

Seismology and Geology Monitoring Using Satellite Navigation Systems

Frank Webb, Ph.D.

Satellite Geodesy and the Dynamics of the Earth's Crust

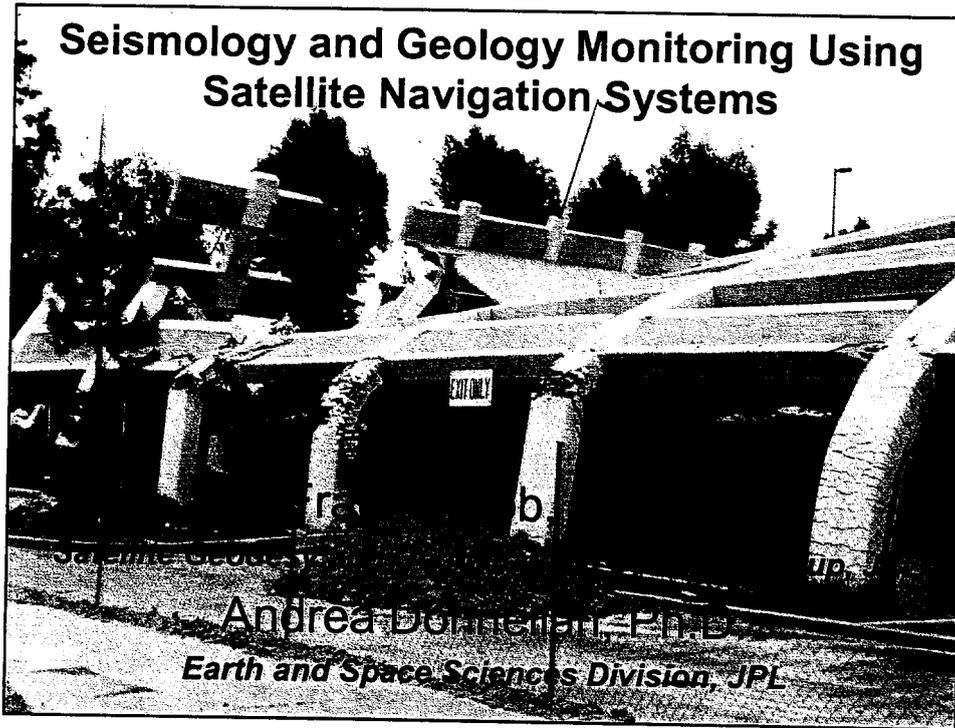
Andrea Donnellan, Ph.D.

Earth and Space Sciences Division

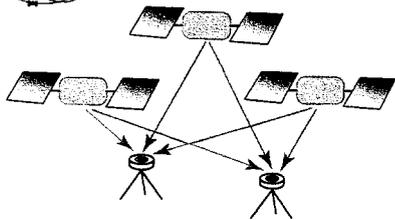
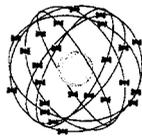
Jet Propulsion Laboratory

California Institute of Technology

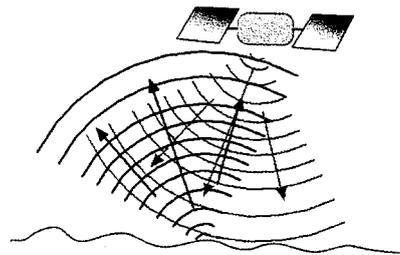
Seismology and Geology Monitoring Using Satellite Navigation Systems



