USArray and other deep seismic studies of continental structure and processes in the Colorado Plateau and Rio Grande Rift

Rick Aster
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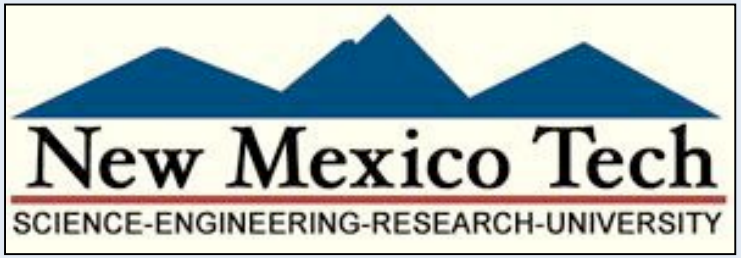
Earth and Environmental Science Department
PASSCAL Instrument Center and EarthScope Array Operations Facility P.I.

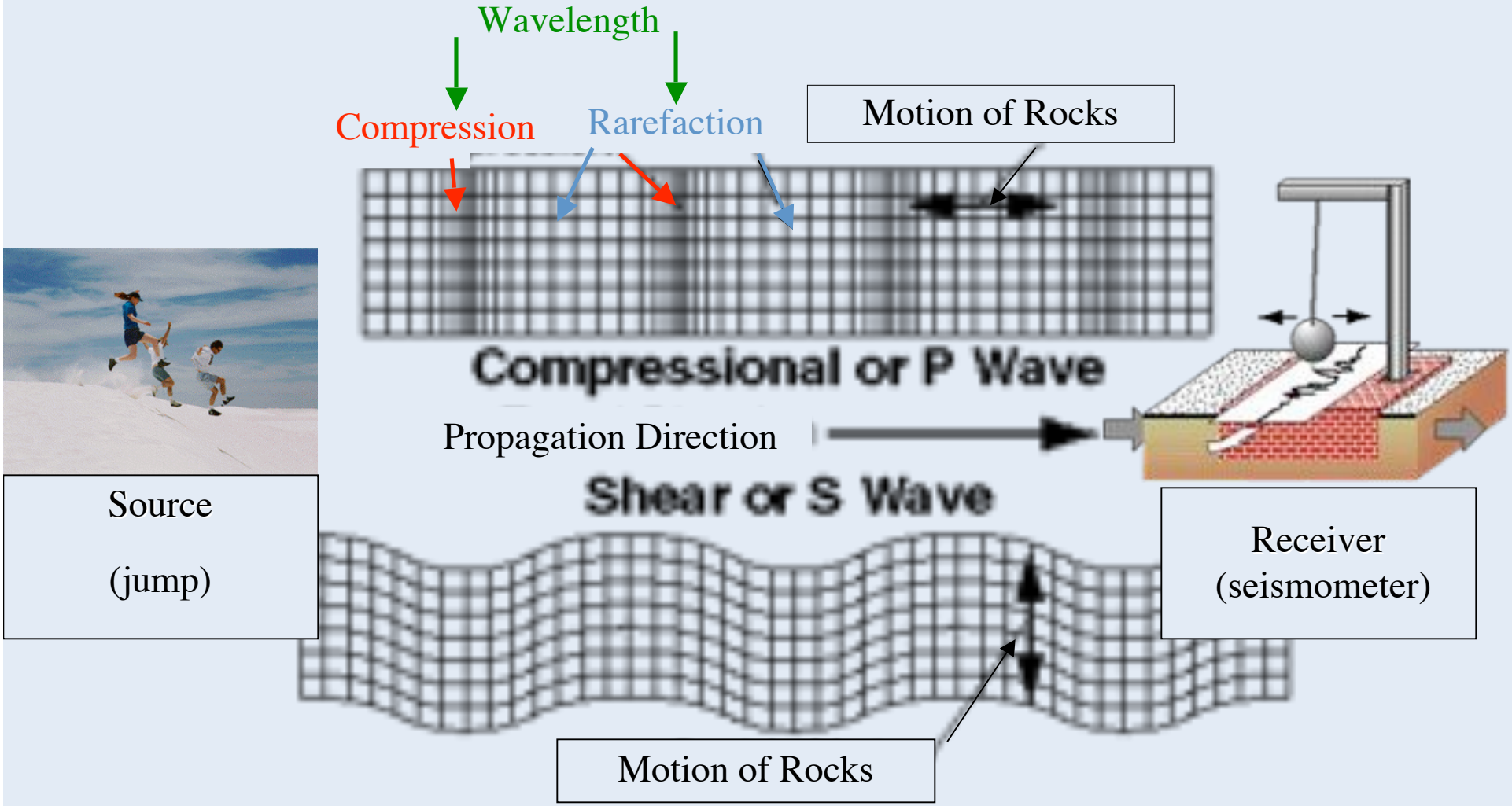


NMMNHS, October 25, 2009

Overview

- We are in a “golden age” for “discovering the Earth” using new seismological imaging techniques. EarthScope is the present-day culmination of this drive to understand the Earth.
- Touch on a few things have learned (and are working on learning) about the large-scale history and structure of the Southwestern U.S. and New Mexico with EarthScope and other new data.

Seismology: Source, Propagation, Receiver



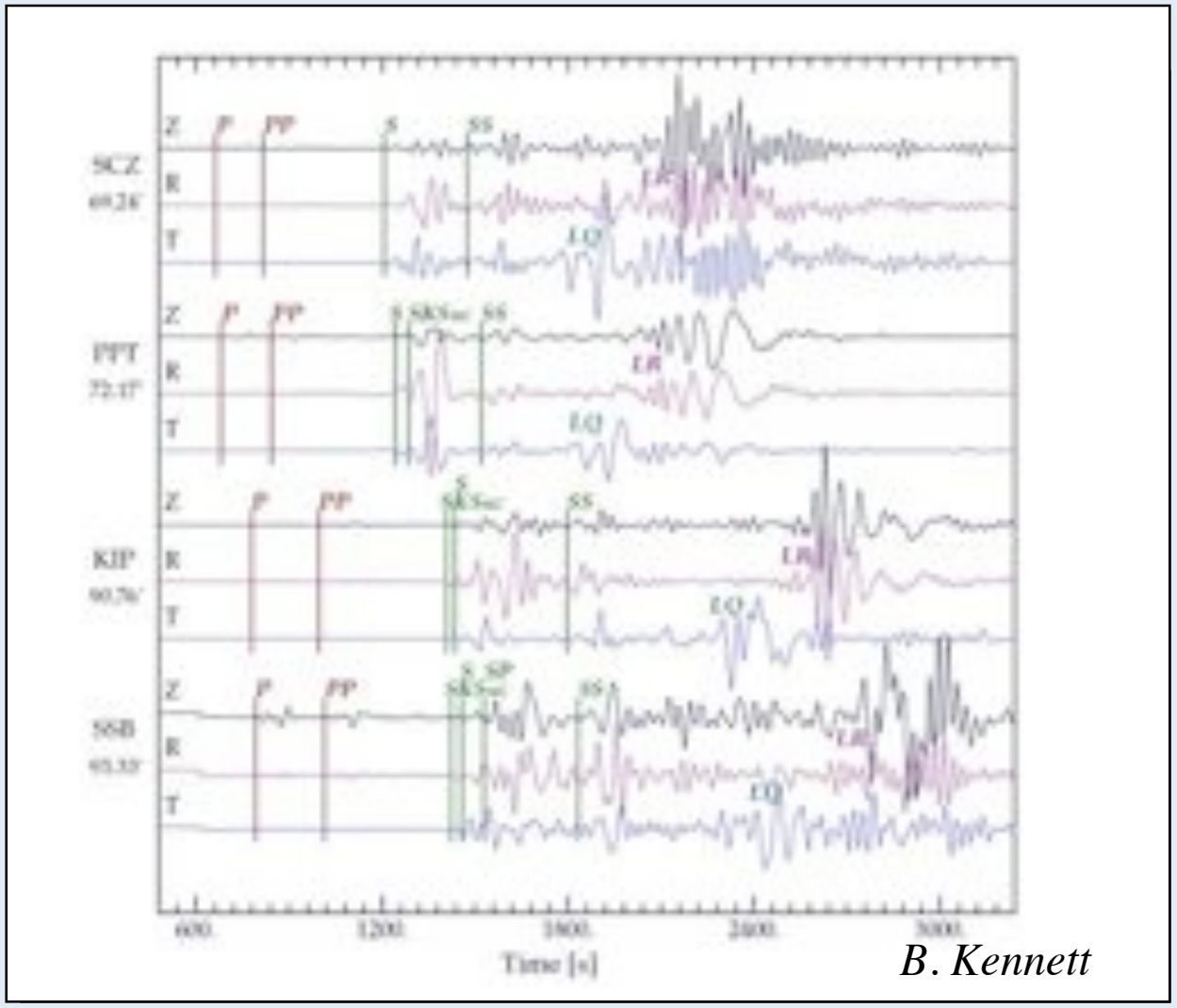
Excellent seismometer java applet c/o Fritz Keller:

http://www.ifg.tu-clausthal.de/java/seis/sdem_app-e.html

Seismic Waves are Highly Sensitive to Elasticity and Density Changes

- **Refraction**
- **Reflection**
- **Conversion**

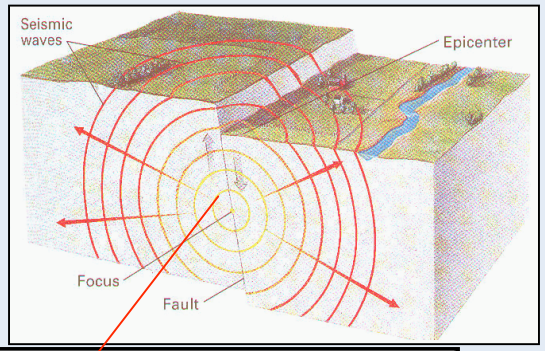
…enable us to "x-ray" the Earth (and earthquakes provide free illumination!)



