MARGINS-RCL Workshop

Lithospheric Rupture in the Gulf of California – Salton Trough Region

Regional Geodesy

Shimon Wdowinski

University of Miami

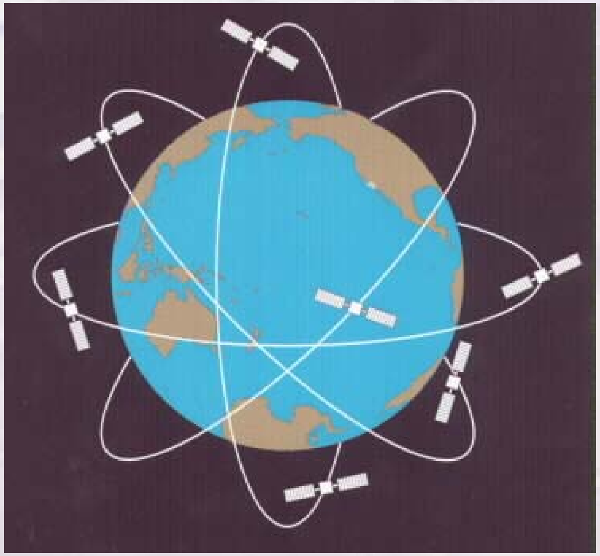
Rowena Lohman, Kim Outerbridge, Tom Rockwell, and Gina Schmalze

Presentation Content

- **Introduction**
  - Methods
  - Observations
  - Objectives
- **Geodetic studies**
  - Plate motion
  - Crustal deformation
  - Model constraints
- **Summary**

Space Geodetic Techniques

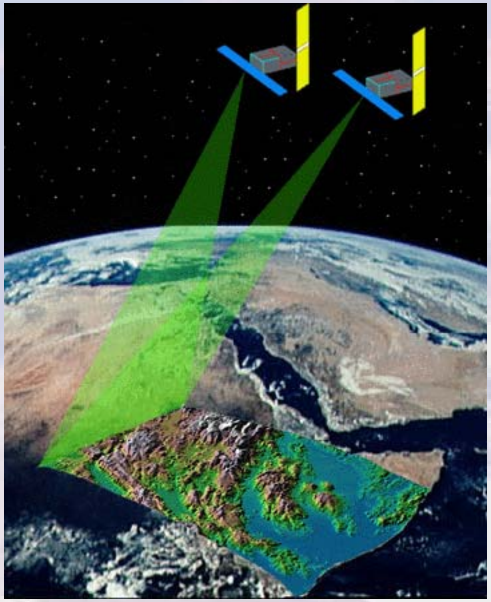
Globa Positioning System (GPS)



Measures point positioning

- 3-D vector
- Absolute measurement
- mm-level accuracy (sub-mm/yr)
- Low spatial resolution
- High temporal resolution
- Horizontal components are more accurate

Interferometric Synthetic Aperture Radar (InSAR)



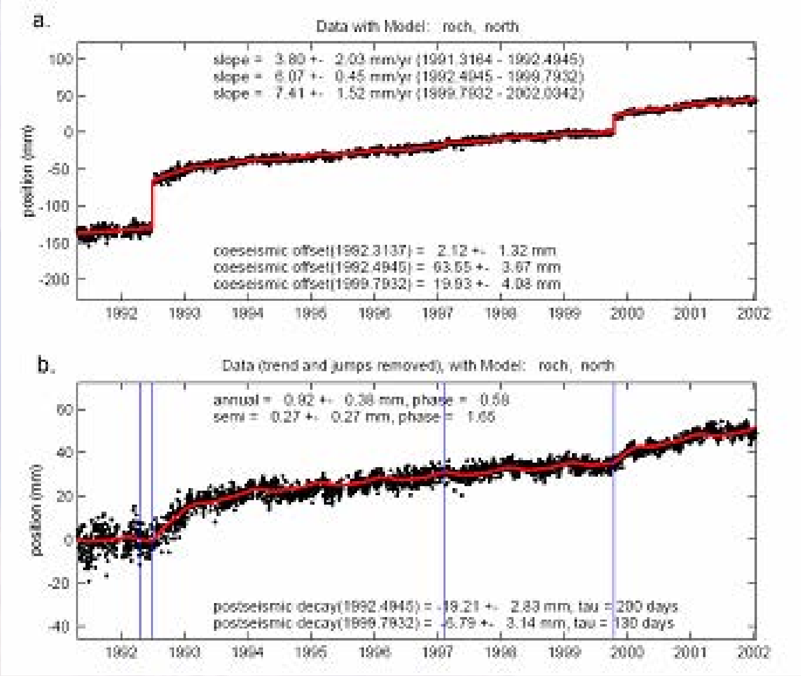
Measures surface changes

- Line of sight (LOS)
- Relative measurement
- Sub-cm level detection capability
- High spatial resolution (7-50 m pixel)
- Low temporal resolution
- Higher sensitivity to vertical movements

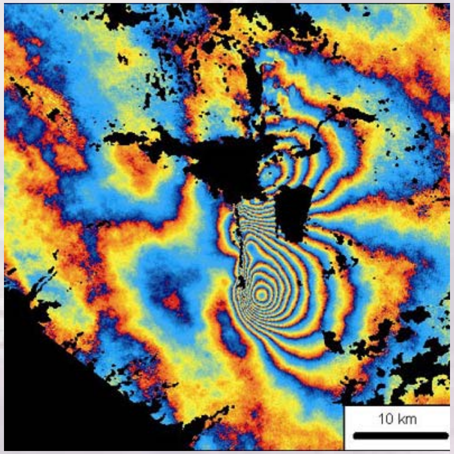
Geodetic observations

- **Rigid plate motion**
- **Crustal deformation**
  - Earthquake deformation cycle
  - Creep
  - Transient (slow EQs)
- **Non-tectonic crustal movements**
  - Seasonal variations
  - Hydrology
  - Man-induced

Continuous GPS time series (ROCH-N)



Nikolaidis (2002)



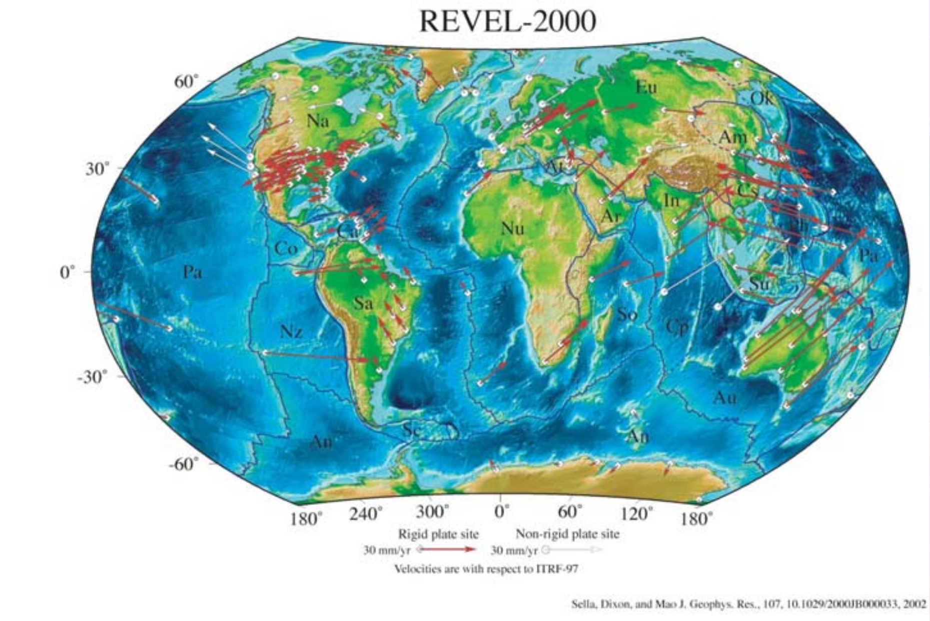
2004 Bam EQ (Iran)

Objectives

- **Plate Motion**
  - Does Baja California behave as a rigid block/s?
  - Does Baja California move as part of the Pacific plate, as assumed by global plate models?
  - If not, what is the relative motion between Baja and the other major plates (NA, Pa)?
- **Crustal deformation**
  - Where does the present-day deformation occur (mainly interseismic)?
  - What are the present-day slip rates along the main active faults?
  - Are there additional unaccounted deformation processes (creep, post-seismic, others)?
- **Model constraints**
  - What can we learn about crustal properties?
  - What can we learn about faulting and other deformation processes?

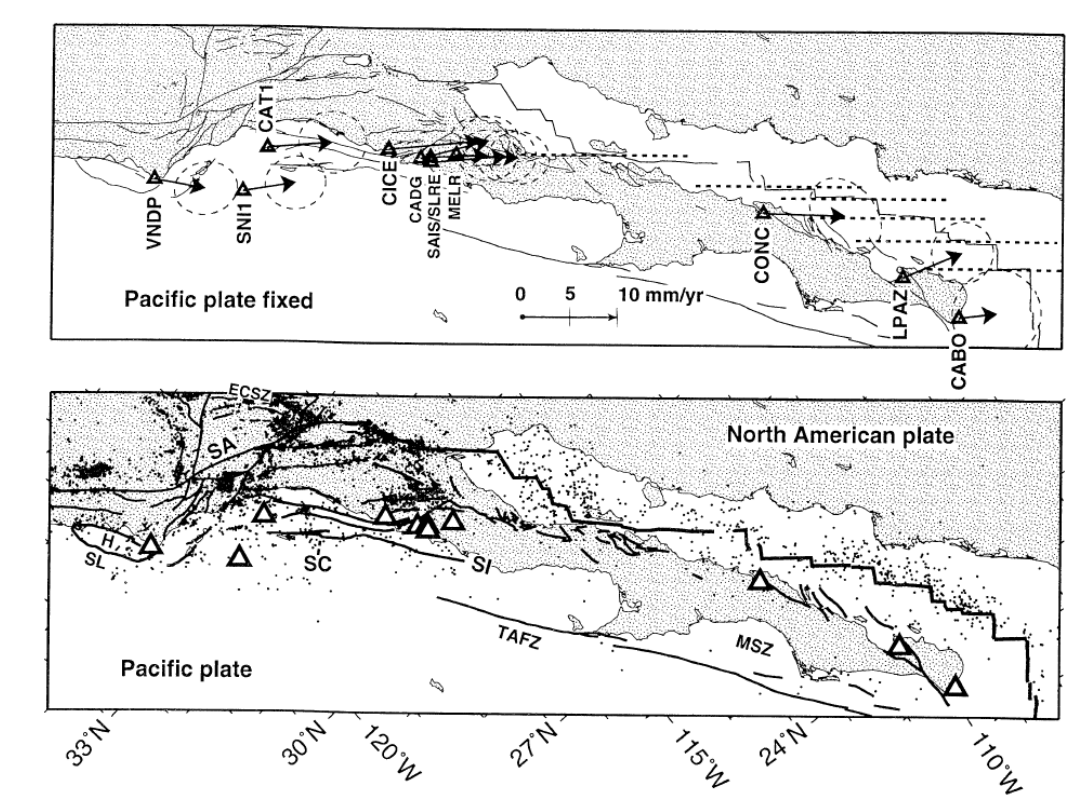
Plate motion

- **global plate models consider Baja as part of PA.**



Sella et al., (2002)

Plate motion



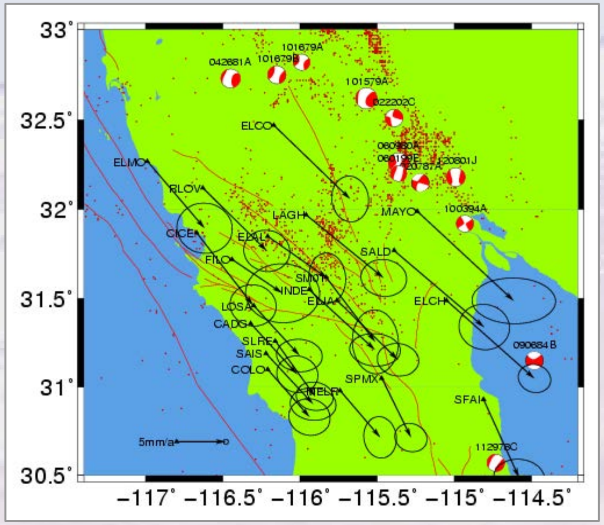
Velocity w/r to Pacific plate.