GPS and InSAR

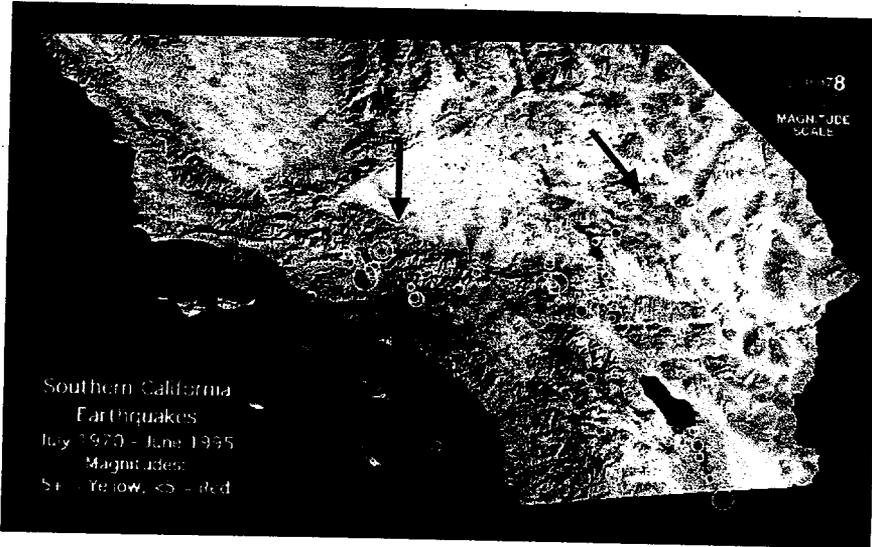


GPS Constellation and Network

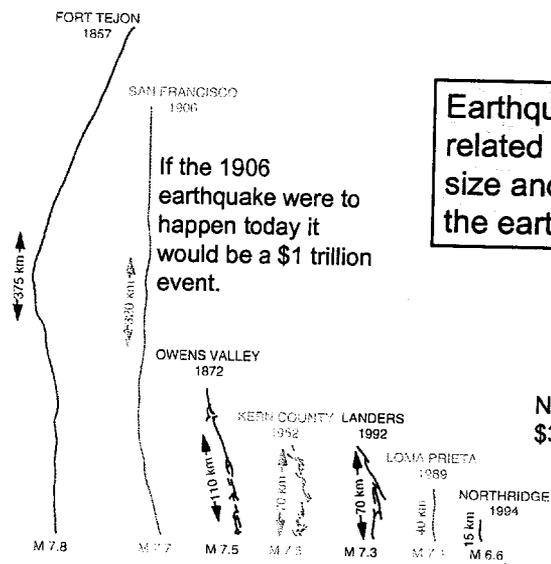


Synthetic Aperture Radar

Southern California is Actively Deforming



Large California Earthquakes



If the 1906 earthquake were to happen today it would be a \$1 trillion event.

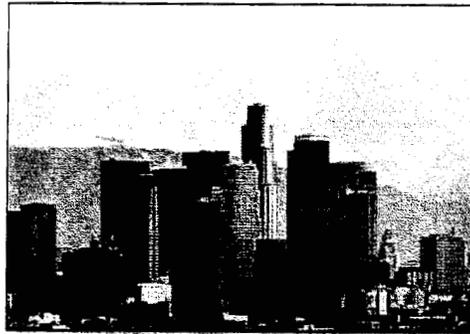
Earthquake damage is related to both the size and location of the earthquake.

Northridge was a \$30 Billion event

Recent GPS Results Show Concentrated Deformation Near Downtown Los Angeles



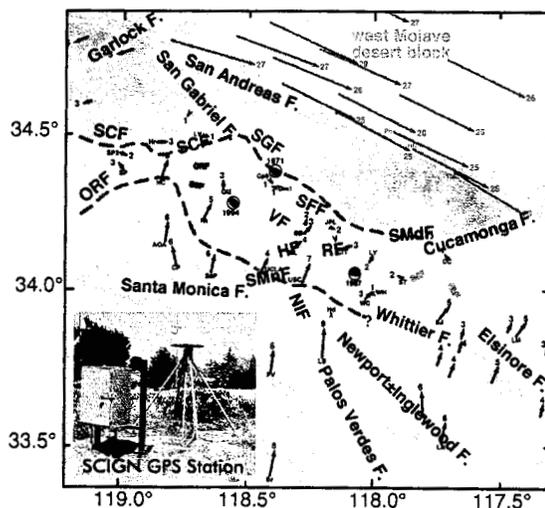
Los Angeles is moving, literally



INCK UT / AP file

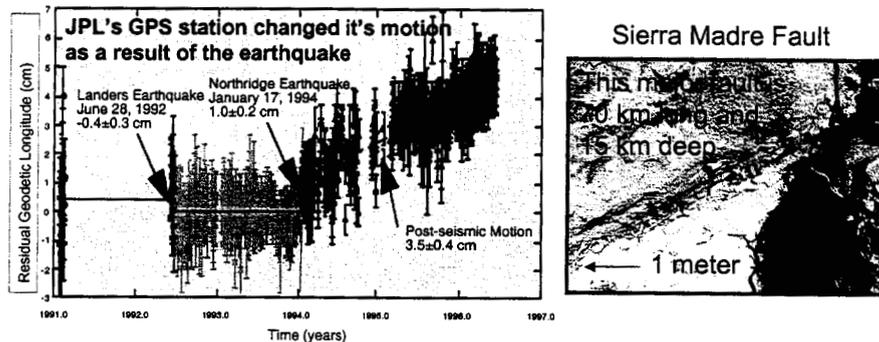
LOS ANGELES, August 4 — Scientists at the Jet Propulsion Lab in Pasadena, Calif., have made measurements that suggest that downtown Los Angeles is moving toward the San Gabriel Mountains, and that a new mountain range is being formed beneath Hollywood.

GPS Results from the Southern California Integrated GPS Network



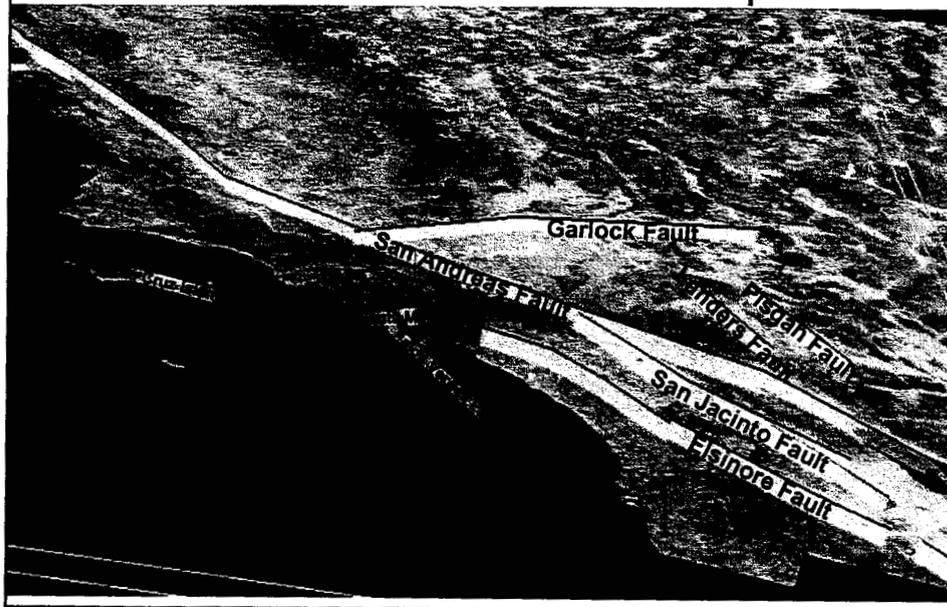
- Shortening is occurring in a narrow band just south of the mountains.
- Shear is observed across the San Andreas
- The mountains are behaving as a block.
- Suggests active faults at the front of the mountains and near downtown Los Angeles