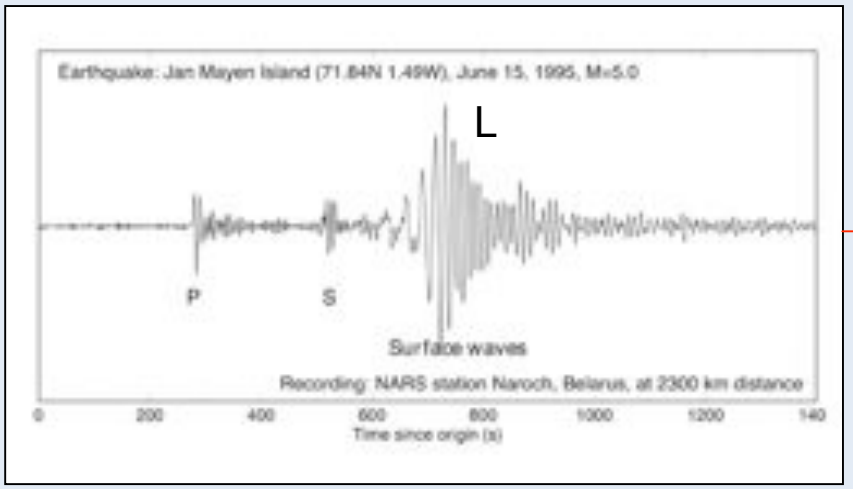
http://www-crewes.geo.ucalgary.ca/Samples/ZoepExpl/ZoeppritzExplorer.html

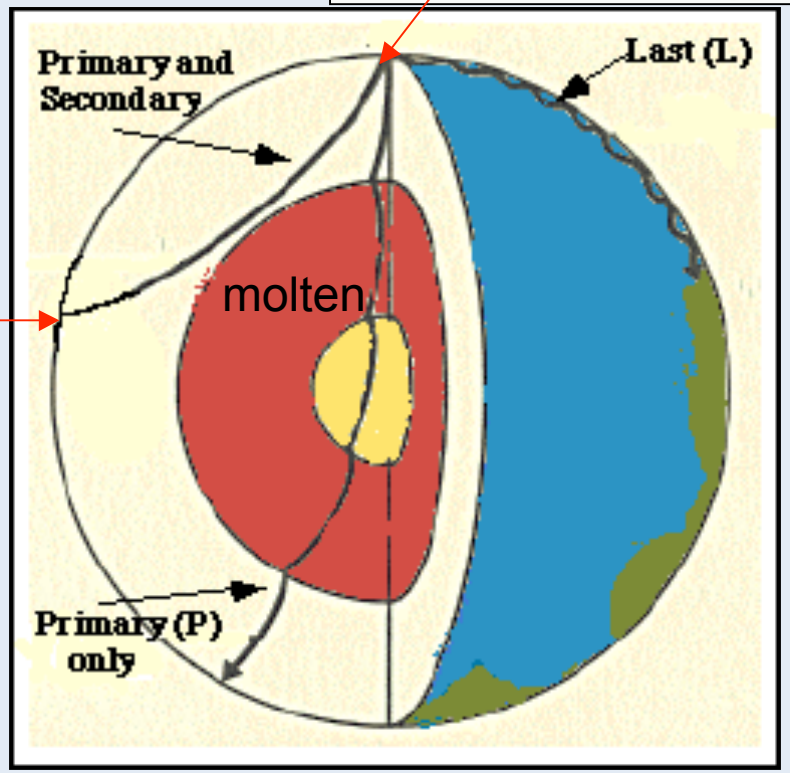
Seismic Waves Propagate Through the Entire Earth with Little Attenuation

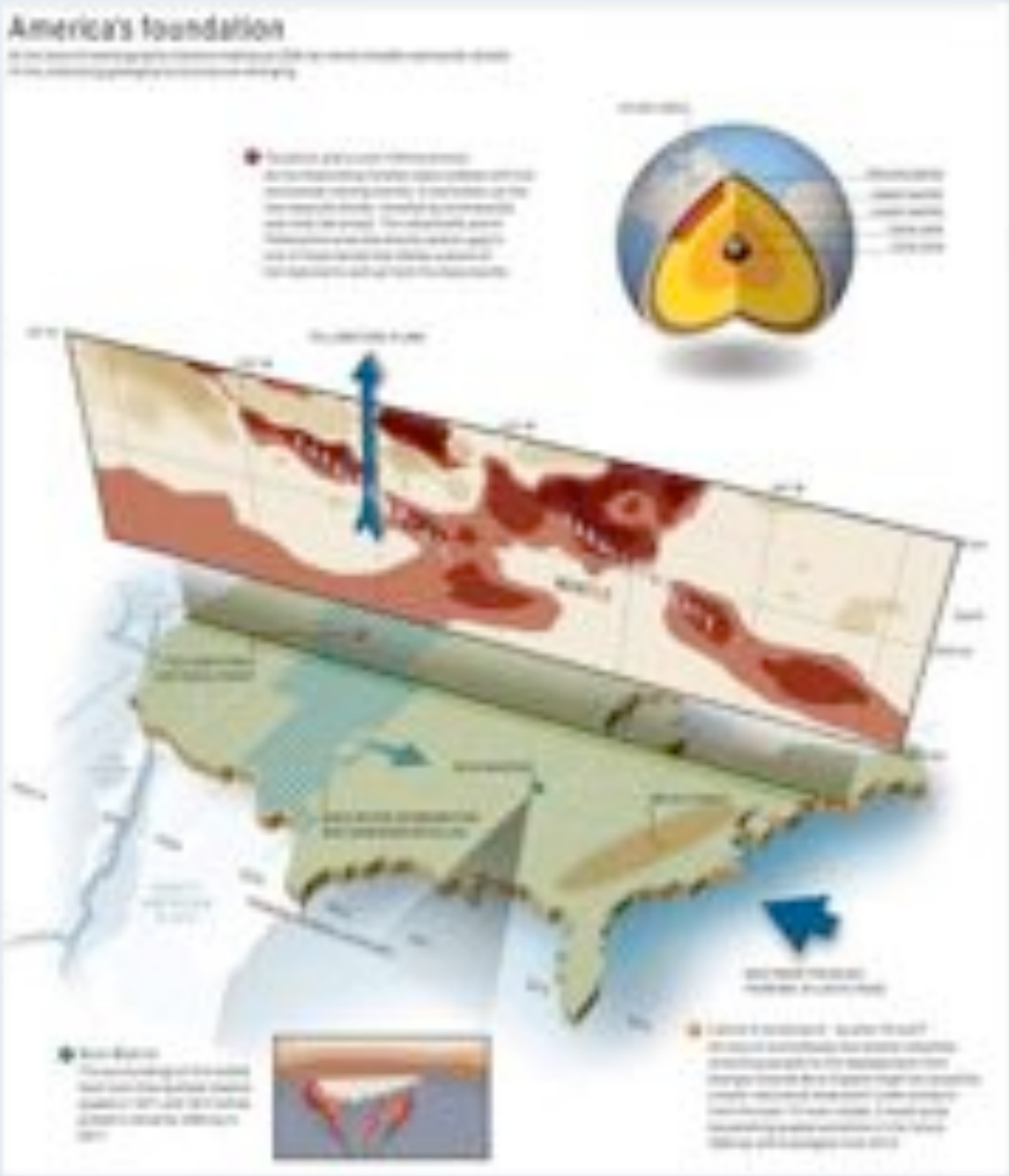
Source (Earthquake)



Recording (Seismogram)







The Earth is dynamic

The Continents are a complex interplay of past history, new processes, and reactivated old structures

The nearest plate boundary for most people is directly below their feet (the lithosphere-asthenosphere boundary 100-200 km down).