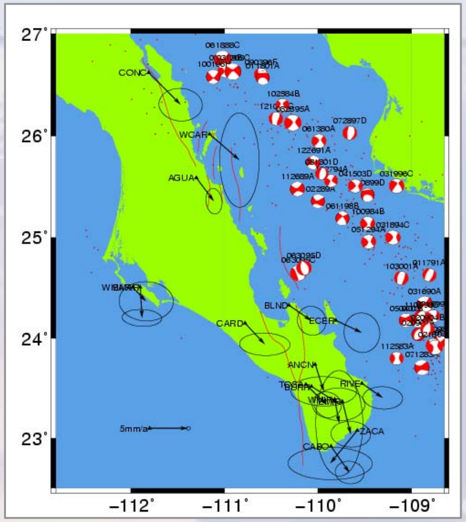
GPS observation:

- **Coastal site in Baja, south of the Agua Blanca Fault show 3-8 mm/yr motion w/r to the Pacific plate.**
- **The relative motion between Baja and Pacific plate is absorbed by a "Baja California Shear Zone" (analogous to ECSZ).**

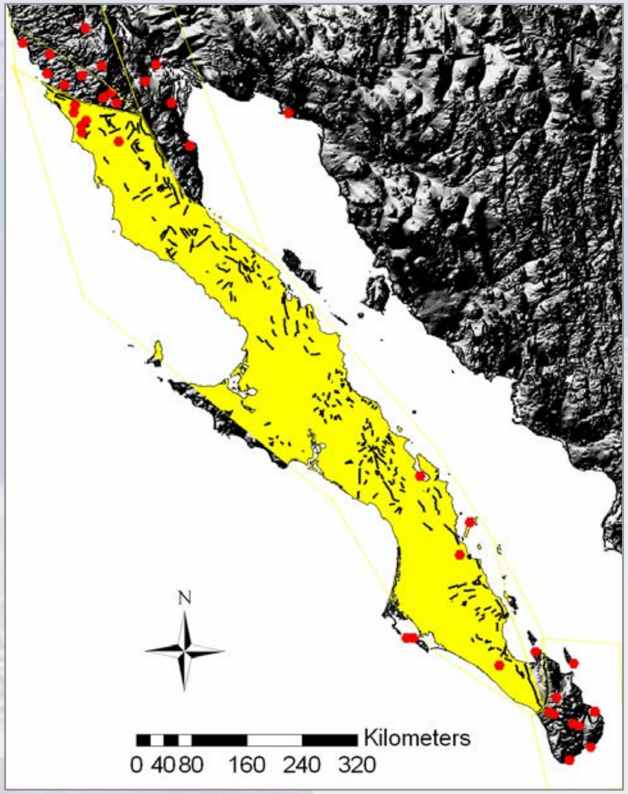
Dixon et al. (2000)

Plate motion

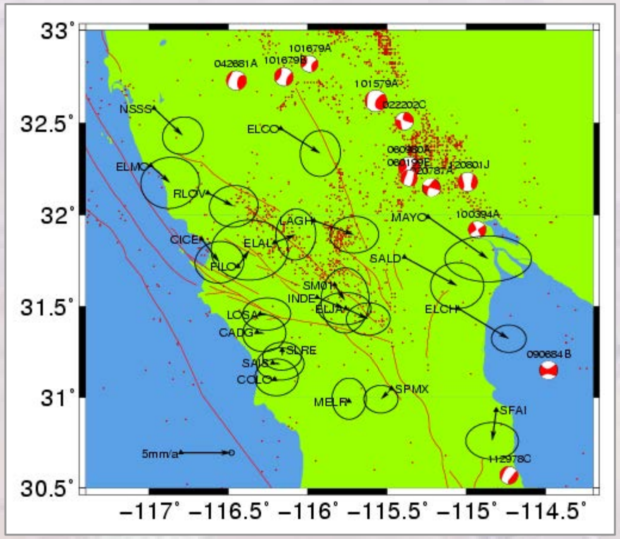


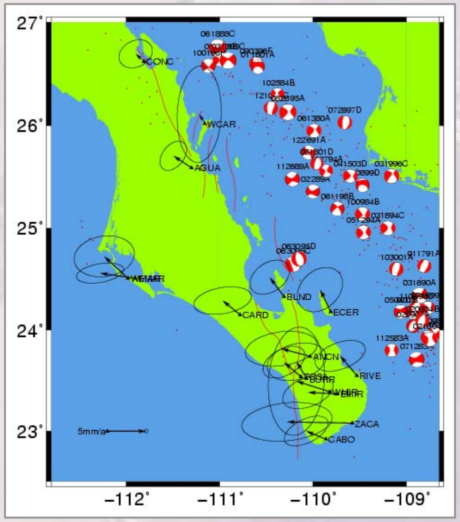


Velocity w/r to stable Pacific plate.



Central Baja Block

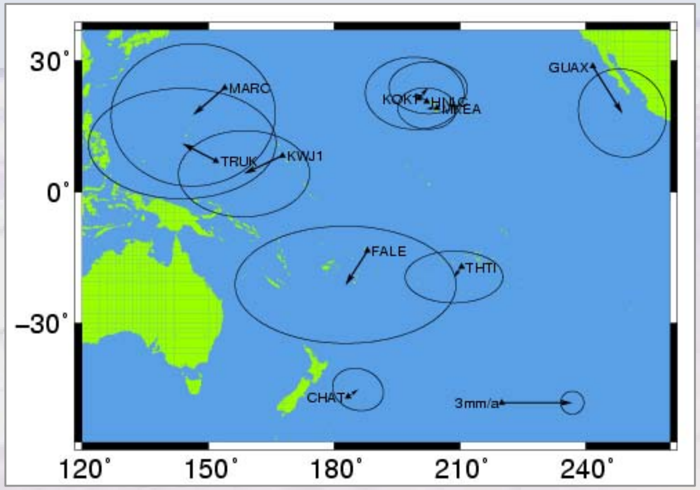


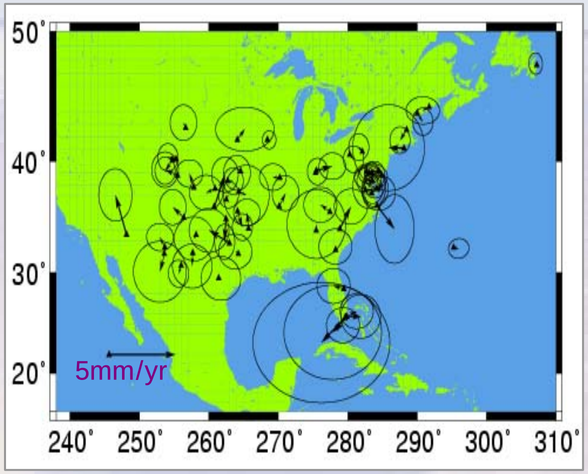


Velocity w/r to central Baja Block.

Ch. Plattner, R. Malservisi, T. Dixon and others

Plate motion



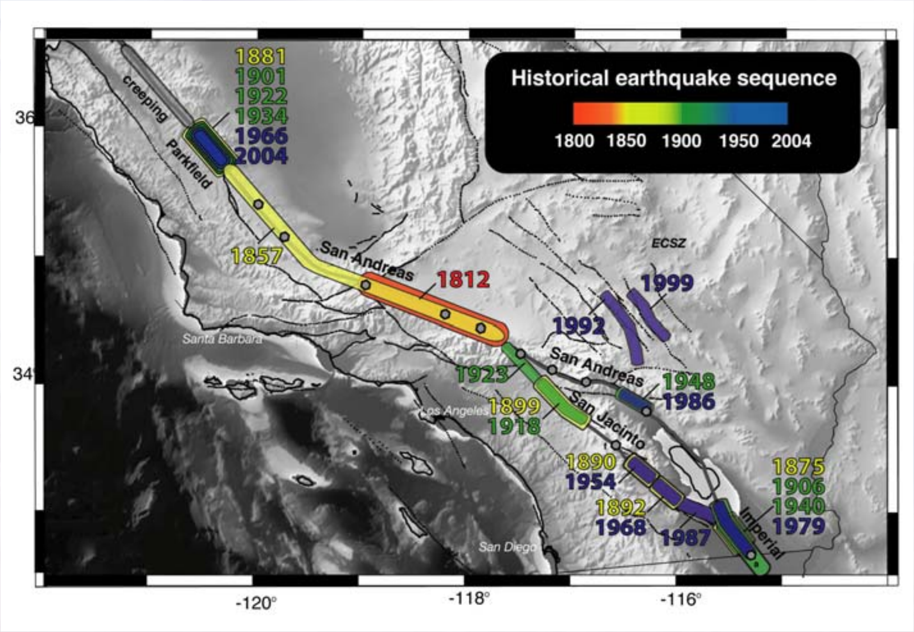


Conclusion:

- **The central part of Baja California moves as a rigid block. The residuals at Baja vary between 3-5 mm/yr,**
- **Baja does not move with the full Pacific rate. Thus the Gulf of California does not accommodate the full PA-NA motion.**
- **The sites north of the Agua Blanca fault and in the Cabo region are subjected to crustal deformation.**

Ch. Plattner, R. Malservisi, T. Dixon and others

Crustal deformation
Co-seismic



- **The 1940 Mw=7.1 and 1979 Mw=6.6 Imperial Valley earthquakes were studied using geodetic data (levleing, triangulation and trilateration) collected in 1931, 1941, 1978, 1981**
- **The studies estimated a right-lateral slip of 0.8-4.8 m (2 segments) for the 1940 event and 1-4 m for the 1979 event.**