The Northridge Earthquake Affected the Sierra Madre Fault 30 Km Away



- The earthquake probably triggered shallow slip on the Sierra Madre Fault.
- This was the first time that long range fault interactions were observed.

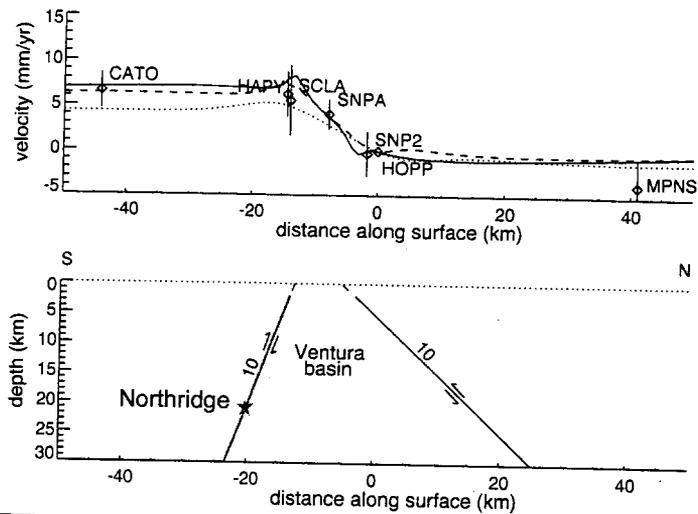
Earthquake Faults Interact and Can be Monitored from Space



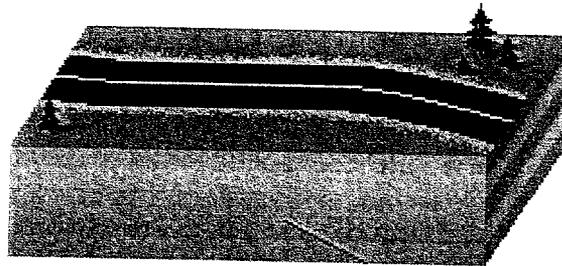
GPS Results Indicated Active Faults

"...would yield an earthquake of moment magnitude $M_w \approx 6.4$... and a $M_w \approx 6$ earthquake is still large and potentially damaging."

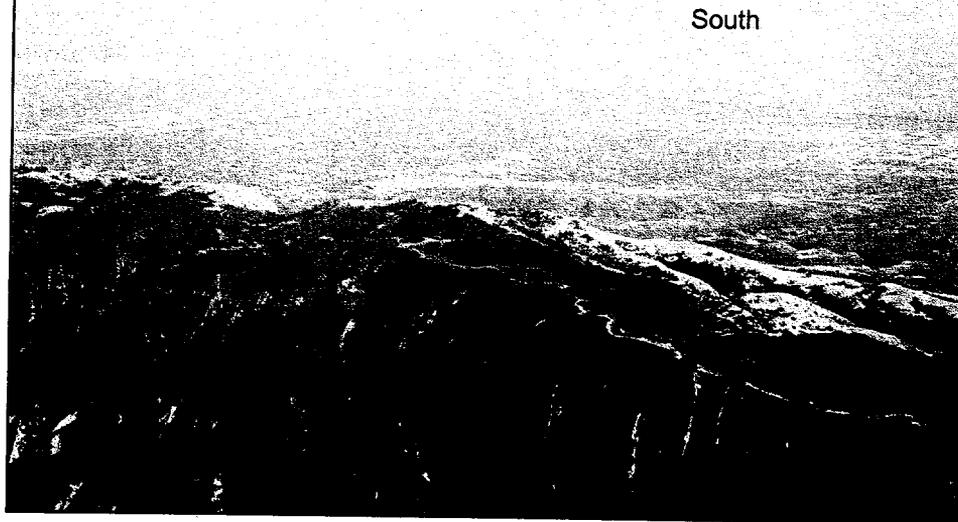
Donnellan et al., Nature, November 25, 1993.