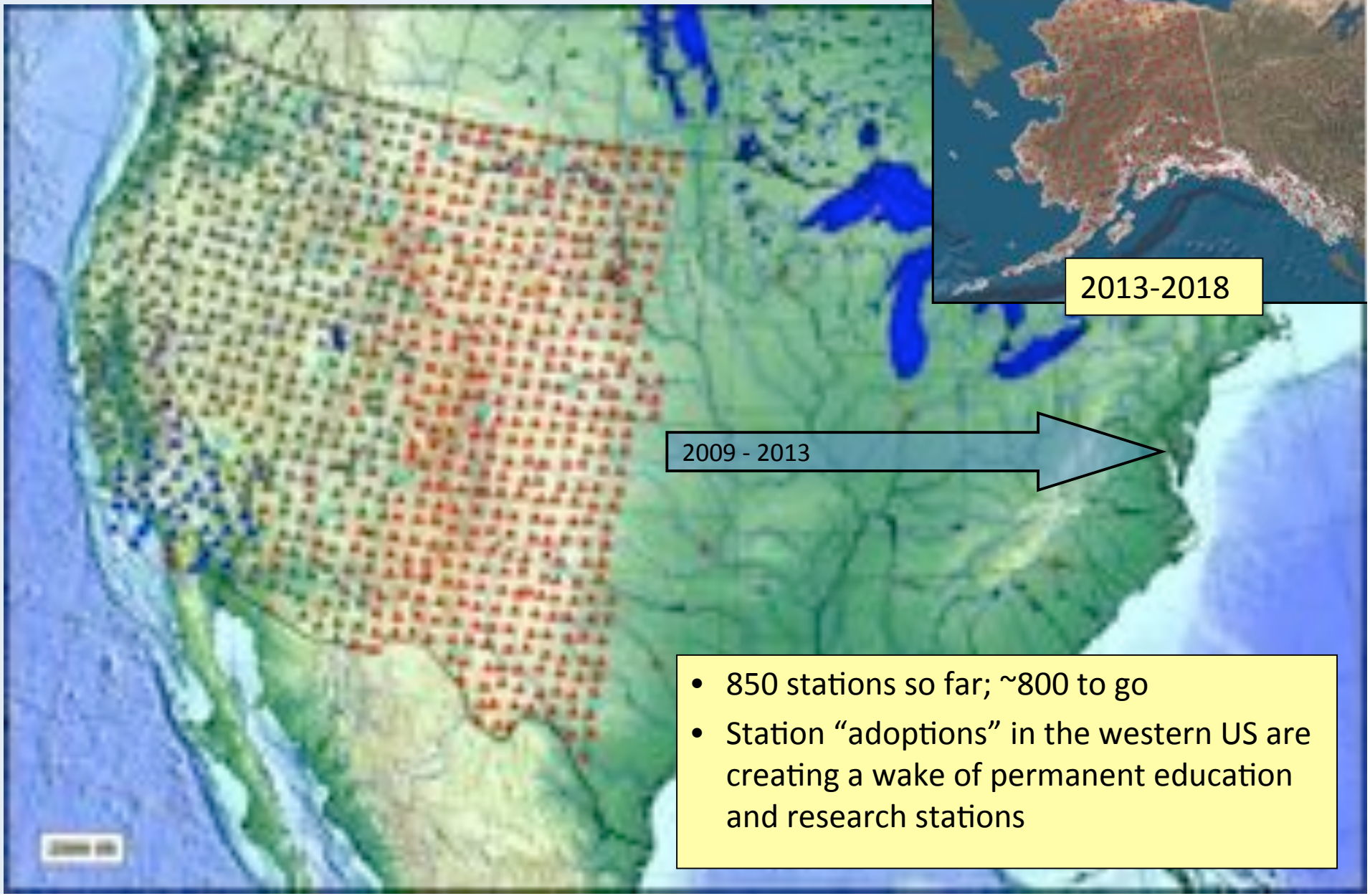
The mantle “lava lamp” contains structures from continental to 10s of km-scale and couples strongly to Earth’s surface.

New Scientist, 11 April, 2009

Scientific History in our Backyard; EarthScope Instruments, 8/12/08

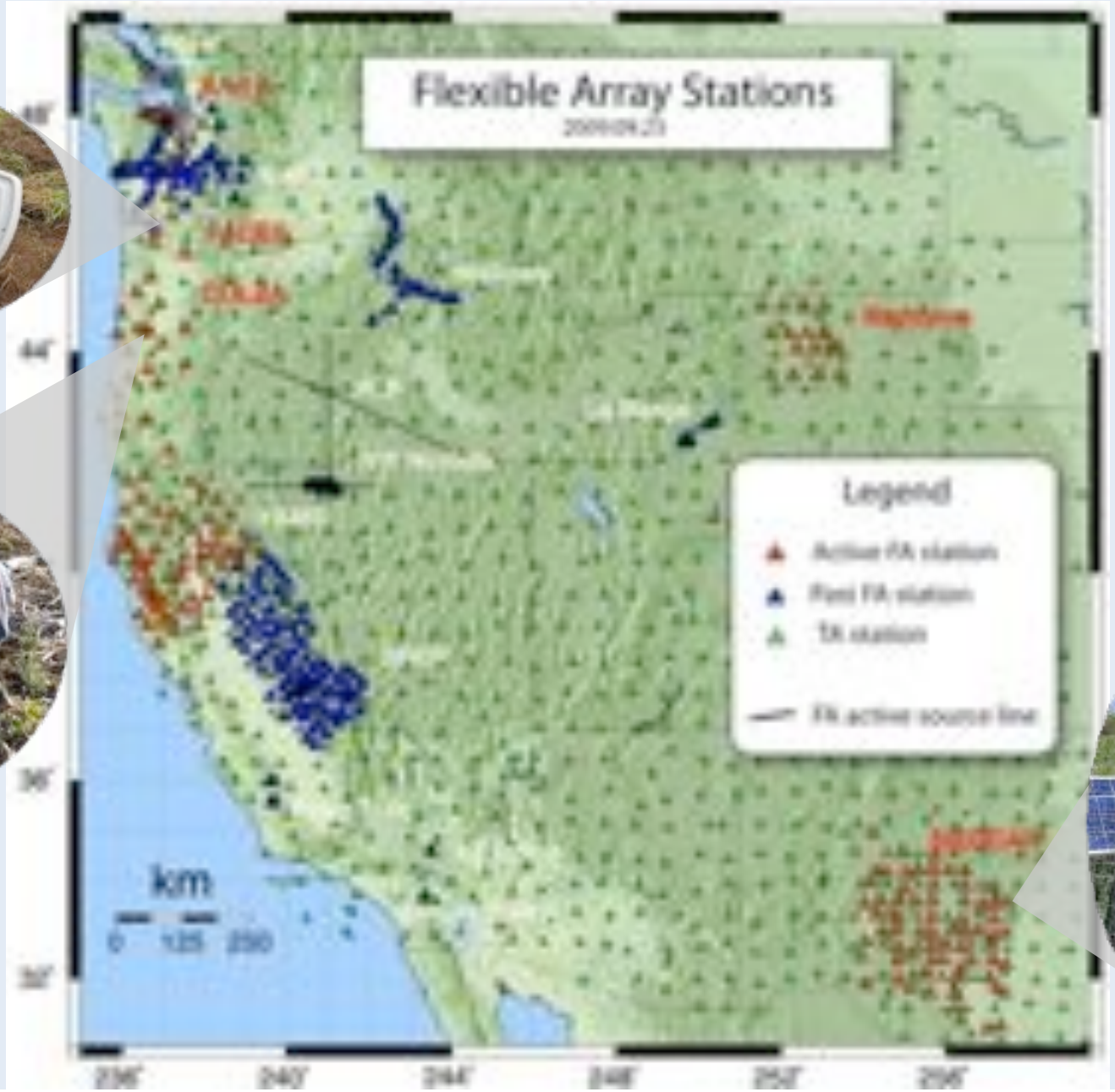
NM Tech IRIS PASSCAL Instrument Center and USArray Array Operations Facility