***Reilinger* (1984)**

***King and Thatcher* (1998)**

1940 Mw=7.1 Imperial Valley EQ

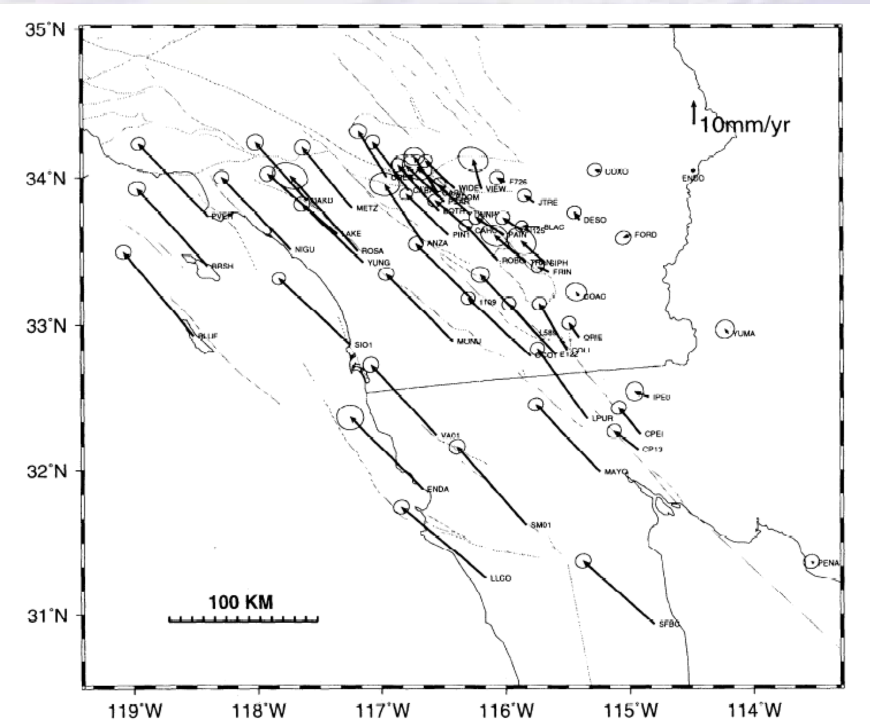
Crustal deformation
Post-seismic

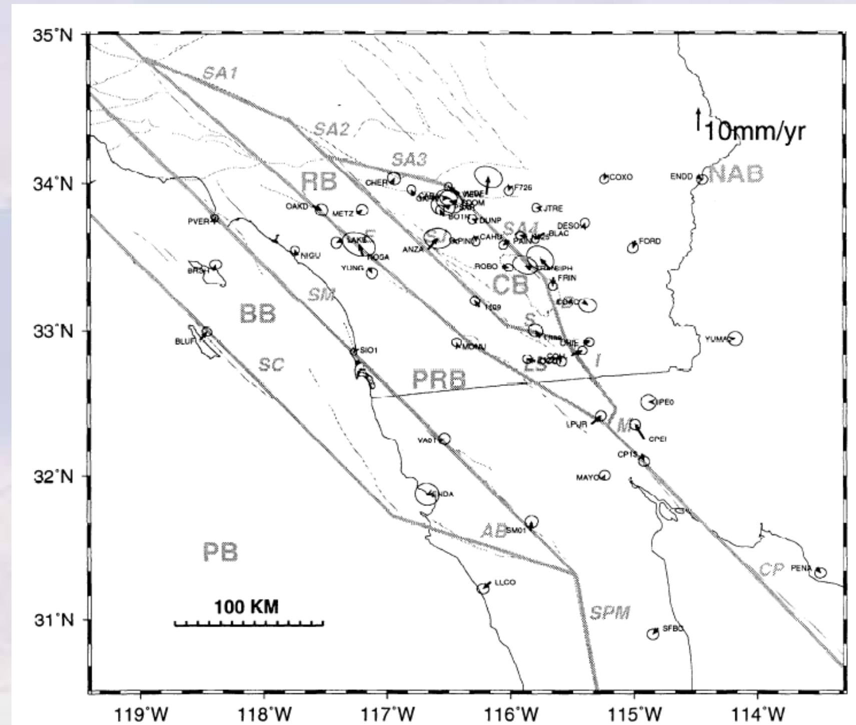
- **Geodetic data indicate 30-75 cm of post-seismic deformation following both 1940 and 1979 Imperial Valley EQs.**
- **The post-seismic deformation was described as creep occurring during 6 month after the main events.**

Reilinger (1984), Langbein et al. (1983).

Crustal deformation

Inter-seismic



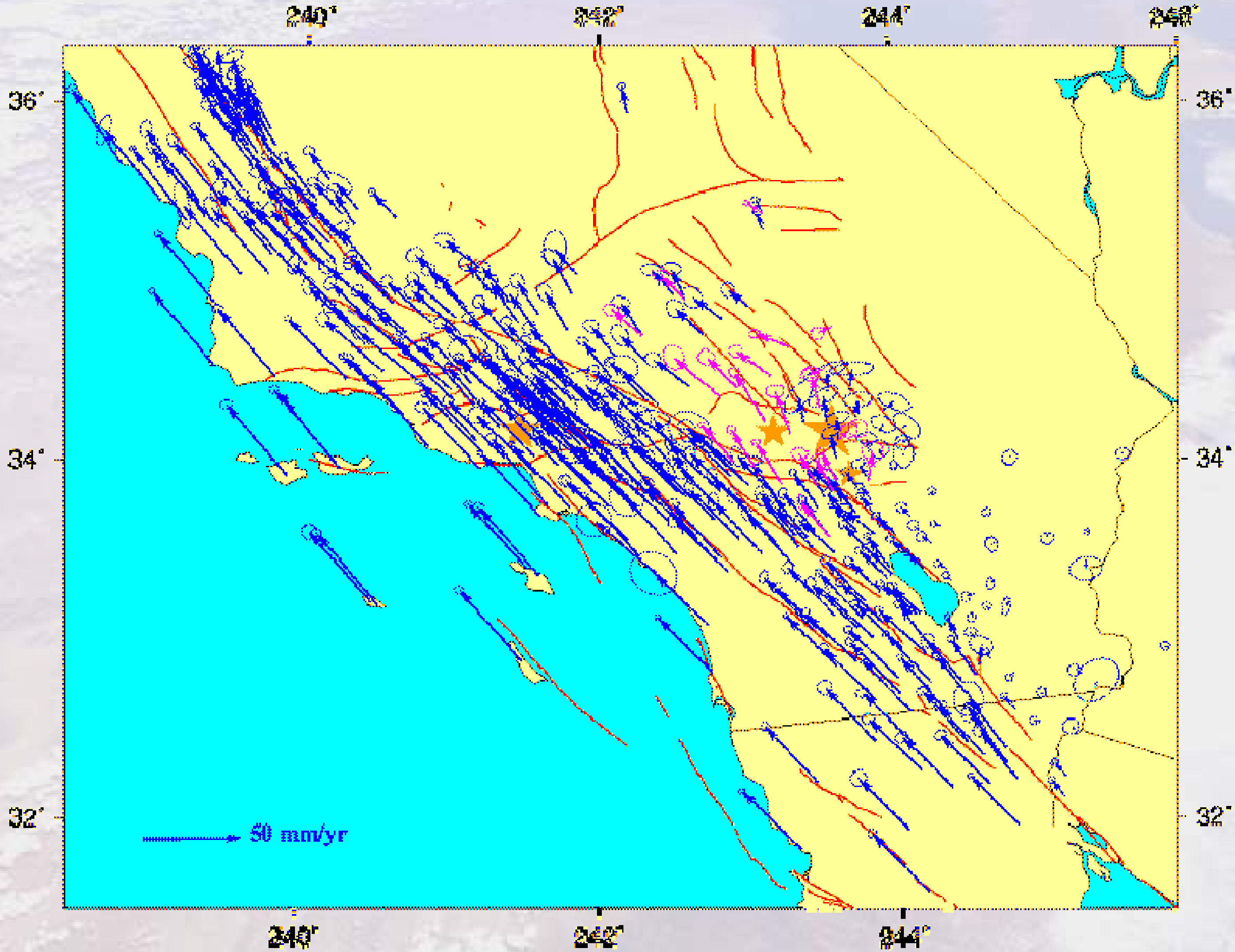


Bennett et al. (1996)

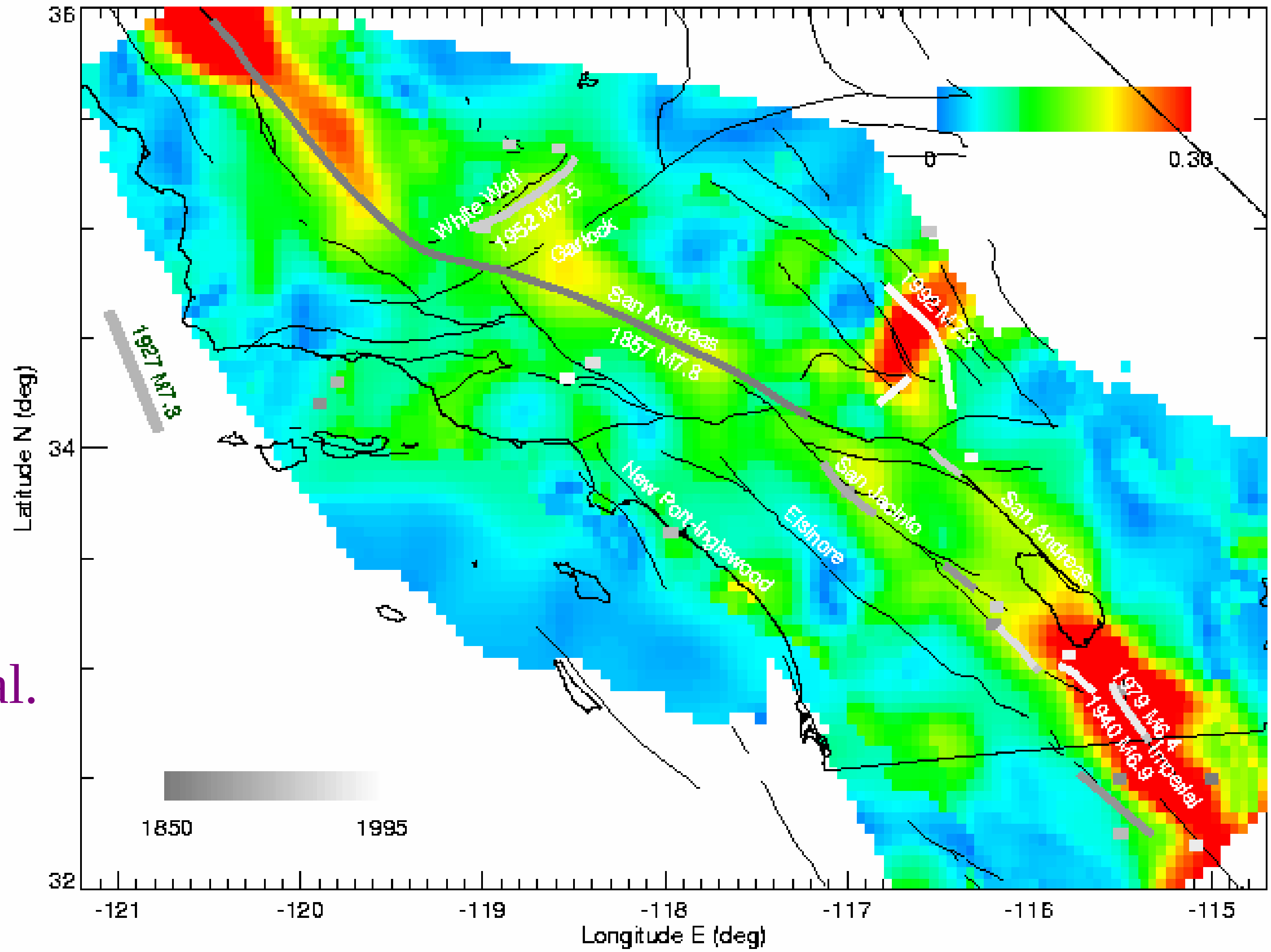
- **First GPS derived velocity field for northern Baja.**
- **Using dislocation models they estimated slip rate for major fault segments.**

The SCEC 2.0 velocity field

(released in 1998)