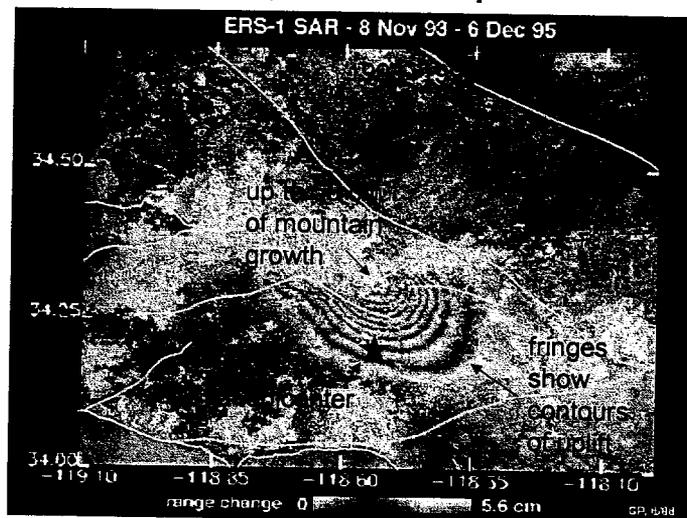
Northridge Occurred on a Blind Thrust Fault



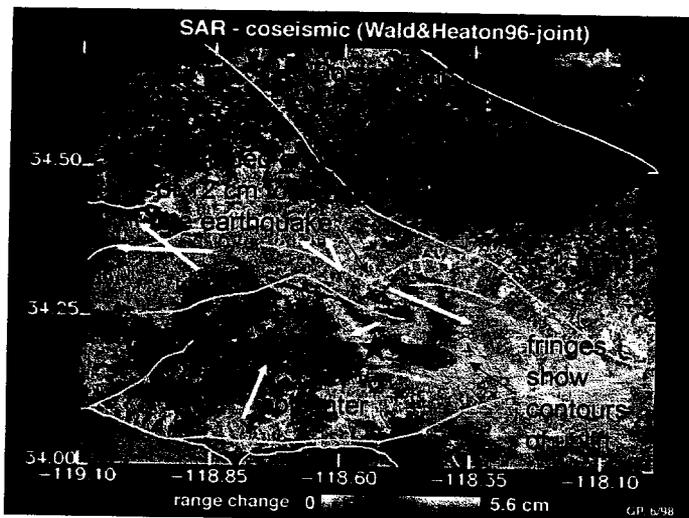
Aerial View of Northridge Showing Region Above the Fault Rupture



The Northridge Earthquake was Observed with Synthetic Aperture Radar

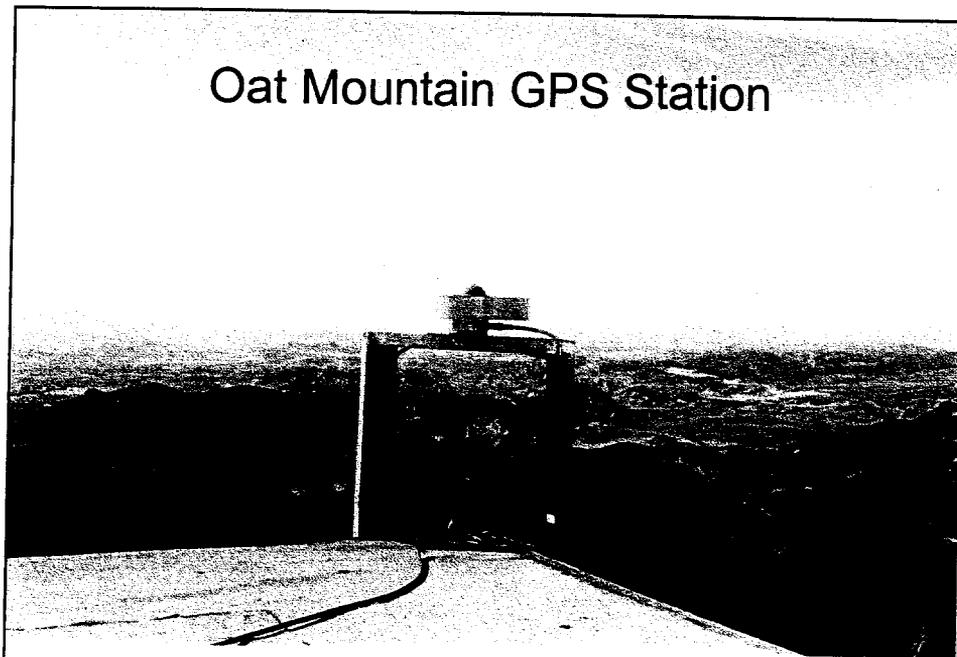


Postseismic Motion was Observed with InSAR and GPS



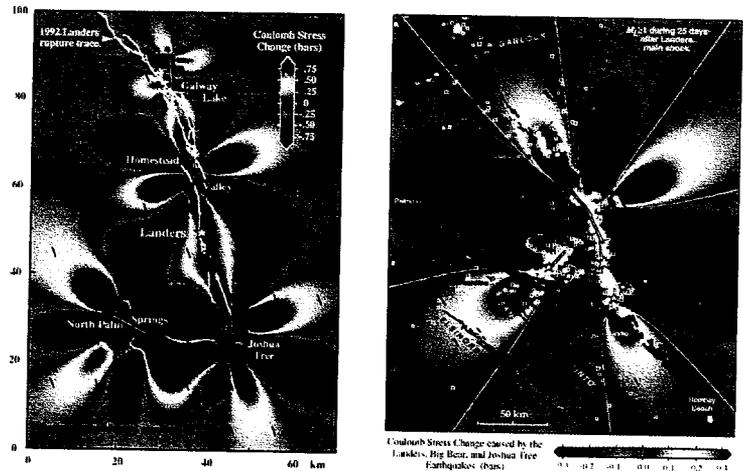
90% of the motion was quiet and not observable with seismometers

Oat Mountain GPS Station



This mountain grew 40 cm in the Northridge Earthquake.