Transportable Array

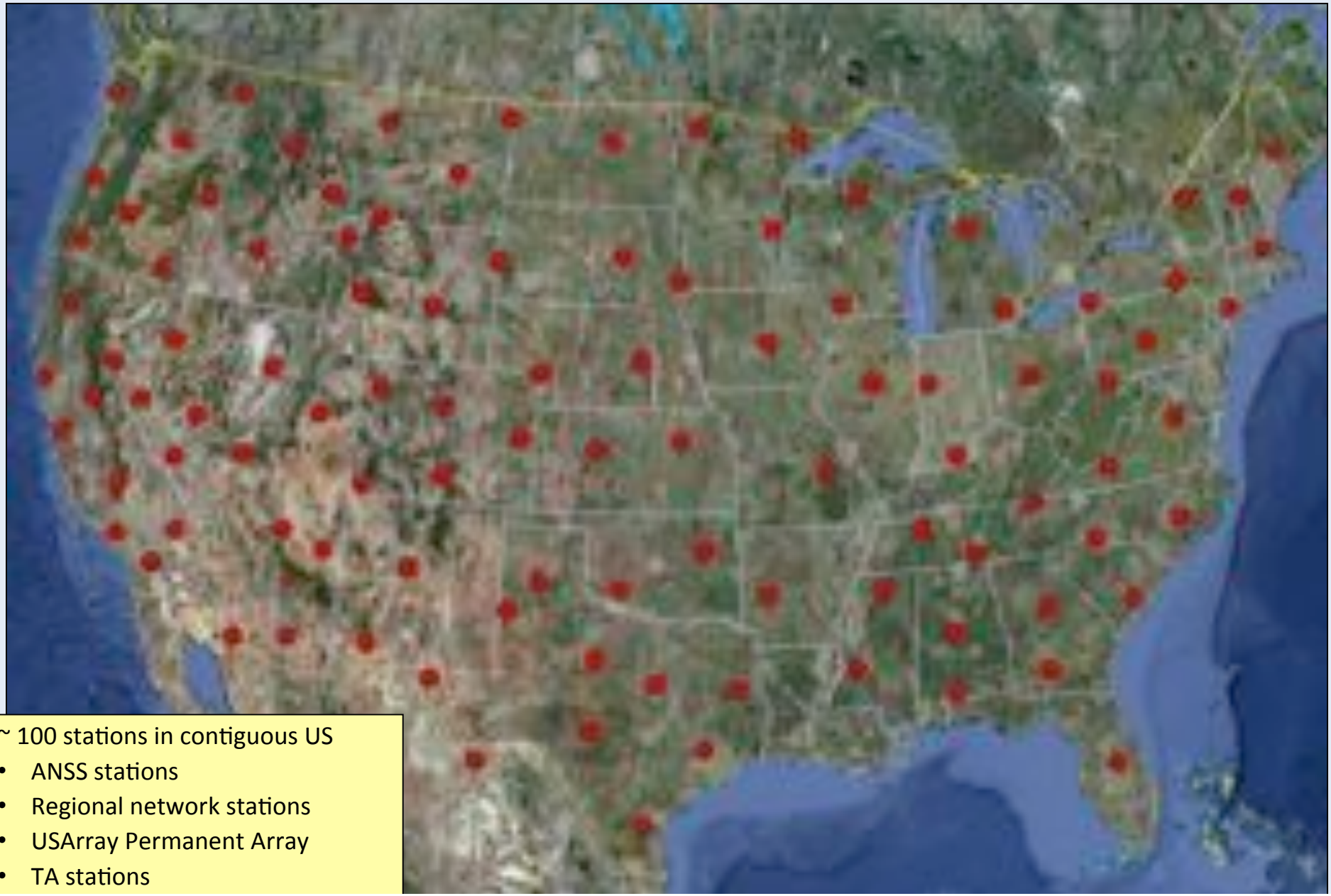


- 850 stations so far; ~800 to go
- Station “adoptions” in the western US are creating a wake of permanent education and research stations

Flexible Array



Reference Network



~ 100 stations in contiguous US

- ANSS stations
- Regional network stations
- USArray Permanent Array
- TA stations

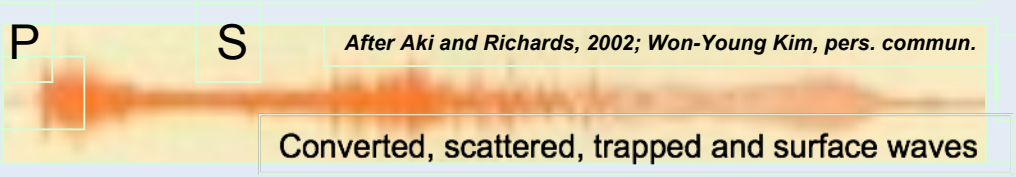
Seismologists analyze seismograms using many different signal processing techniques…

J.B.J. Fourier (1787-1830)

Filtering:

10 minutes

“Broadband” Seismogram

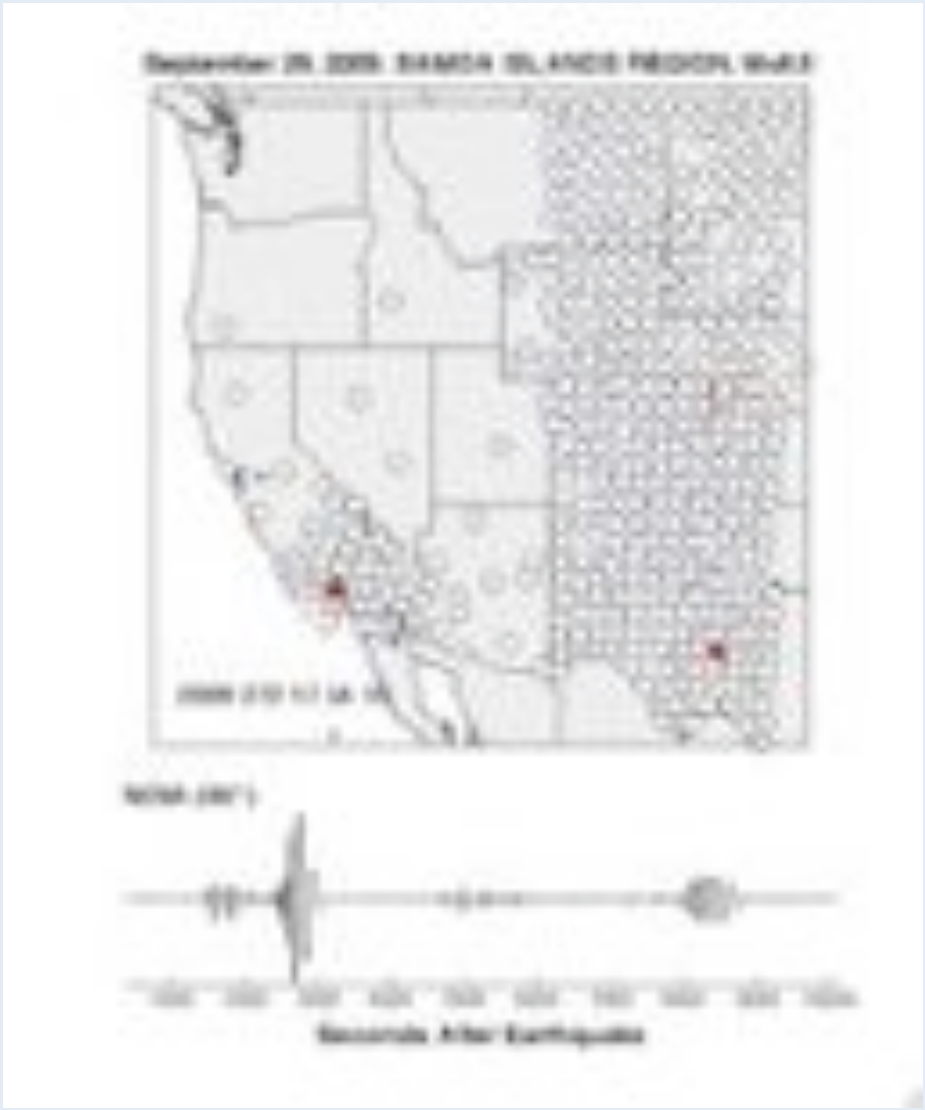


1 micron/s

1000 x speed

Semipalatinsk (Kazakhstan, former Soviet Union) nuclear test, July 8, 1989, recorded in China at a range of 955 km

Visualization of vertical ground motion from a large teleseismic earthquake…



- Signals are dominated by surface (Rayleigh) waves.
- Displacement amplitudes are 10's of to ~100 microns.
- Signals from a large earthquake anywhere in the world are easily detectible for up to many hours.

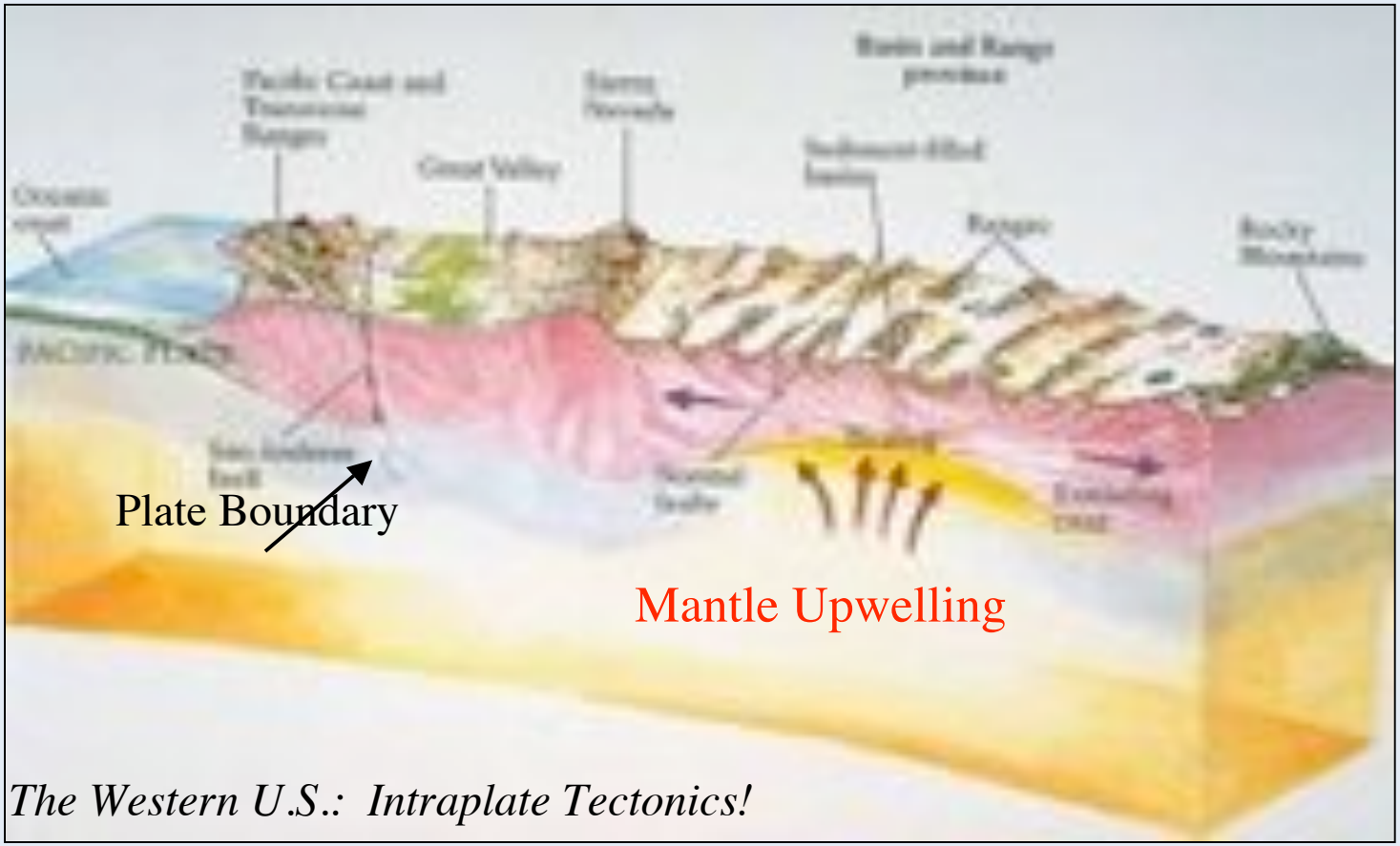
c/o Chuck Ammon, PSU.