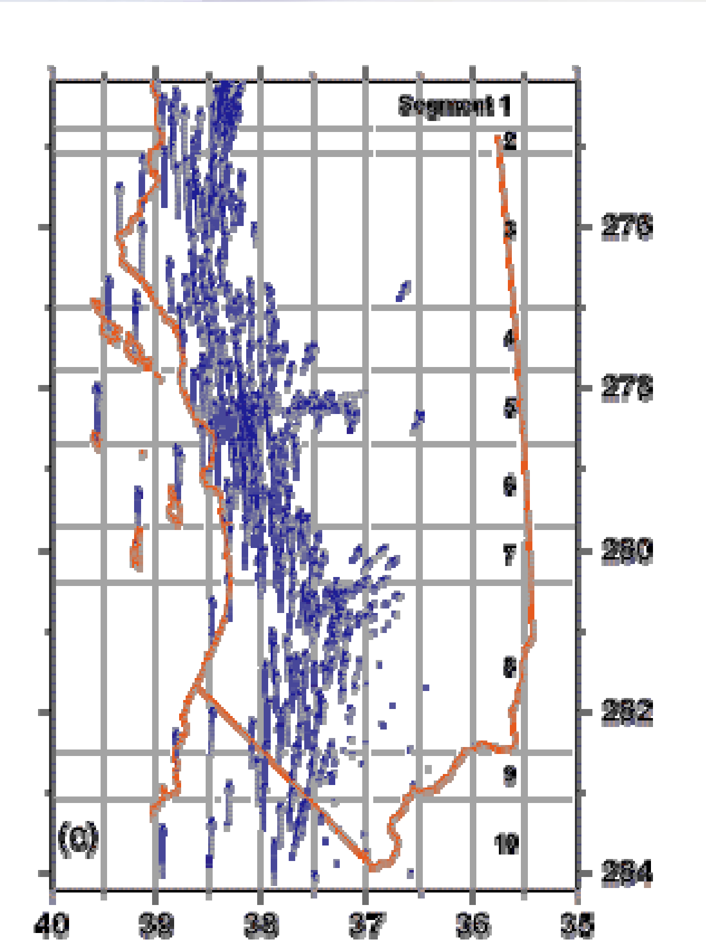


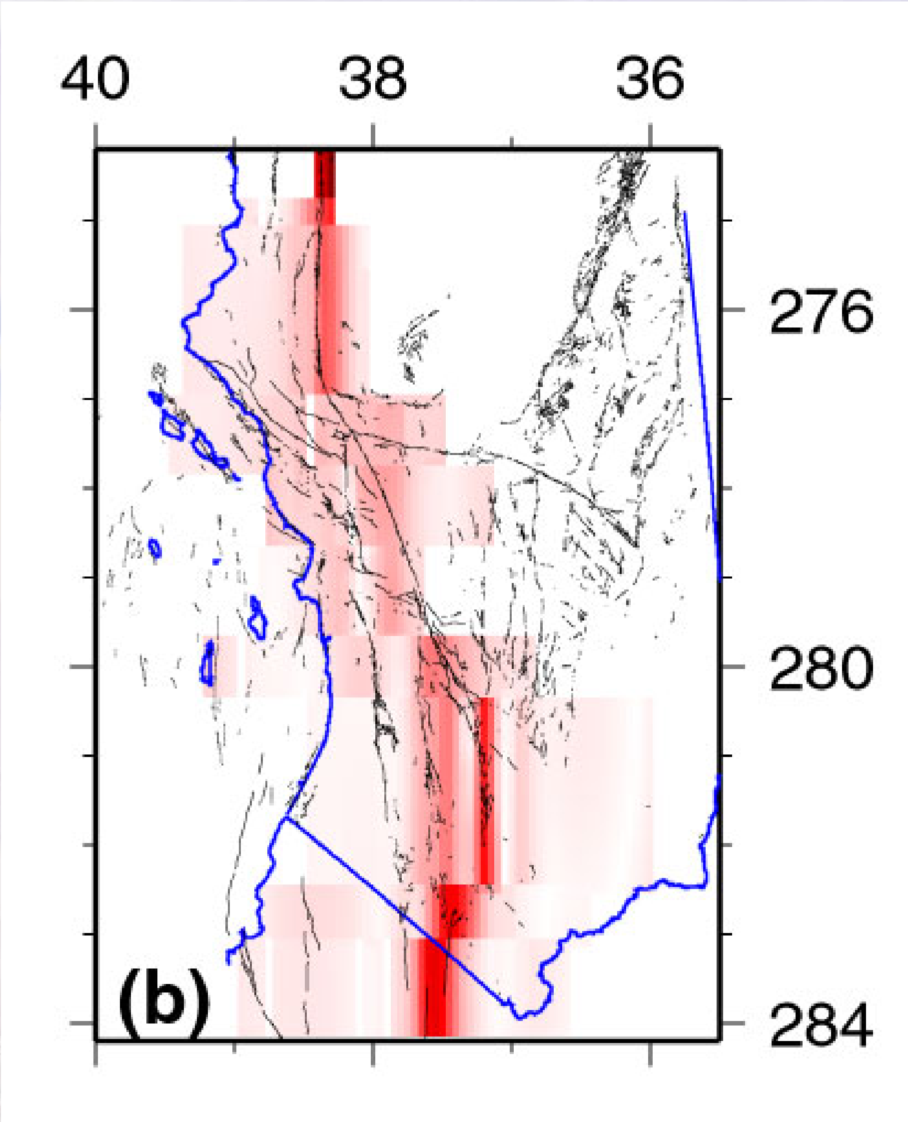
2-D Deformation Analysis



Jackson et al. (1997)

Quasi 2-D Deformation Analysis

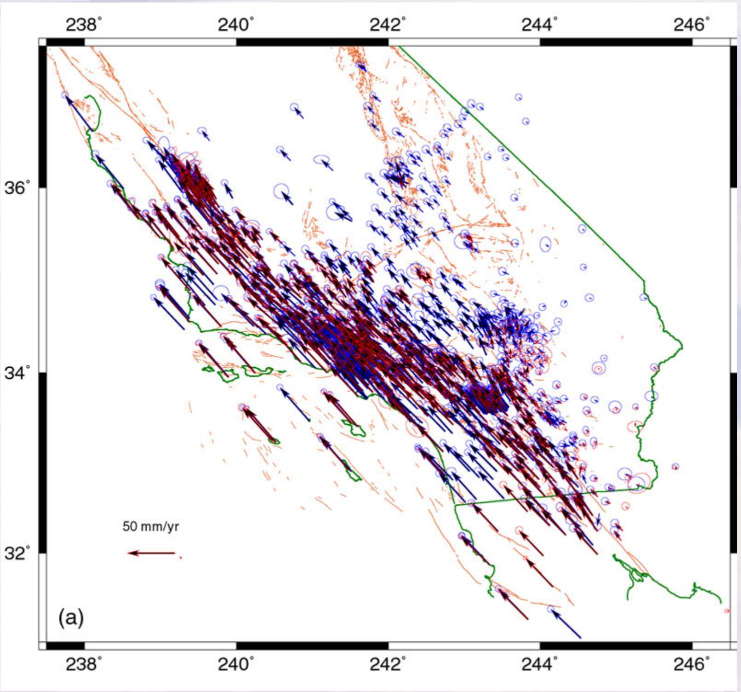


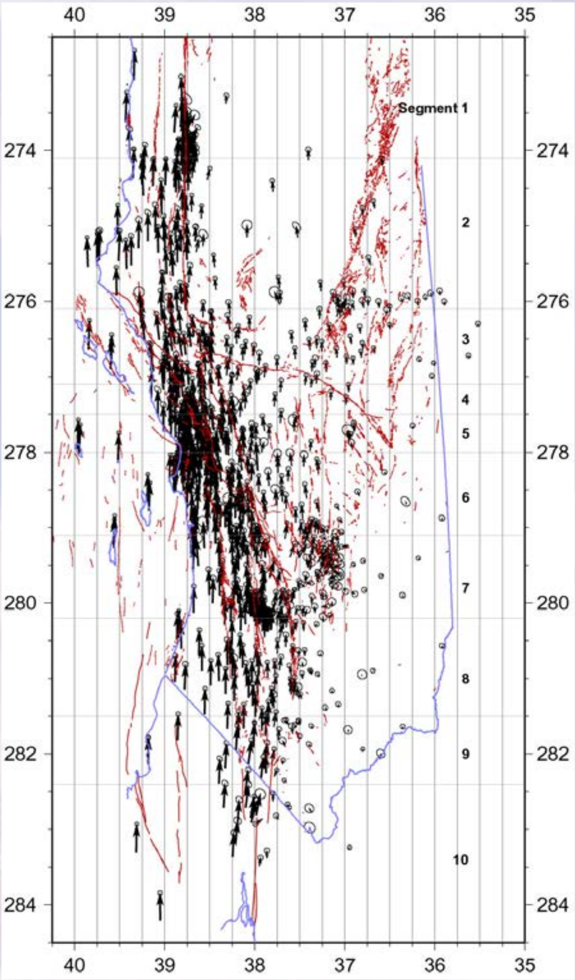


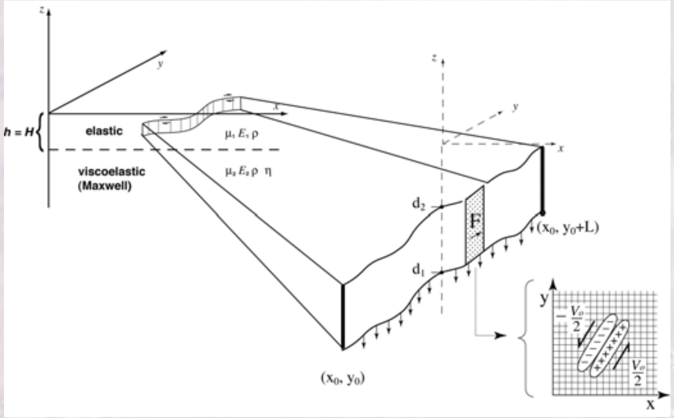
Wdowinski et al. (2002)

Analysis of the SCEC 3.0 V-field

(released in 2004)