Stress is Transferred Between Faults

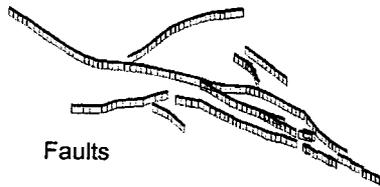
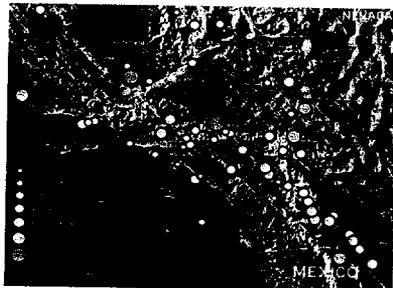


King et al., Bull. Seismological Soc. Am., 1994

Subsequent earthquakes occur in regions of increased stress.

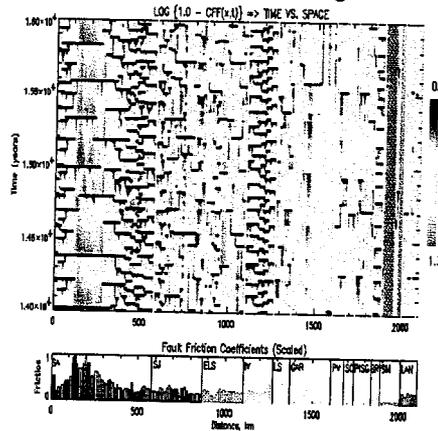
Earthquakes on One Fault May Turn Earthquakes On or Off on other faults

Southern California Seismicity



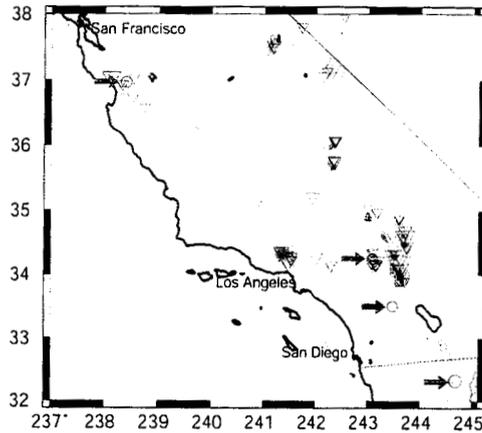
Faults

Space-time Stress Diagram



Courtesy John Rundle

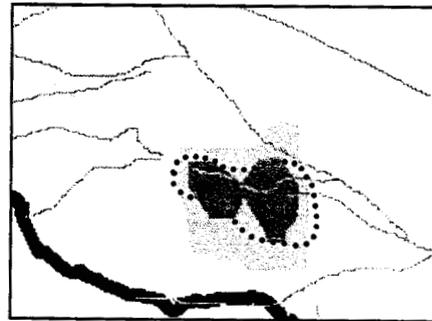
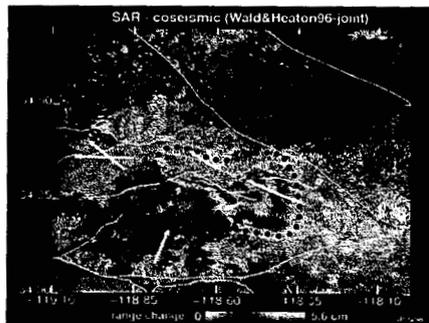
Pattern Recognition Techniques Show Promise for Earthquake Forecasting



- Red regions indicate anomalies detected through Principal Component Analysis.
- Blue triangles and circles are earthquakes
- Recent earthquakes have occurred in the anomalous regions.

Courtesy John Rundle

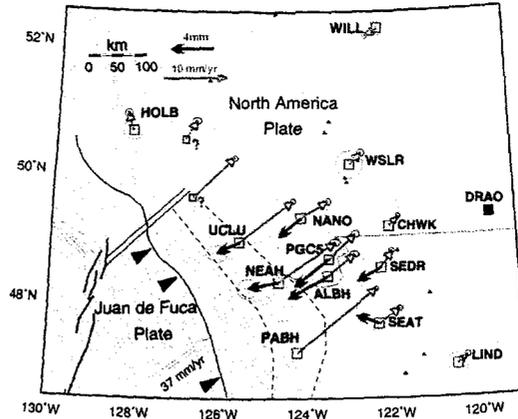
Comparison of InSAR and Seismic Anomalies



- Similar anomaly shows up in both the postseismic deformation indicated by GPS and InSAR (Donnellan et al) and seismic anomalies identified using Principal Component Analysis (Rundle and Tiampo).
- Mojave desert shows a similar correlation near Barstow and the Blackwater Fault (Rundle and Tiampo; Peltzer).