So, what do seismologists actually measure from these data?

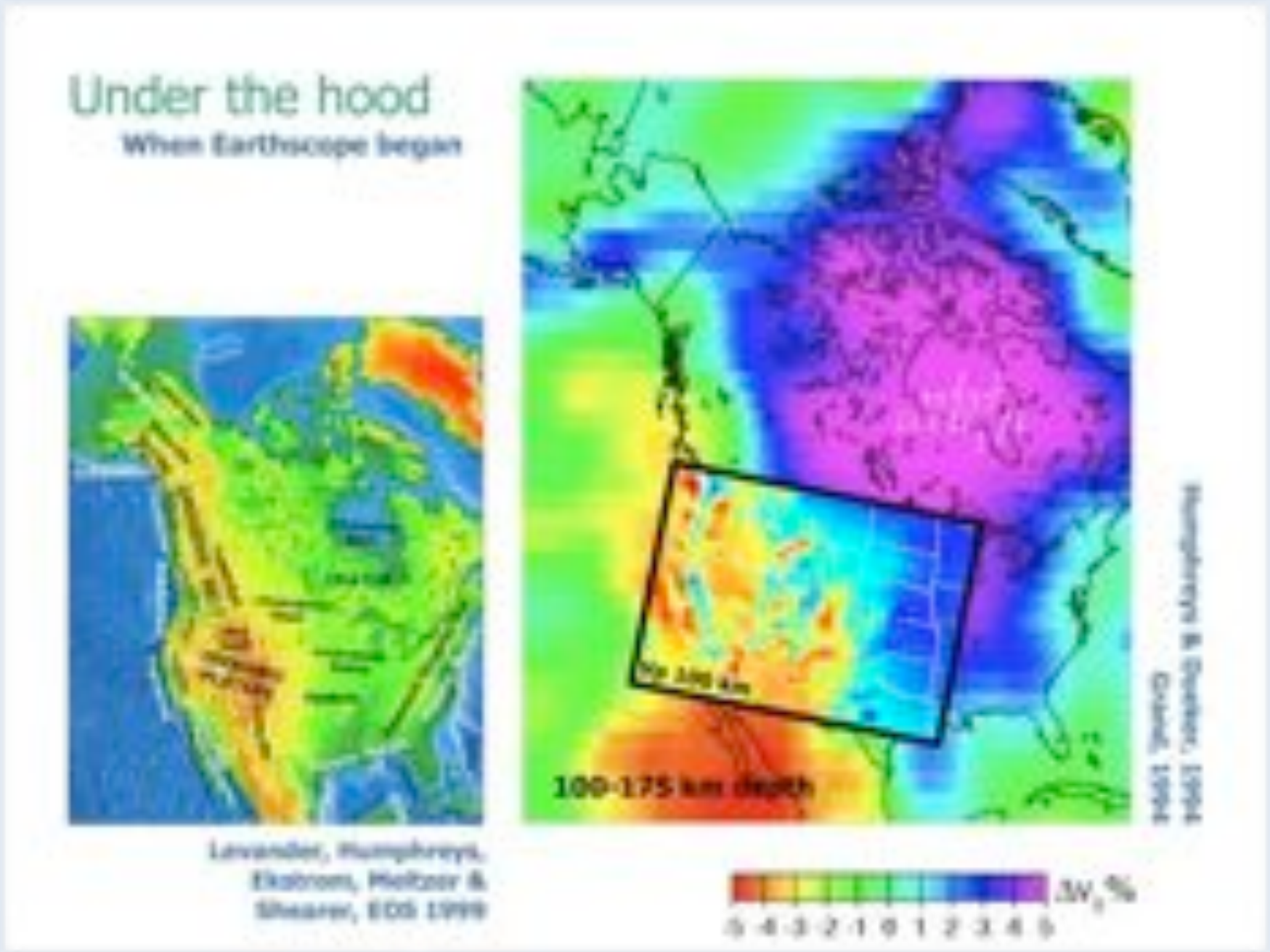
- Fundamental measurements (often measured as a function of period/frequency). These measurements are used to both study sources and receivers.
  - Presence or absence of arrivals ("phases"). *Reflecting/refracting discontinuities.*
  - Arrival times (absolute and relative to the entire network/array). *Seismic velocity structure.*
  - Polarization (orientation of ground motion in 3-d). *Seismic anisotropy.*
  - Amplitude of ground motion. *Seismic attenuation, discontinuity details, focusing, unfocusing, etc.*
  - Complete and detailed waveforms (*full waveform modeling; the future!*)

The Western U.S is a remarkable region of extended deformation (comparable to Tibet and the Andes in extent). This was a major motivation for EarthScope.

•In much of the interior western United States, mantle upwelling has produced a heating, thinning, and stretching of the crust thousands of kilometers from the plate boundary.



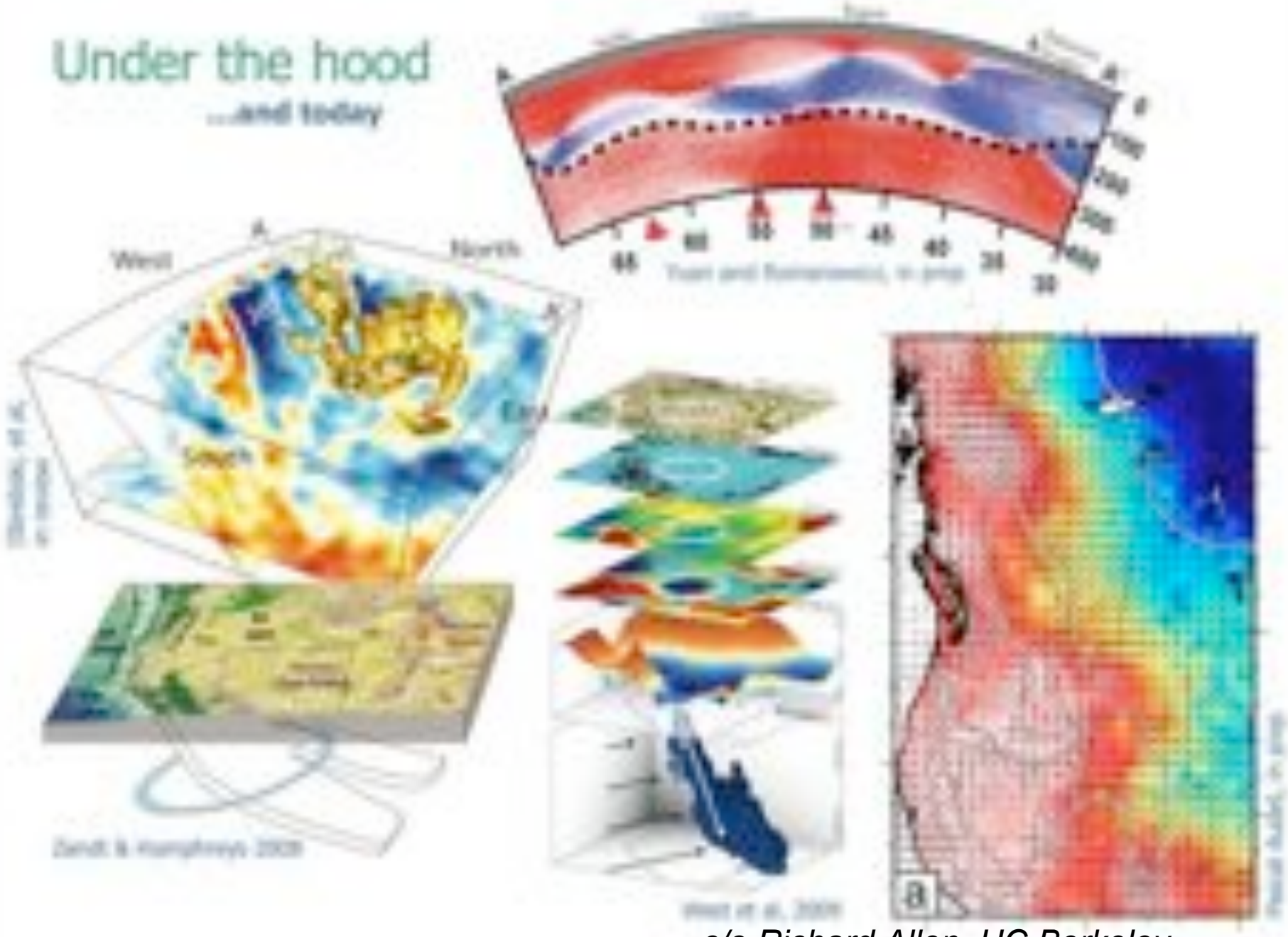
The Western U.S.: Intraplate Tectonics!