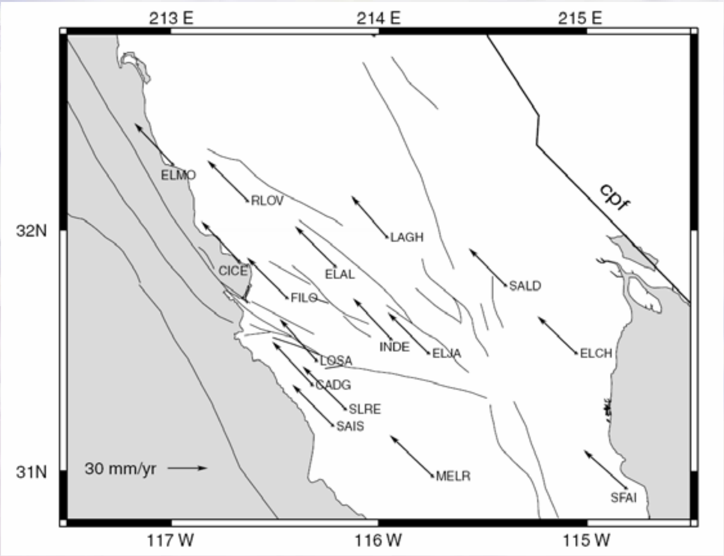


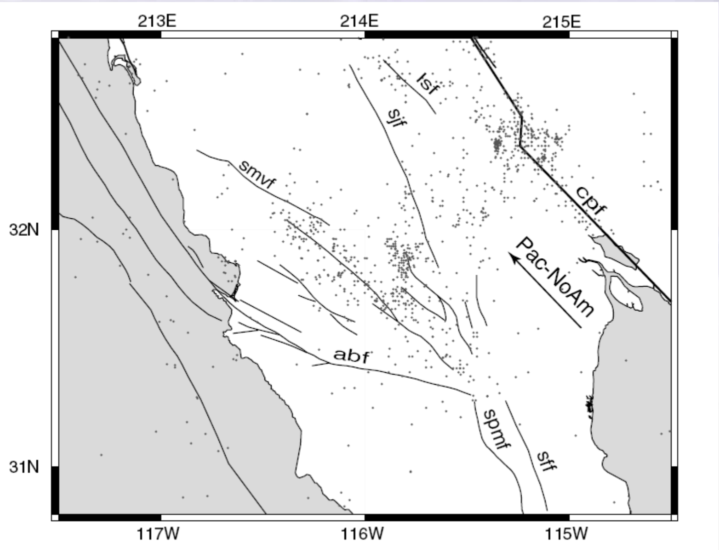


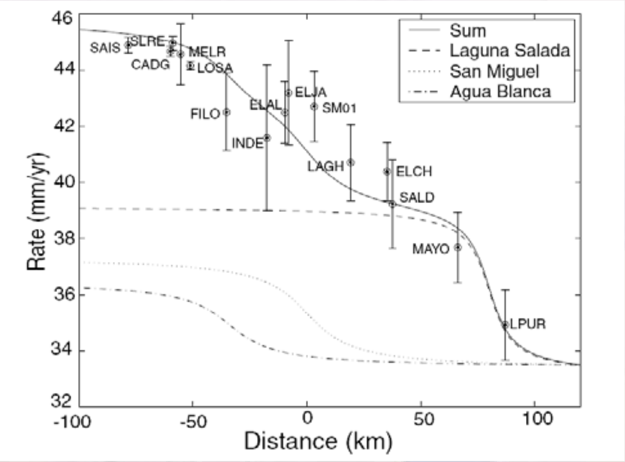
Wdowinski et al.

Crustal deformation

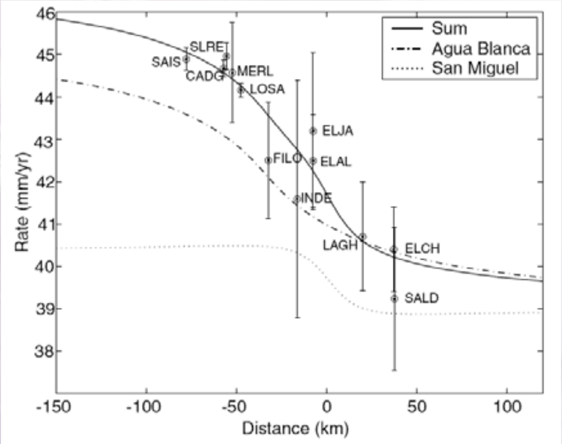
Inter-seismic







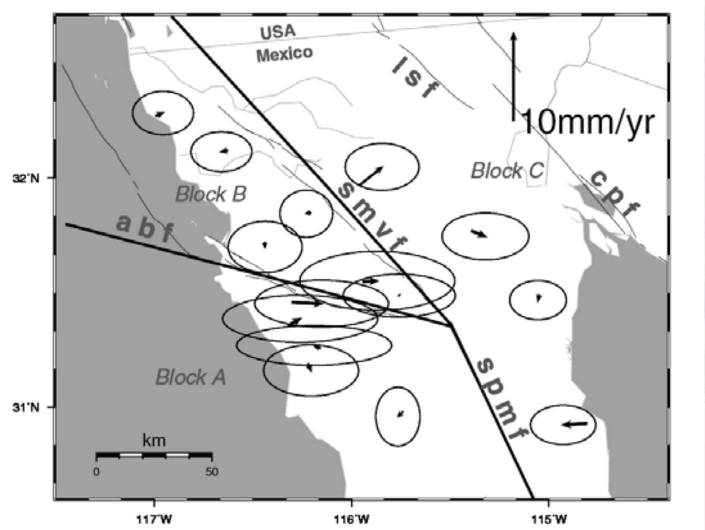
Dixon et al. (2002)

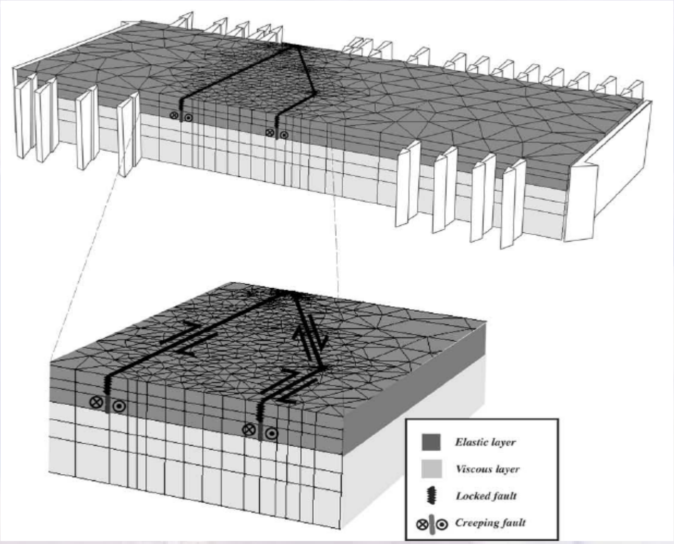


Elastic model

Visco-elastic model

Crustal deformation
Inter-seismic





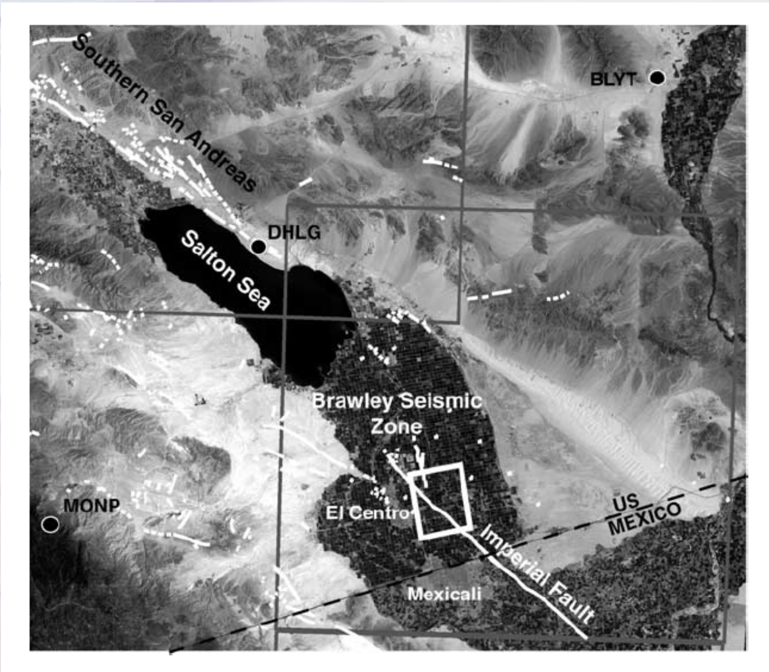
Conclusions:

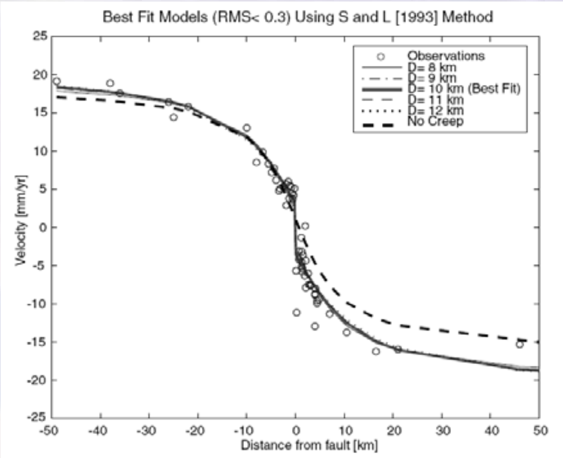
- Slip rate of the Agua Blanca and San Miguel Vallecitos faults is 4-8 mm/yr.
- Elastic half-space models predict roughly equivalent slip rates for the two faults, in the range 2–4 mm/yr.
- Viscoelastic models suggest that the Agua Blanca fault slips at a long-term rate of about 6 ± 1 mm yr1, while the San Miguel-Vallecitos fault slips at about 1 ± 1 mm yr1, in better agreement with geological data.

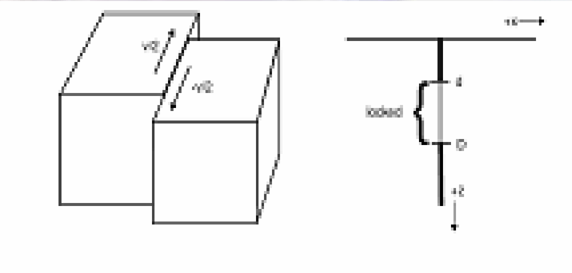
Dixon et al. (2002)