Space-Based Methods are Showing an Increasing Number of Slow Events

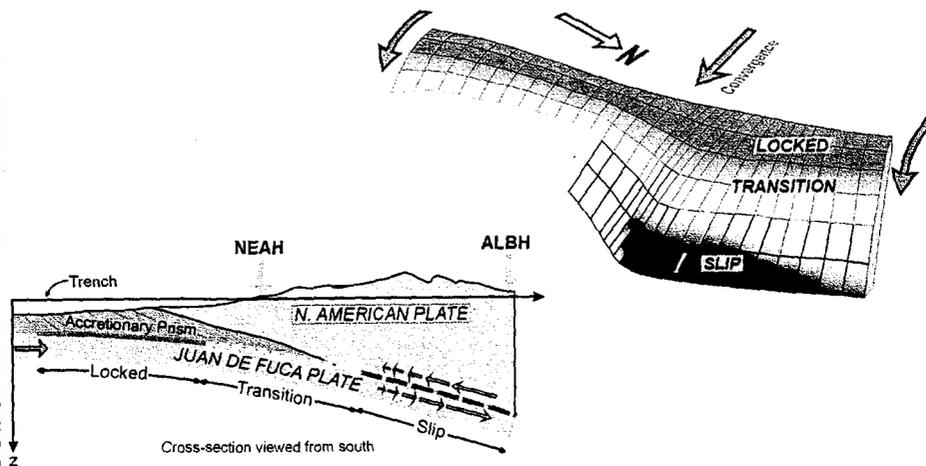
- Slow “earthquakes” are observed in Cascadia and Japan along the subduction zones.
- In Canada, these events take about 15 days, propagate northward, and occur every 16-18 months.



August 1999 Transient Displacements Versus Long Term Velocities

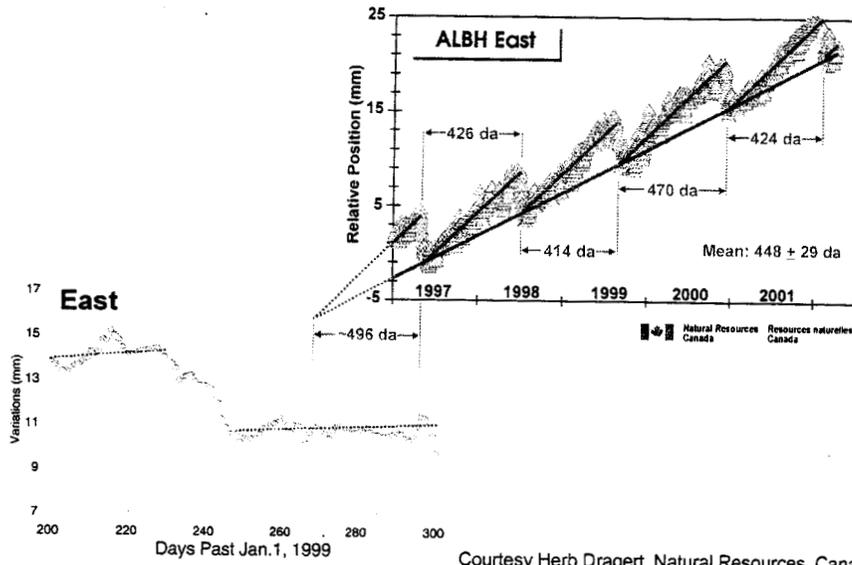
Courtesy Herb Dragert, Natural Resources, Canada