c/o Richard Allen, UC Berkeley

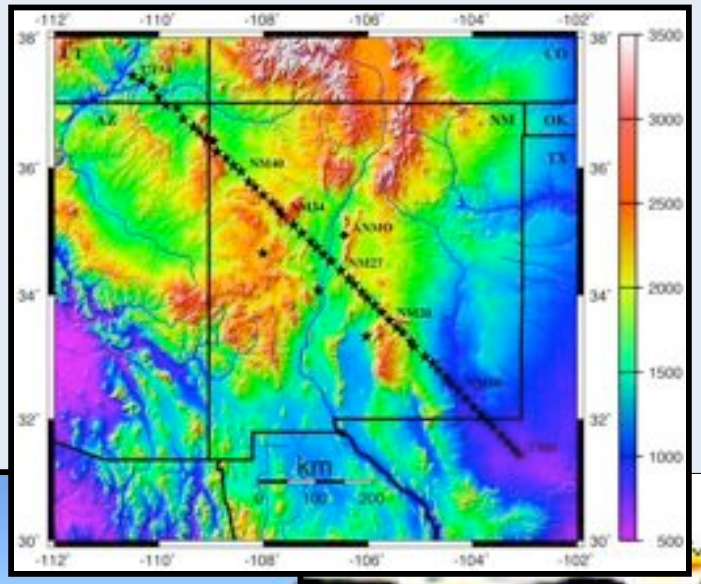
Under the hood

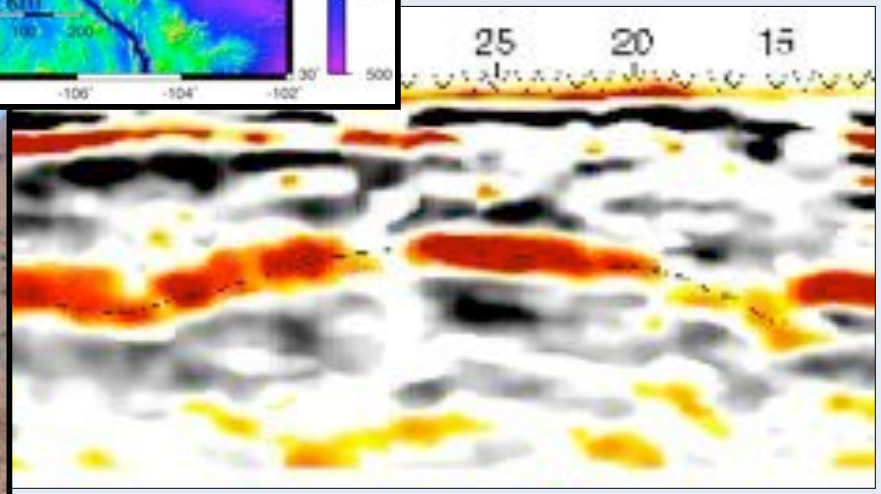
...and today



c/o Richard Allen, UC Berkeley

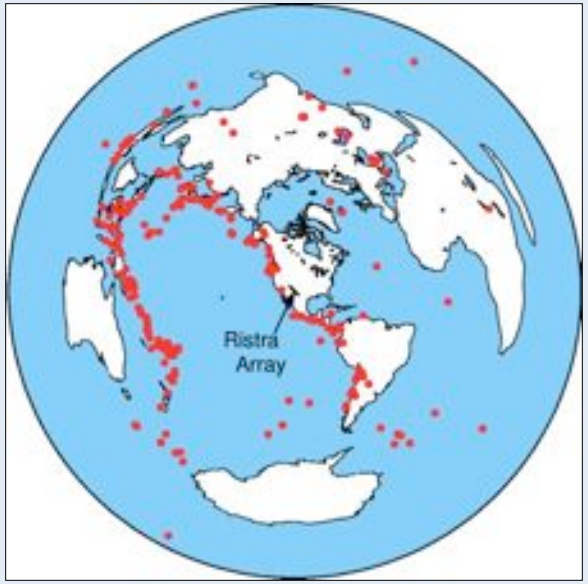
Example Research: RISTRA (Rio Grande Rift Seismic Transect)



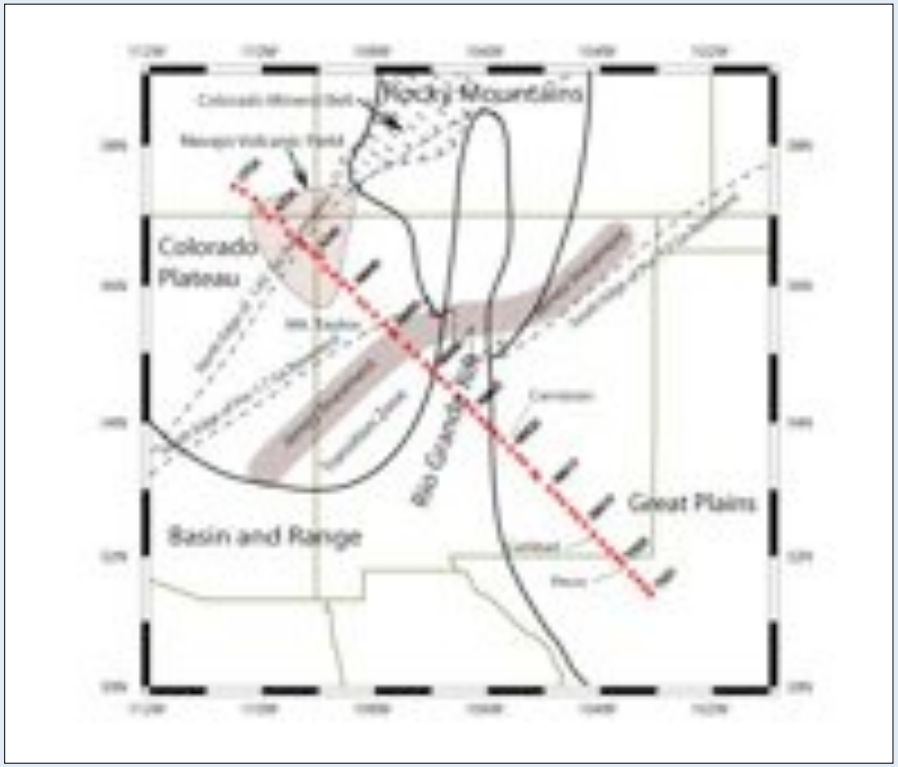


- A 950 km nearly great circle transect.
- Pre-EarthScope
- Recorded 401 earthquakes with $m_b \geq 5.6$ and 129 with $m_b \geq 6.0$.

Research supported by NSF and Los Alamos IGPP. Logistical and equipment support from the IRIS PASSCAL Program.