Crustal deformation

Creep



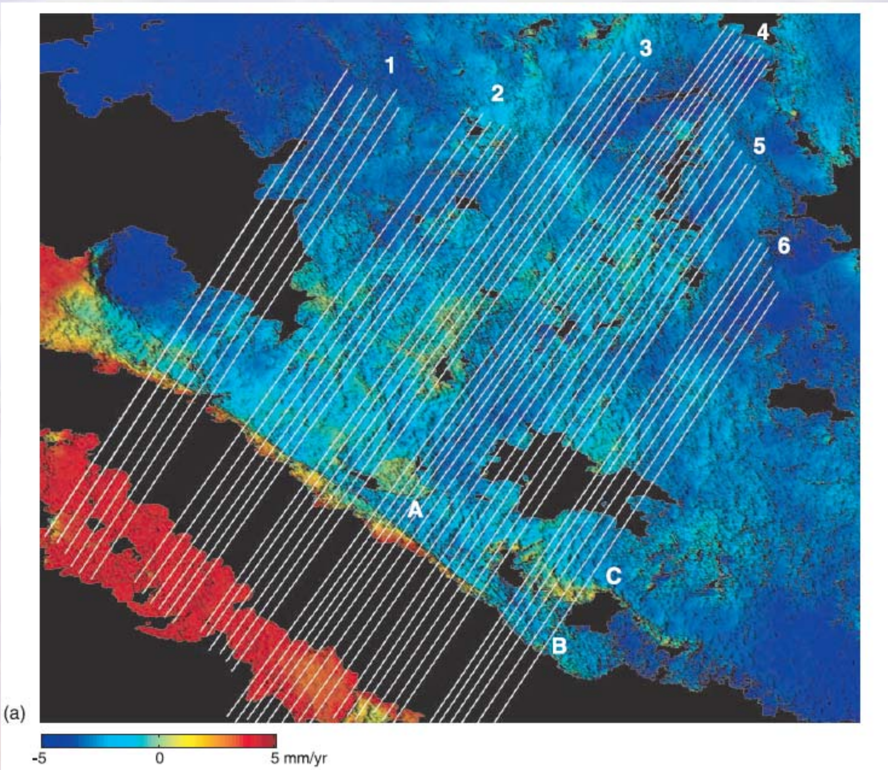


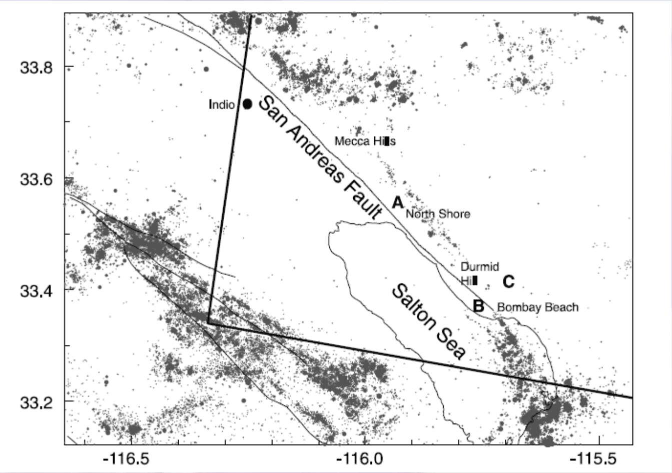


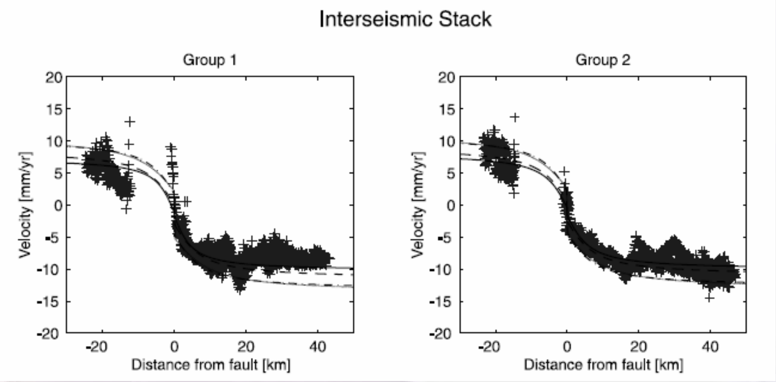
- <u>GPS</u> measurements across the Imperial Fault show ~45 mm/yr of slip
- Using Elastic dislocation model, they show slip partitioning: 35 mm/yr below 10 km and 10 mm/yr above 3 km.

Lyons, Bock, & Sandwell (2003)

Crustal deformation
Creep





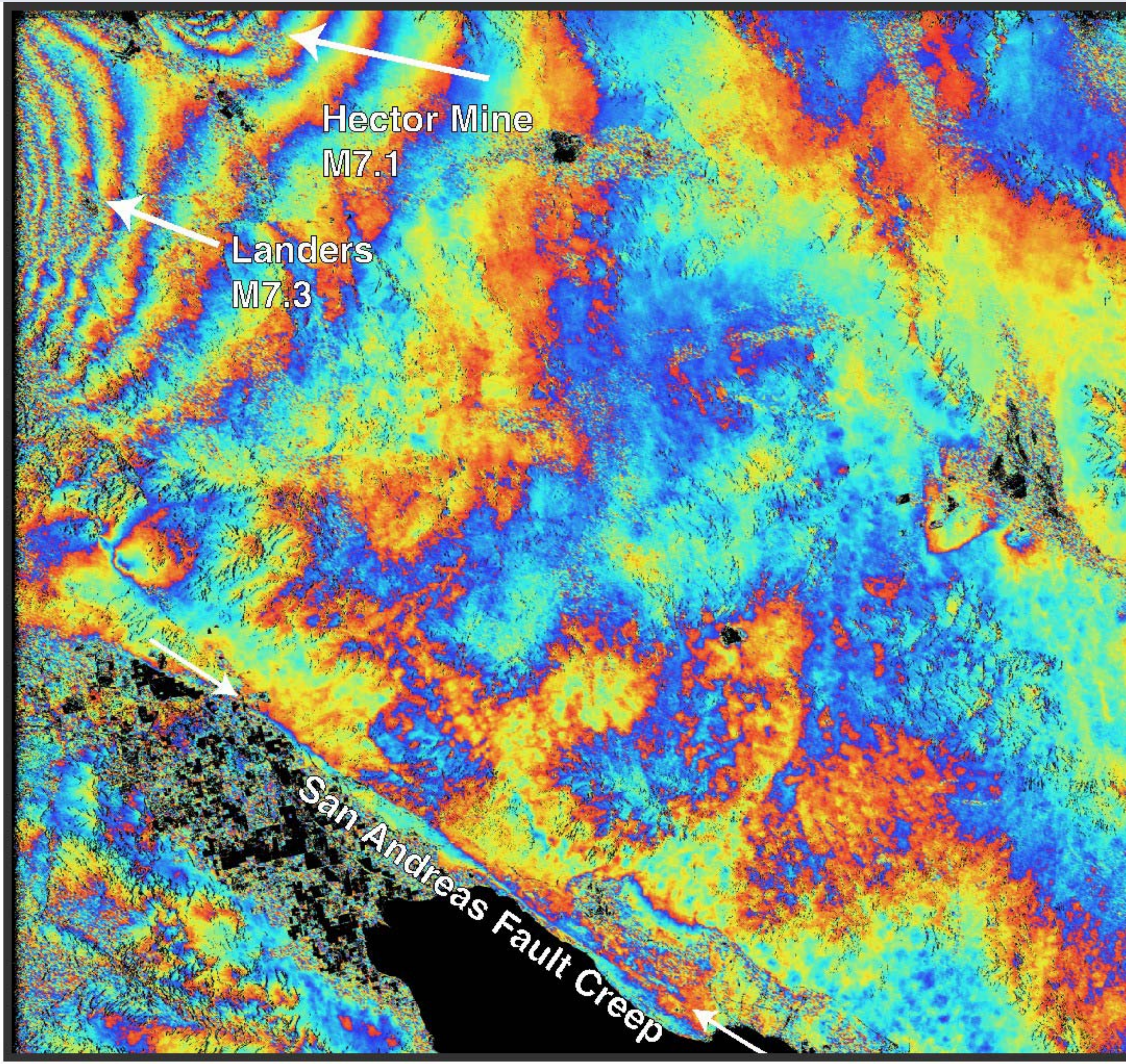


<u>InSAR</u> measurements of the southern Salton Trough area show:

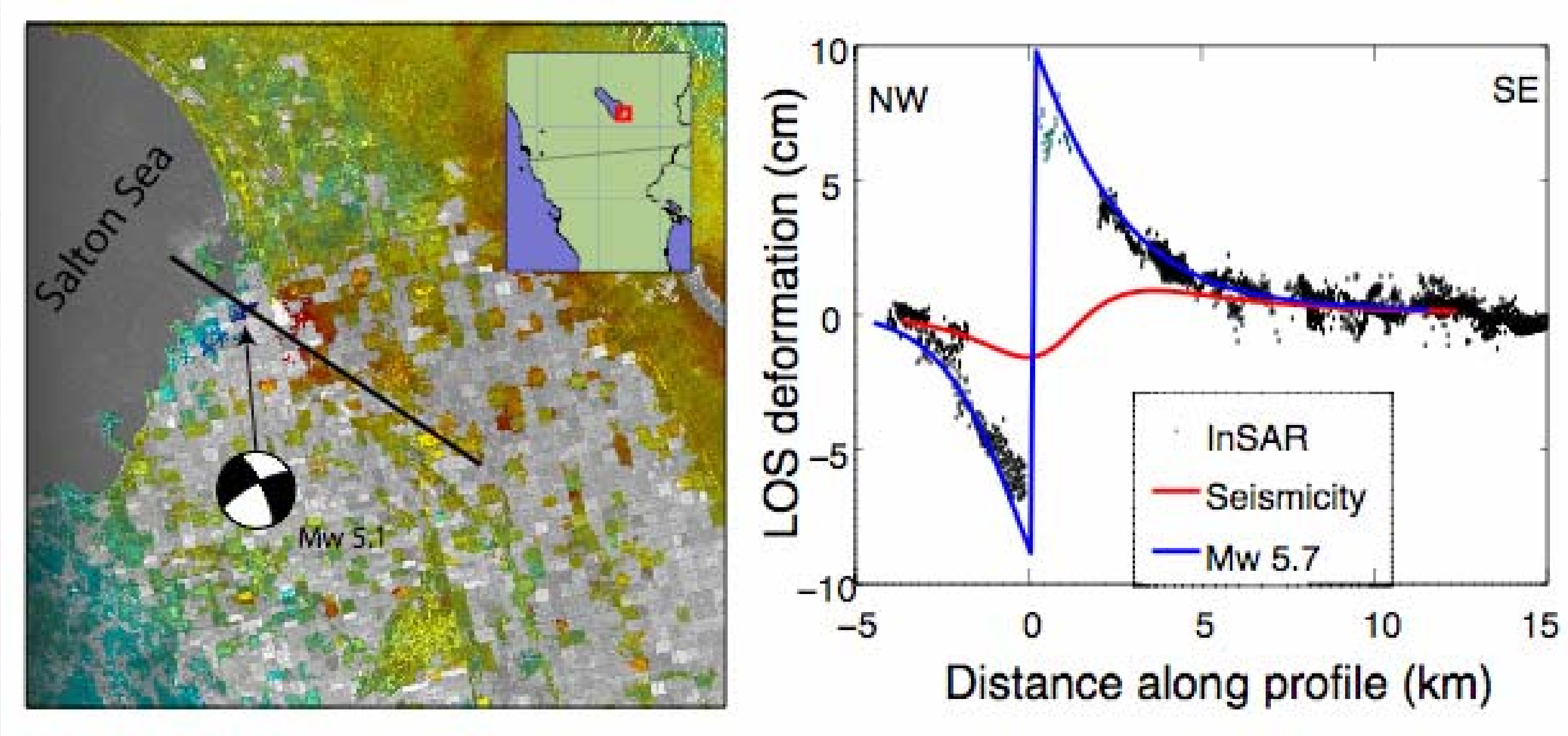
- **12-18 mm/yr creep along the southern San Andreas Fault.**
- **10 cm of triggered slip following the 1992 Landers EQ.**

Lyons & Sandwell (2003)