Slip Occurs on the Deep Part of the Subduction Zone



Courtesy Herb Dragert, Natural Resources, Canada

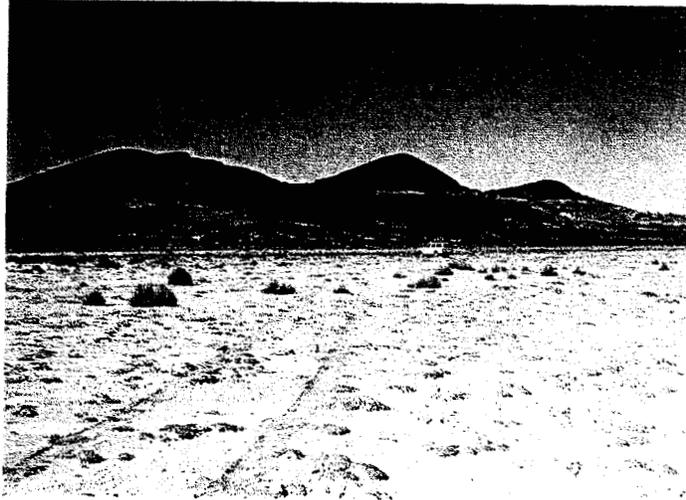
Periodic Slow Earthquakes in Cascadia



Differential GPS can be used for Geologic Applications



Measuring Shorelines to Estimate Mantle Viscosity



Differential GPS can Provide Sub-Meter Accuracy in Near Real Time



Earthquakes in Continents

Mongolia

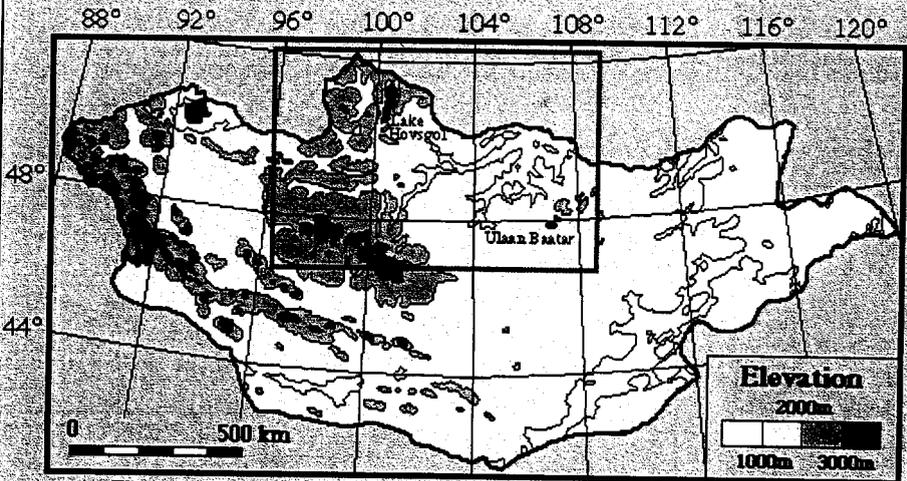
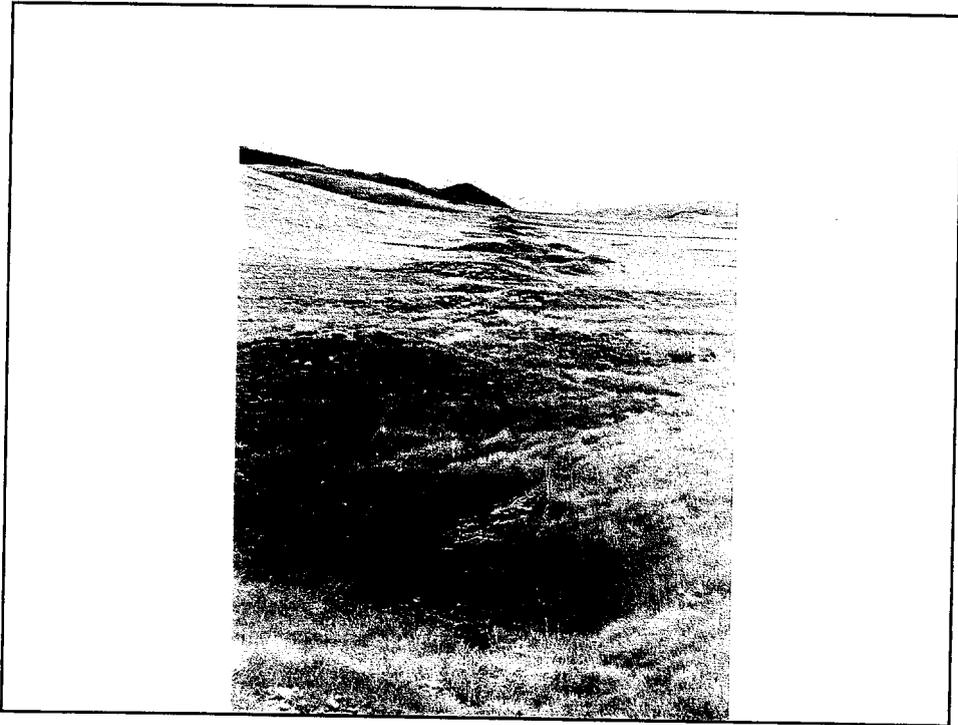
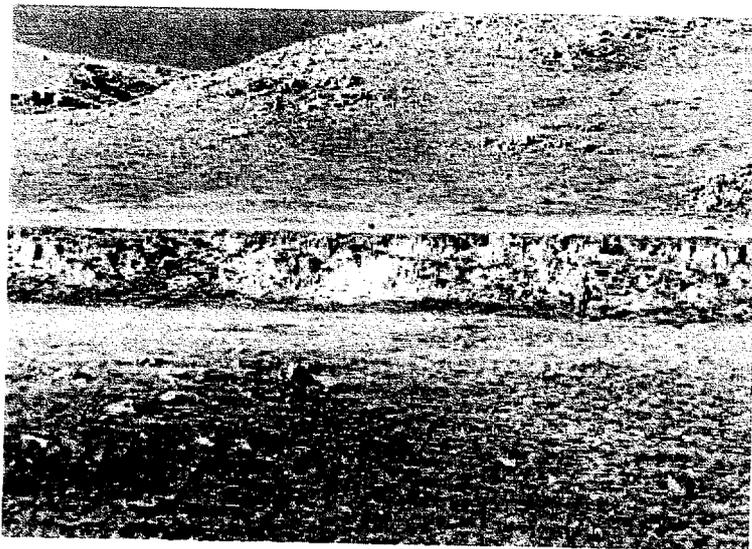
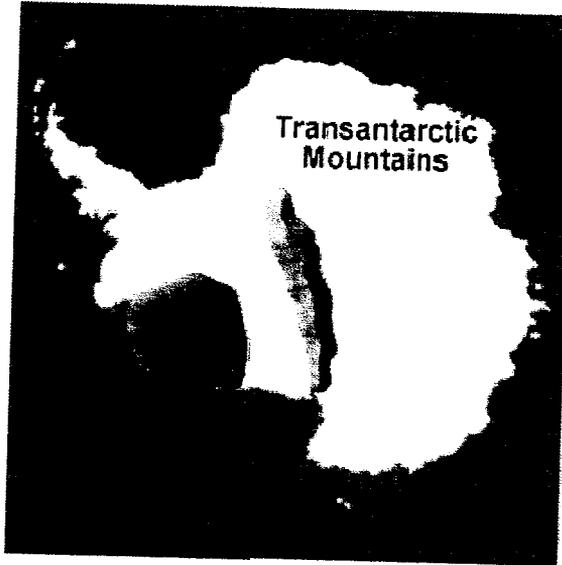


Figure 1: Elevation map of Mongolia. The red box designates the territory covered on our reconnaissance trip in September, 1996. See below for details of the trip route.



