain accumulation consistent with geodesy, paleoseismology, laboratory constraints on rheology, and long term evolution of landforms? What are the loading processes for intraplate earthquakes, and how does strain partitioning into different fault types depend on loading and rheology?

How to solve these questions? New, modified deployments and instrumentation (for sidebar)

1. **Rapid post event** response drilling close to fault zones to understand friction and in-situ stress. Time-dependent hydro-frac monitoring close to a fault zone (SAFOD)?
2. **Baseline** Better strategies to implement integration and synthesis of diverse observations for a time-dependent description of crustal strain accumulation, such as the PBO strain-meter, seismic, drill hole, and geodetic data streams.
3. New offshore deployments (e.g. OBS, pressure sensors, seafloor geodesy) for seafloor-based monitoring of plate boundaries.
4. Support of regional, problem-centered collaborations on natural laboratories
5. More remote imaging (e.g. noise tomography, better focal mechanism inversions) of time-variable fault strength and ambient stress.
6. More strainmeters

Strain

- Interseismic strain accumulation
- Development of models for interseismic strain accumulation, particularly models that account for long-term (10ka) deformation of brittle crust.
- Transient strain and tilt, borehole and long baseline
- Understanding the causes of transient strain; processes other than transient slip on faults,
- What controls slow slip (vs fast earthquake slip).
- Paleoseismic constraints.
- anisotropy

Rheology

- Laboratory experiments vs field inferences
- Ductile rheology of lower crust and mantle
- Rheology of brittle crust (distributed); how do faults evolve to account for geometric mismatches, new faults form.
- Rheology of faults (friction laws) under all relevant conditions, materials, and rates.
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Stress

(Perhaps can characterize in terms of absolute stress vs stress changes)

- In-situ stress and pore-pressure measurements.
- Temperature measurements both regional and near field following earthquake.
- Seismic methods for inferring stress
    - Focal mechanism inversion
    - Anisotropy
    - Changes due to changes in wave speeds
- Dynamic stressing during earthquakes – role in triggering. Measure? Vs model
- Inferences on absolute stress based on rotation of slip in response to known stress perturbation.
- Modeling of stress accumulation and stress transfer.
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