Shallow Creep on Southern San Andreas Fault



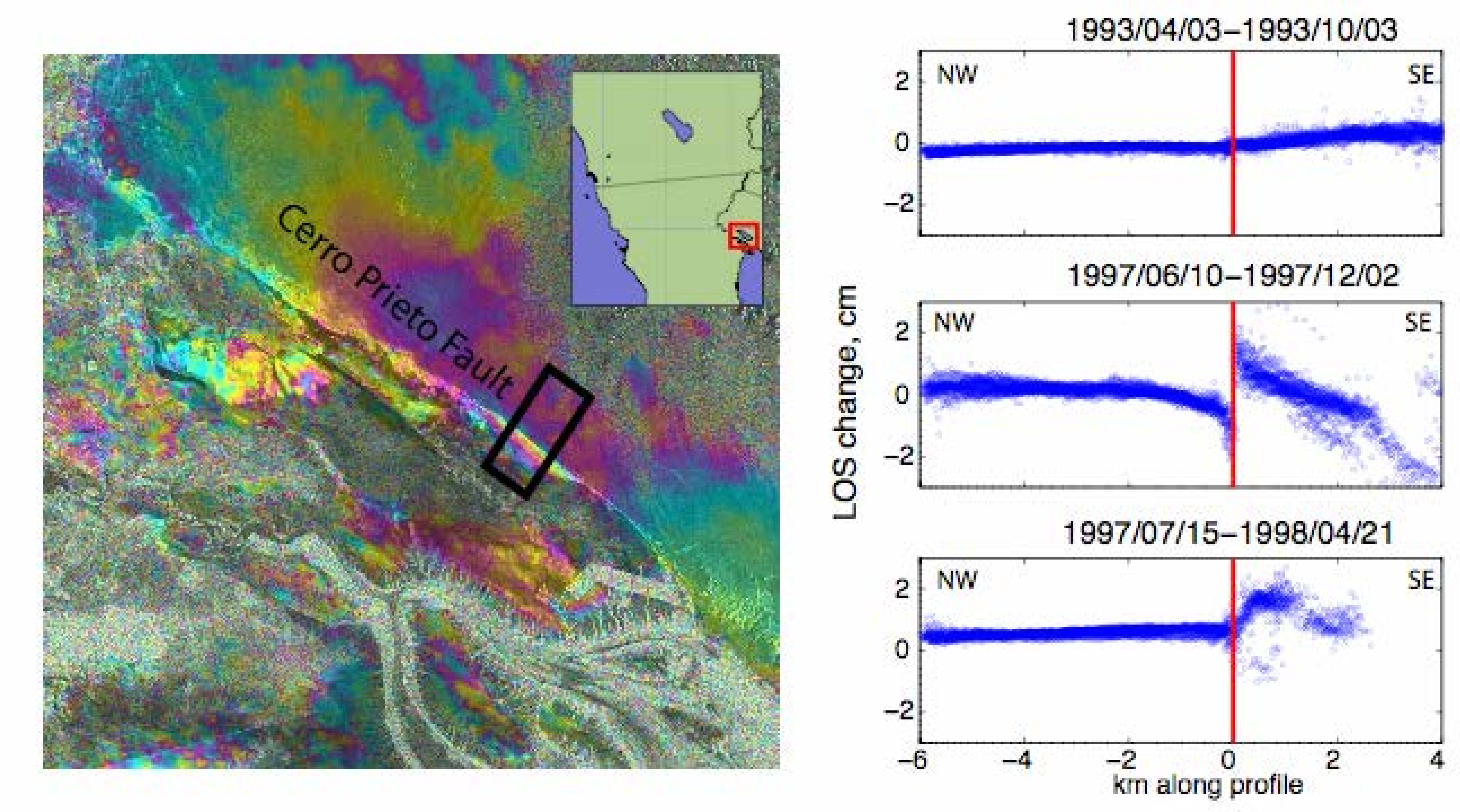
Aseismic slip and 09/05 earthquake swarm



- Seismicity alone can't explain observed deformation
- Mw 5.7 total slip required vs. Mw 5.3 recorded (5x as big)

Rowena Lohman

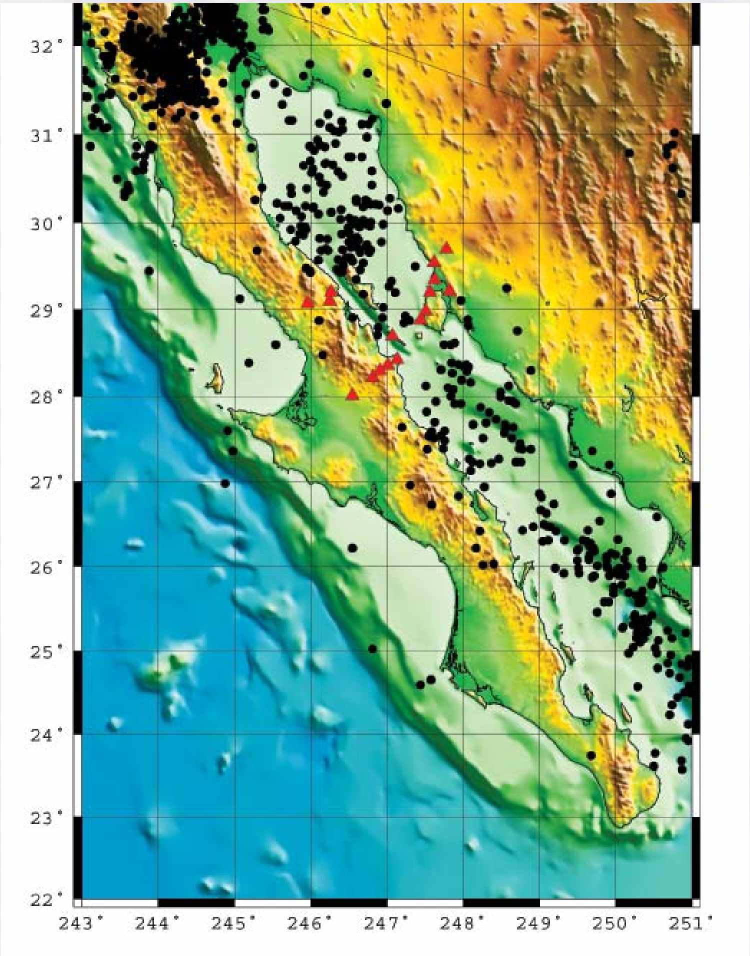
Creep on Cerro Prieto fault



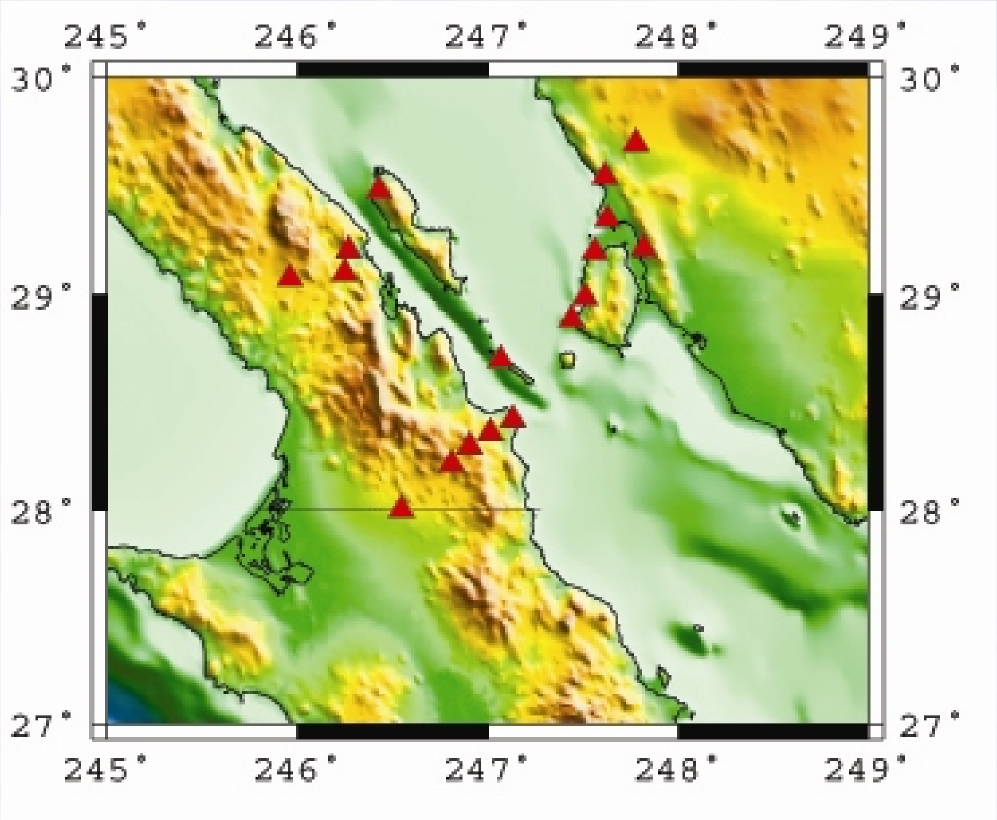
- Observed discontinuity across fault
- Temporally variable, need more observations

Rowena Lohman

Model constraints

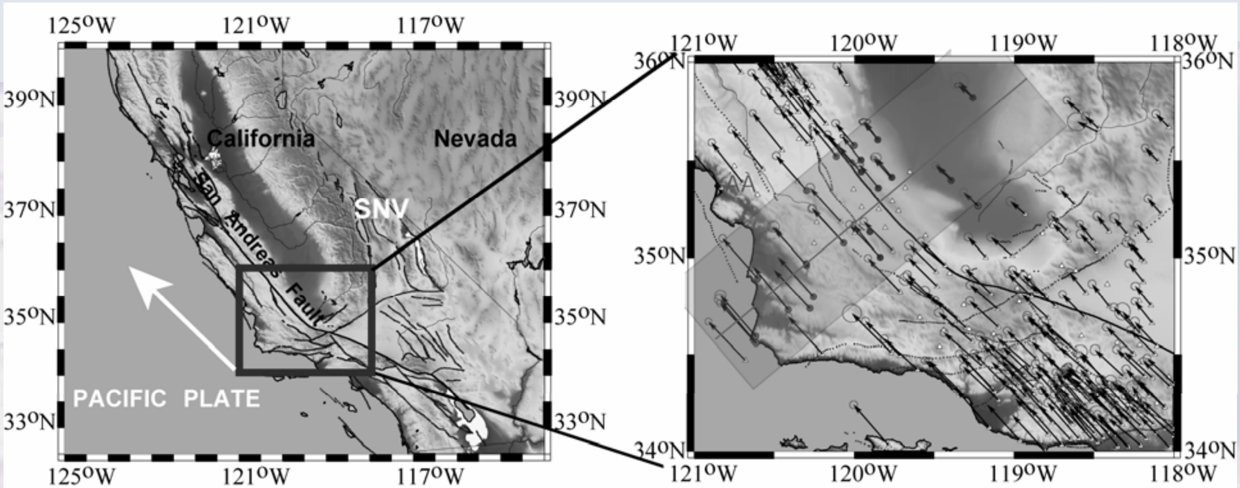


Gina's new GPS network - transect across the Gulf



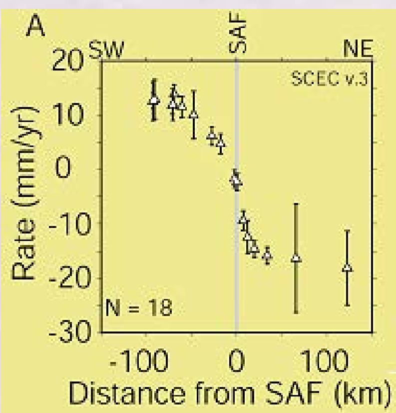
Gina Schmalzle et al.