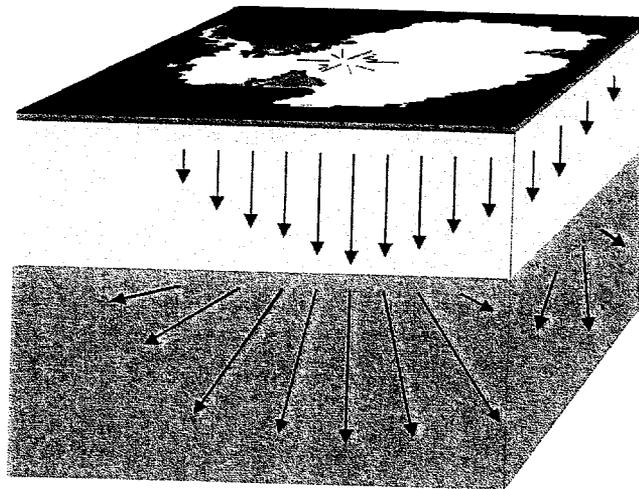


Antarctica

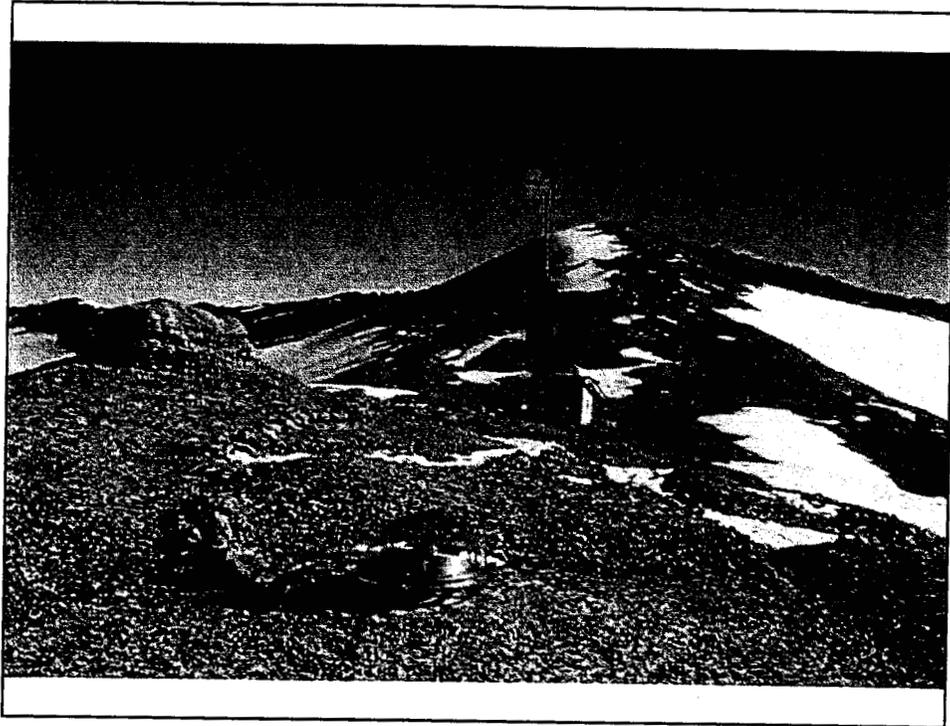


Post Glacial Rebound

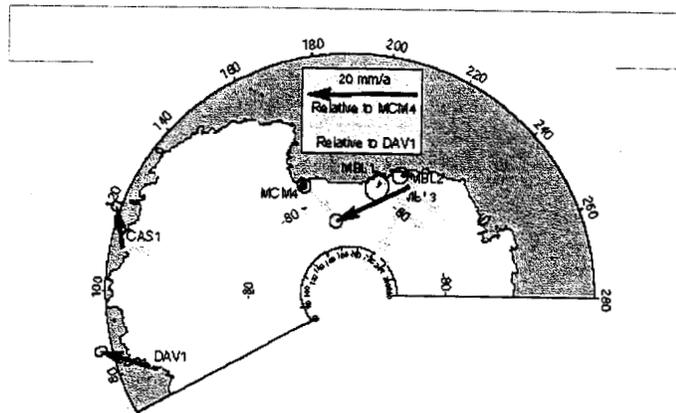
- The thick ice sheet pushes down on the earth
- As the ice thins the mantle flows back
- The surface of the earth rebounds



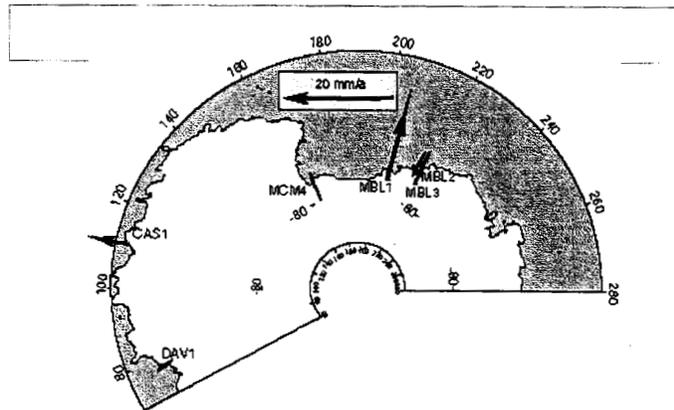




Horizontal Velocities



Vertical Velocities



Results

- Little or no extension.
- Significant right lateral motion between east and west Antarctica
- Dome of uplift centered near the Rockefeller Mountains with a maximum uplift rate of about 10 mm/yr.