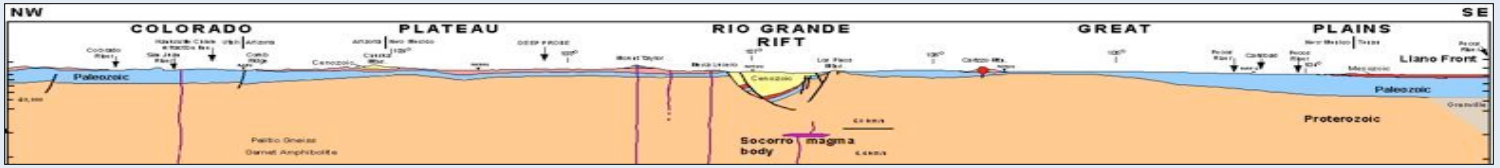


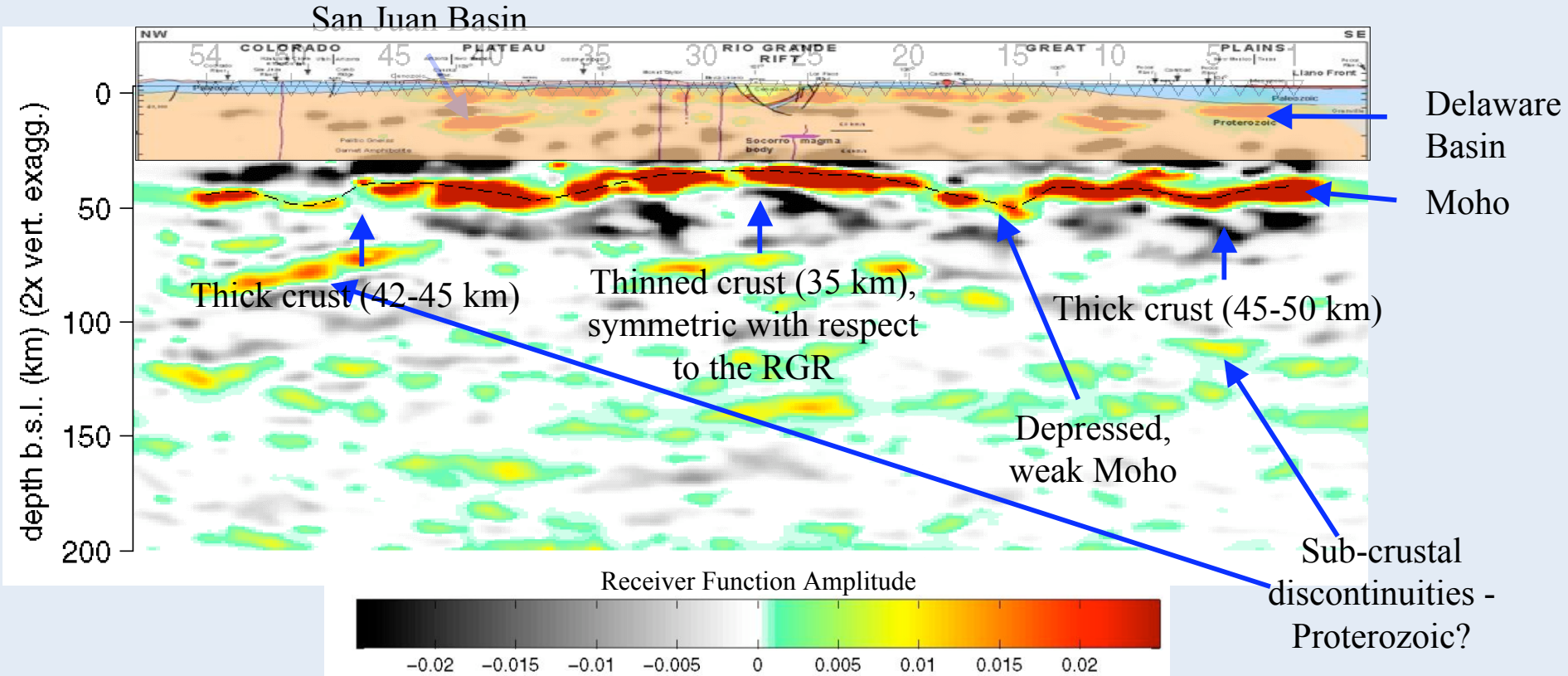
•RISTRA was deployed as a "seismic antenna" to scan the Earth using "teleseismic" signals from worldwide earthquakes.



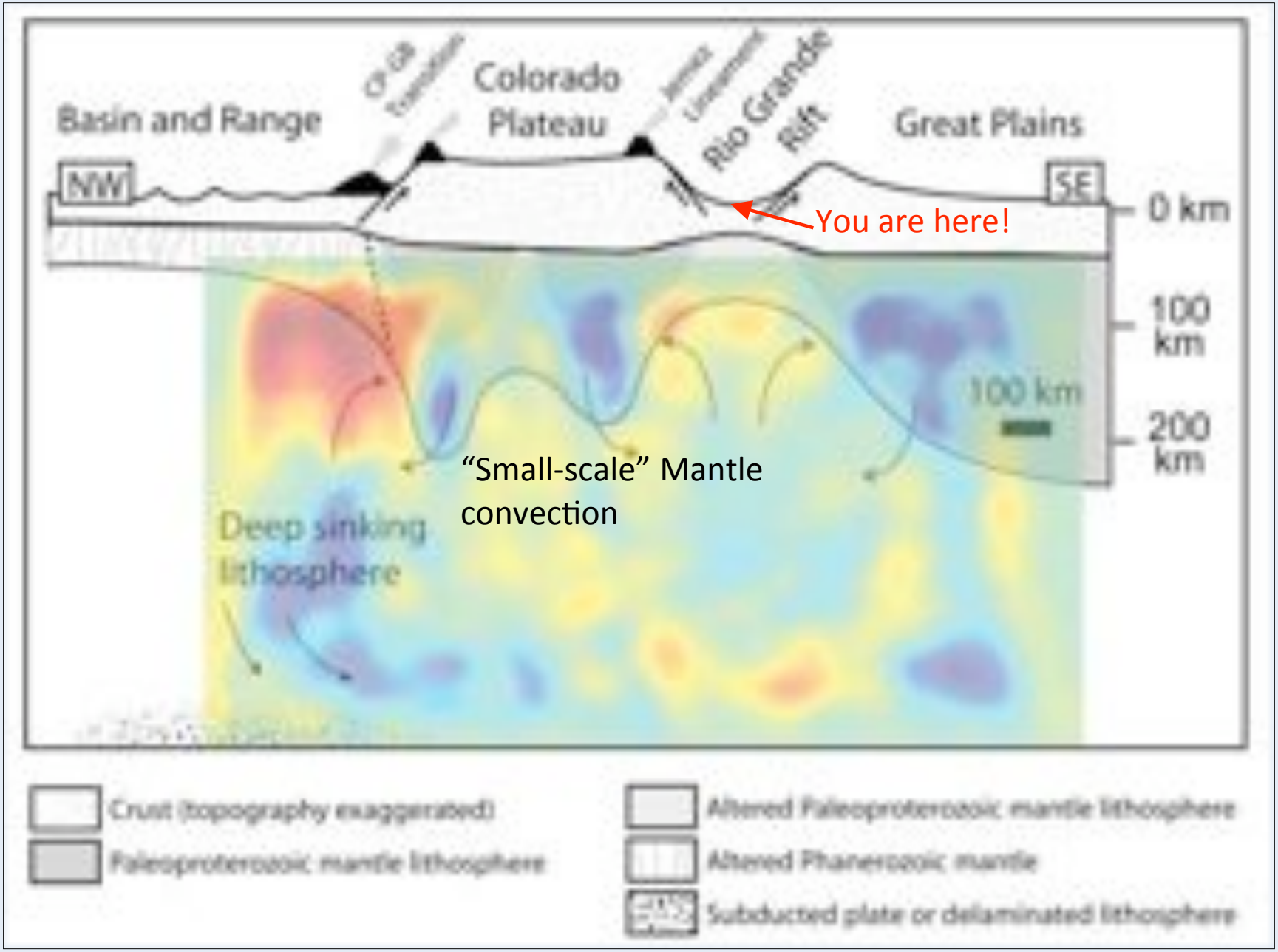
Ancient crustal boundaries affect today's active Earth processes!

RISTRA Receiver Function Imaging

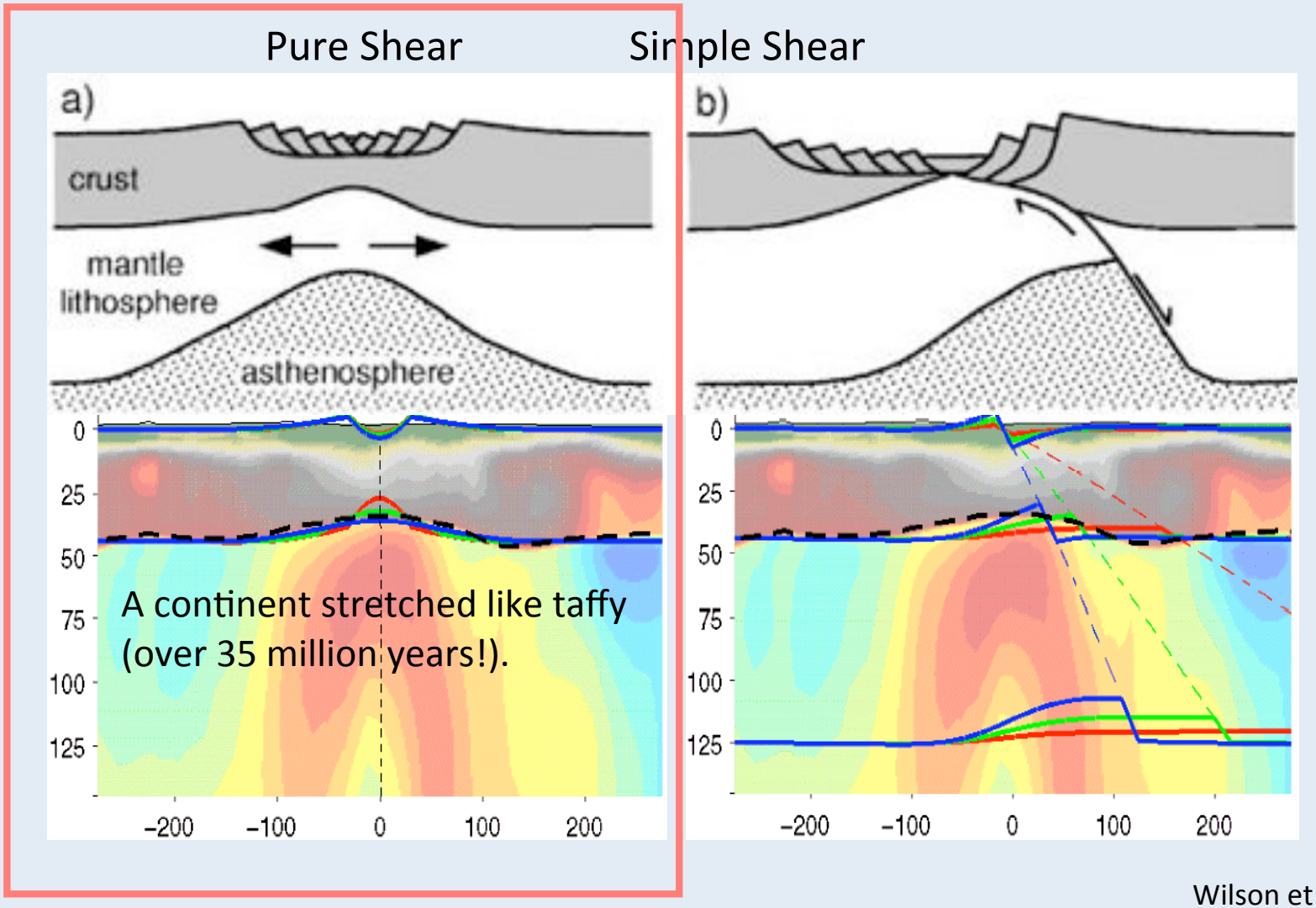




A large scale view of the Southwestern US from RISTRA



Moho and Velocity Symmetry Are Consistent with Pure Shear Necking of the Lithosphere Under the RGR (we still don't know the full 3-d picture)