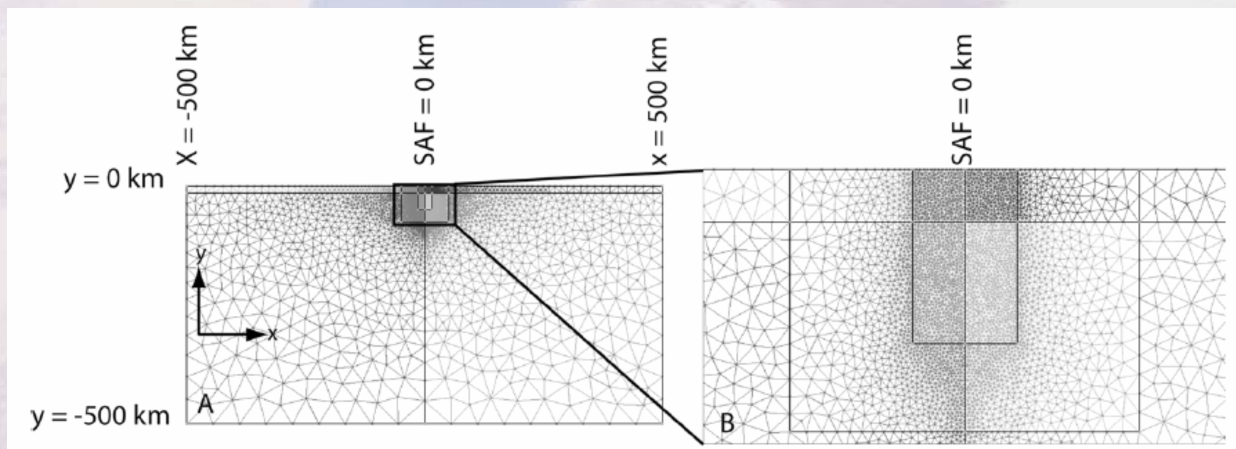
Model constraints



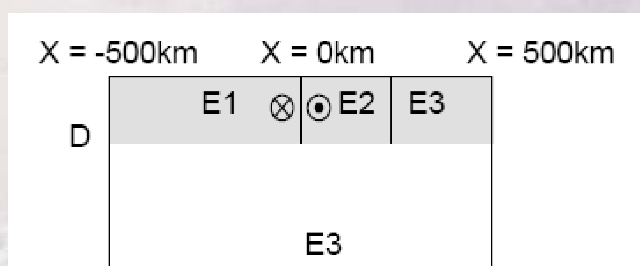
SCEC 3.0
Velocity field

Schmalzle et al., (2006)



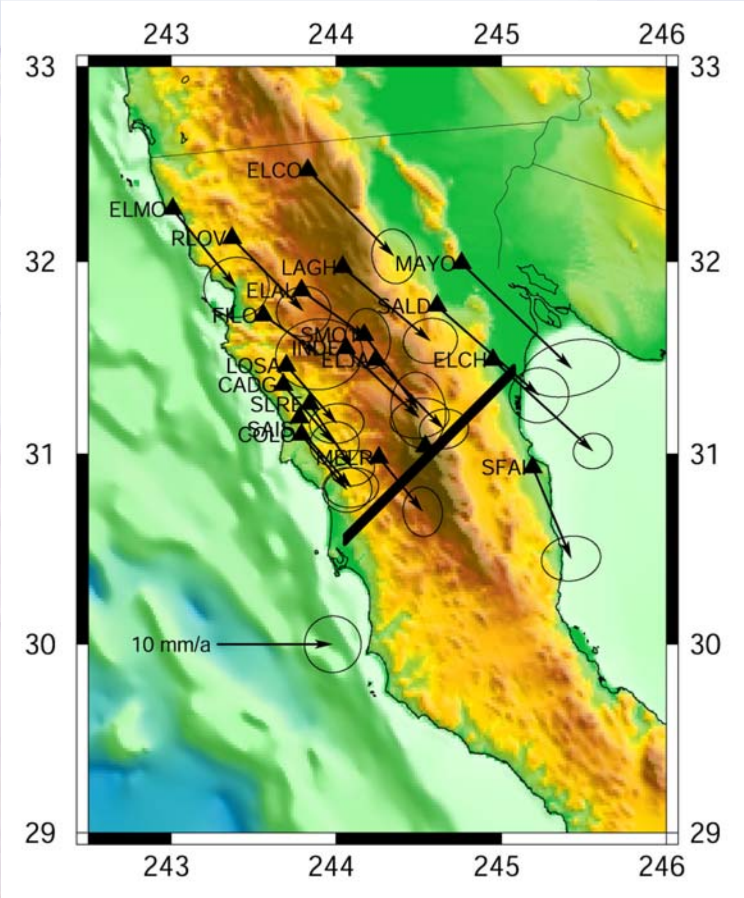


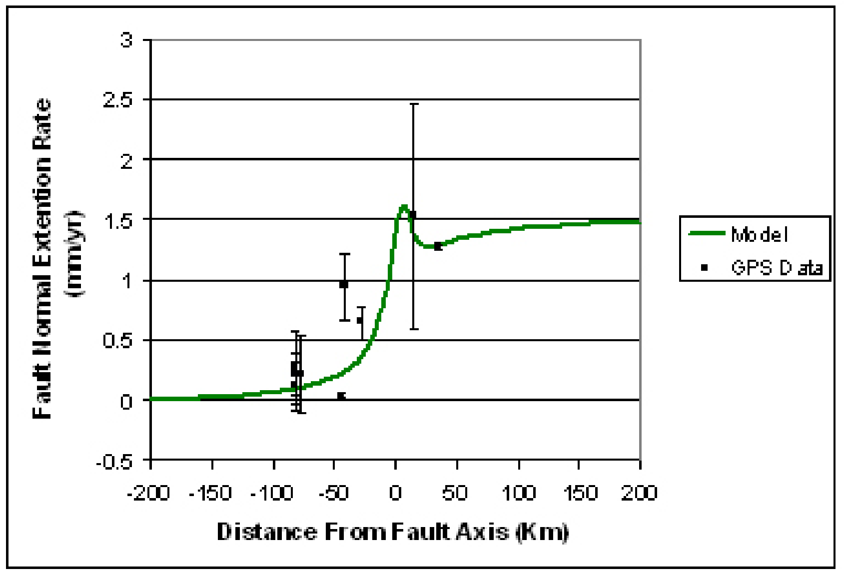
Velocity Profile: Fault parallel component
Asymmetric pattern



Lateral variations of crustal strength

Model constraints





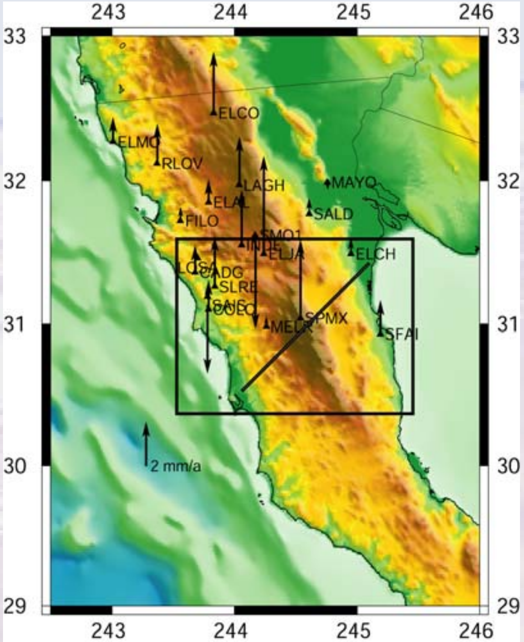
Fault normal extension can be explained by a locked fault model with 1.6±0.2 mm/yr dip-slip motion

GPS velocity field (1996-2004)

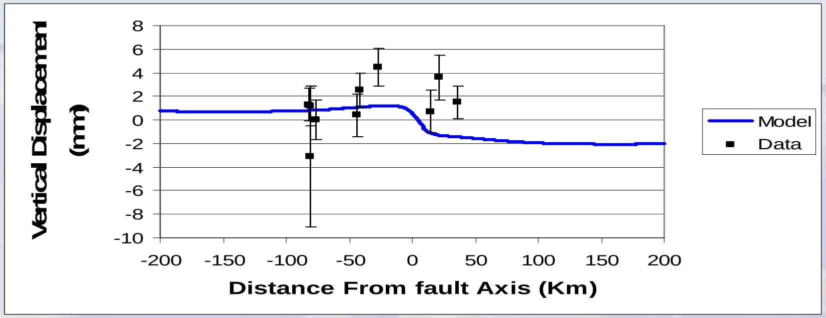
Horizontal components show right-lateral shear + extension

Kim Outerbridge et al.

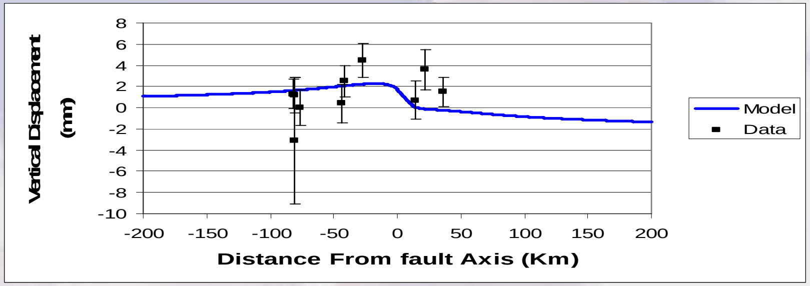
Model constraints



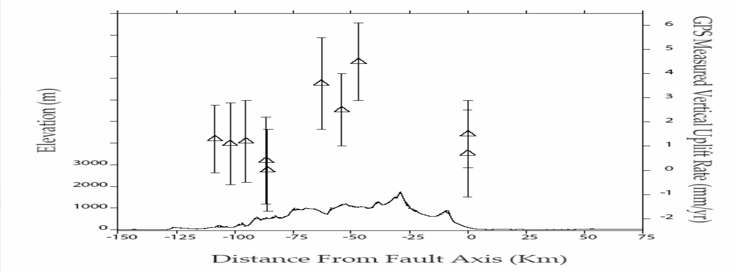
Vertical component

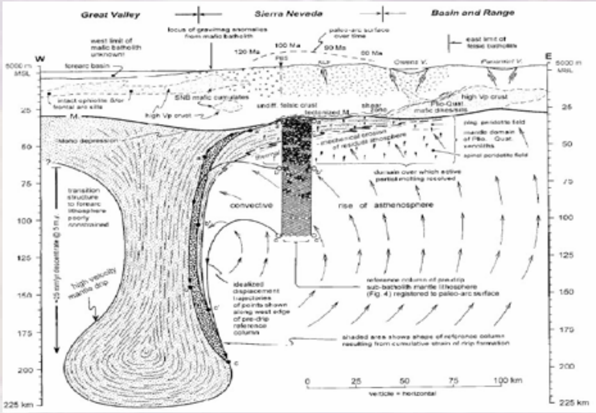


Model:Dip-slip + Isostasy



Model: Dip-slip + Isostasy + Long wavelength load





Saleeby et. Al., 2003

Kim Outerbridge et al.

Summary

- **Plate Motion**
  - **Central Baja behave as a rigid block.**
  - **It moves w/r to the Pacific plate at a rate of 3-8 mm/yr.**
  - **The relative motion between Baja and Pacific is absorbed by a "Baja California Shear Zone"**
- **Crustal deformation**
  - **Co- and Post-seismic:** leveling, triangulation, trilateration measurements indicate:
    - **right-lateral slip of 0.8-4.8 m for the 1940 EQ; 1-4 m for the 1979 EQ.**
    - **30-75 cm of post-seismic deformation following both events.**
  - **Inter-seismic: GPS measurements show strain accumulation across main faults segments. Derived slip-rates are 3-45 mm/yr.**
  - **Creep: GPS and InSAR measurements indicates 9-18 mm/yr creep along the southern San Andreas and the Imperial faults. InSAR also shows 10 cm of triggered slip following the 1992 Landers EQ.**
- **Model constraints**
  - **Geodetic measurements can constrain estimates of crustal strength and its lateral variations.**
  - **GPS observed vertical movements in northern Baja suggests a long wavelength (deep) uplifting process, possibly delamination of mantle lithos.**