The San Andreas Fault in fine detail: seismology and rock physics
Feature instead of technique

• Tectonics Setting
  – Boundary between North American and Pacific Plates
  – Right-lateral strike-slip

• Focus on Parkfield region
  – Recurring earthquakes, mag 6 recur @22 yr intervals
  – Extensively instrumented with surface seismometers
  – SAFOD drilling program into the fault at depth
Instrumentation in the Parkfield region
Parkfield High Resolution Seismic Network

- 13 borehole seismometers
- Operated by the Berkeley Seismological Laboratory
- Operational since 1987 with 10 stations, expanded to 13 in 2001

• **Methods**: Magnetotelluric (MT) profile across fault

• **Reflection seismic survey**

• **Results**: flower structure of fractured material near surface, narrowing at depth

• **Low resistivity fault core, suggesting presence of fluids**

![Diagram of seismic reflection data](image)

Figure 3. A: Migrated seismic reflection data on profile normal to fault. The depth of 1 km corresponds to a two-way travel time of 1 s. B: Electrical resistivity model that best fits observed magnetotelluric data presented in Figure 2. Location of active trace on basis of creep is denoted by T and topography shown on same vertical scale. C: crest of Middle Mountain. D: Schematic interpretation of the seismic and magnetotelluric data. Kg—Salinic granite, Tcr—Coast Range sedimentary units, Tgv—Tertiary Great Valley sequence, Kjf—Franciscan melange, and DZ—damaged zone.

- **Methods**: Magnetotelluric (MT) profile across fault, analysis of $^3$He/$^4$He ratios
- **Results**: conductive zone crossing fault at depth, extending to lower crust & possibly mantle
- Suggest deep mantle fluids originating W of fault, entering fault near surface from E
SAFOD
The San Andreas Fault Observatory at Depth

- 2.2 km pilot hole drilled and instrumented in 2002
- 3.2 km deep main hole drilled in 2007 into the fault zone
- Rock cores extracted directly from the fault
- Seismometer, tiltmeter, and accelerometer placed directly in fault zone at 3.2 km depth

www.icdp-online.de/sites/sanandreas/news/news1.html

www.earthscope.org/observatories/safod

www.icdp-online.de/sites/sanandreas/news/news1.html
• 1-3 meters of fault gouge
• Serpentine layer and fragments

- **Method**: apply shear stress to granular samples of various rocks to measure frictional coefficient
- Some samples from SAFOD drilling cuttings, some from elsewhere
- Frictional coefficient in fault is thought to be very low, from heat flow data
- **Results**: only large concentrations (>50%) of wet serpentinite or talc have low enough frictional coefficient
Seismometers in the Fault

- Seismometer, tiltmeter, and accelerometer placed directly in fault zone at 3.2 km depth
- Only worked for a few days, then all failed due to unknown causes
- A temporary seismometer was installed
Tremor

• Low-frequency (2-8 hz) recurring event, difficult to separate from noise. Multiple stations required for detection
• Found in subduction zones (Cascadia and Japan)
• Also observed on San Andreas Fault

- **Methods**: choose 3-component waveform templates
- Cross-correlate templates with data stream to detect and time events
- Event “families” identified as similar waveforms across multiple stations

- **Results**: tremor migrates to NW along fault
- Migration rate varies widely, 15-80 km/hr
- Propagation can be >20 km along fault
- Seismicity depth 0-15 km
- Tremor depth ~25 km
- 15-25 km unknown ??
- Event frequency increased temporarily after Parkfield 2004 earthquake

- **Methods**: calculate tidal shear, normal, and Coulomb stresses
- Correlate with occurrence of tremor
- **Results**: strong correlation of tremor with right-lateral shear stress (along fault)
- No correlation of earthquakes with RLSS
Key Points

• At Parkfield CA, fault at 3km depth consists of 1-3m of fault gouge, serpentinite
• Fault has low friction and low resistivity, probably due to wet serpentinite
• Earthquakes occur in upper 15 km of crust
• Tremor occurs near base of crust, ~25km depth
• Tremor is influenced by Earth tides, and generally migrates NW along fault
• Earthquakes are not influenced by tides