Wilson et al., 2005

Example ongoing research: Earthquakes in the intermountain region – Geology in real time!

Mass moves

Improved iPods

Jackson 12

ALBUQUERQUE JOURNAL

N.M. Rift Makes Quakes Likely

Earthquakes in New Mexico?!

REMARKABLE EARTHQUAKES IN CENTRAL NEW MEXICO IN 1906 AND 1907

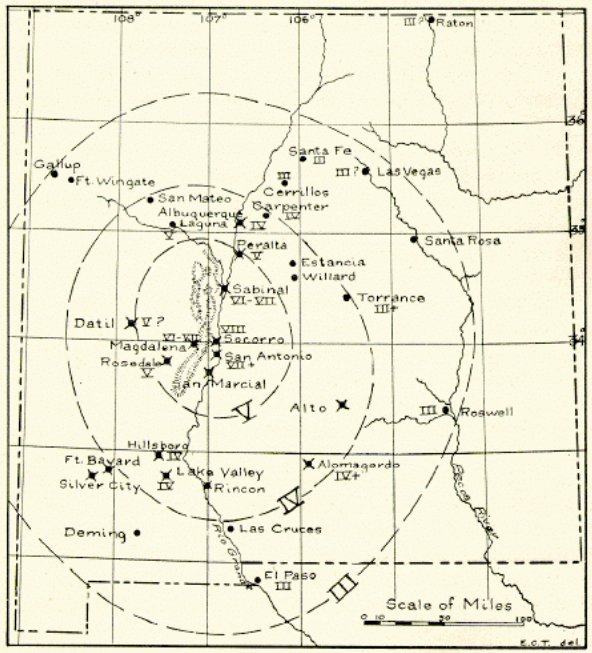
By Harry Fielding Reid

Between July 2, 1906 until well into the year 1907 scarcely a day passed that slight shocks or tremors were not felt at Socorro, in the middle of New Mexico, and in its vicinity; and shocks severe enough to do some damage occurred on July 12th and 16th and on November 15th. The series was inaugurated by smart shocks at 3:15 and 3:30 a.m. on July 2d, felt probably everywhere within fifty miles of Socorro. At Socorro they were strong enough to upset small objects (VI)*, and at Magdalena, twenty miles west, somewhat less strong (V). Six shocks were reported in Magdalena between 3 and 4 a.m. and ten shocks in Socorro between 3:15 a.m. and noon; tremors continued during the afternoon and night. On July 7th smart shocks were felt at Socorro at 1:30 and 4:10 a.m. and at Magdalena about 3 a.m. (All times are in Mountain Standard Time, seven hours slow of Greenwich mean time.)

On July 12th came the first severe shock at 5:15 a.m. which lasted from fifteen to twenty seconds at Socorro (VIII). The walls of many adobe houses were cracked and some brick chimneys were thrown down. Many boulders were shaken down upon the branch railroad to Magdalena a few miles west of Socorro, breaking one rail and a number of ties. The following places report having felt the shock: Socorro, and small towns nearby (VIII); San Antonio (VII-VIII), Elmendorf, sixteen miles south of Socorro, and Carthage, sixteen miles southeast, (VI-VII), San Marcial (VI), Rosedale (IV?), Alamagordo, Silver City, Lake Valley (III-IV), Albuquerque, El Paso (III). It was also felt on the ranches to the east and southeast of Socorro. A slight shock was reported from Fort Wingate about 5 a.m. on July 11th; it is probable that this is an error and that the shock was felt on the 12th; Socorro reports only very slight shocks on the 11th and no other place reports any.

*The Roman numerals indicate the intensities according to the Rossi-Forel scale, see page 32.

In seeking the origin of this series of shocks we naturally examine the geology of the region. The Rio Grande flows in a broad flat valley on old river deposits hundreds, and in places perhaps more than a thousand, feet thick. The valley is limited a few miles from the river on both sides, by a series of mountain ranges. The whole region

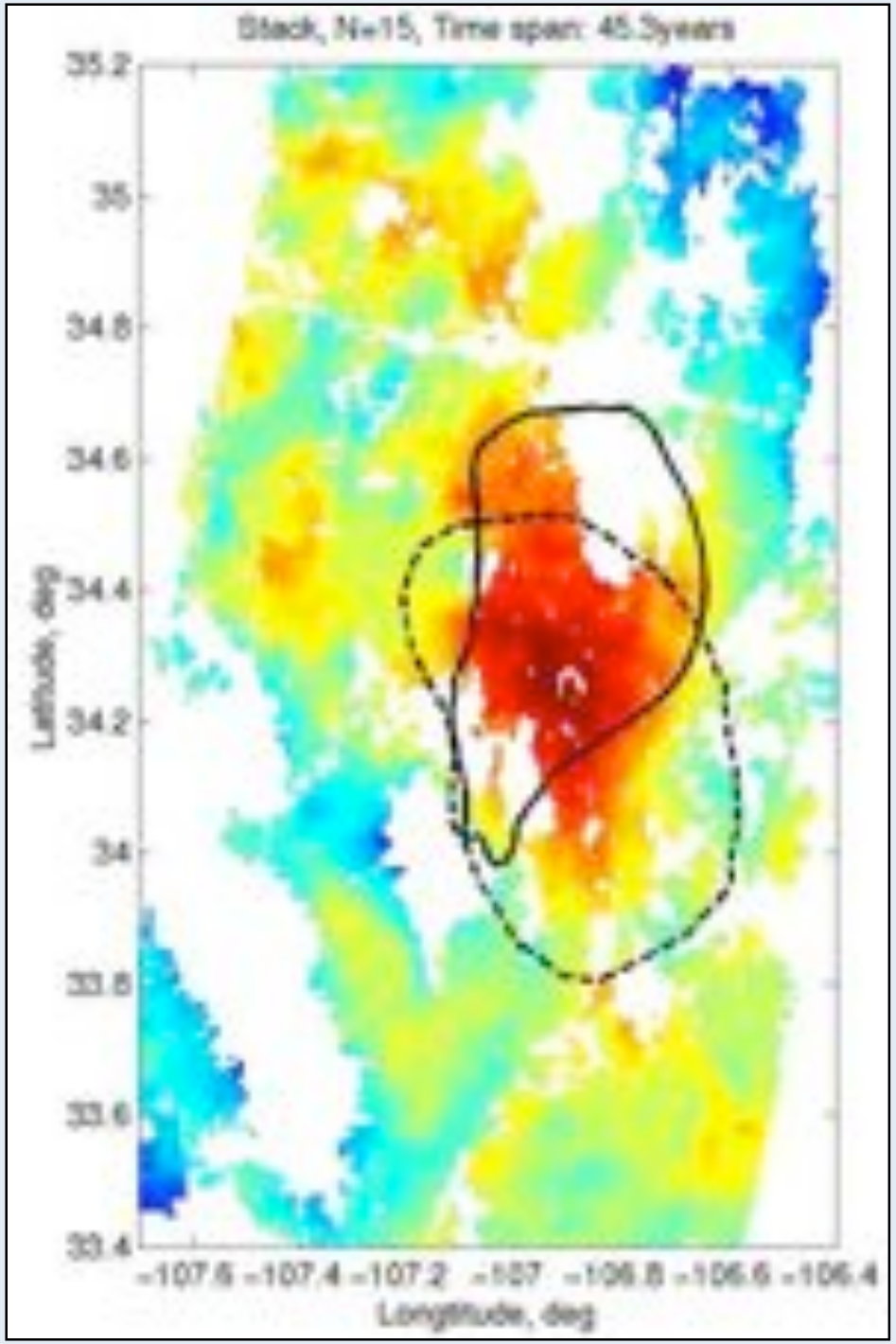


Map of New Mexico showing the isoseismals of the earthquake of November 15, 1906. Intensities (R.-F. scale) are indicated by Roman numerals. The towns marked with a cross reported the shock of July 2 or July 16.

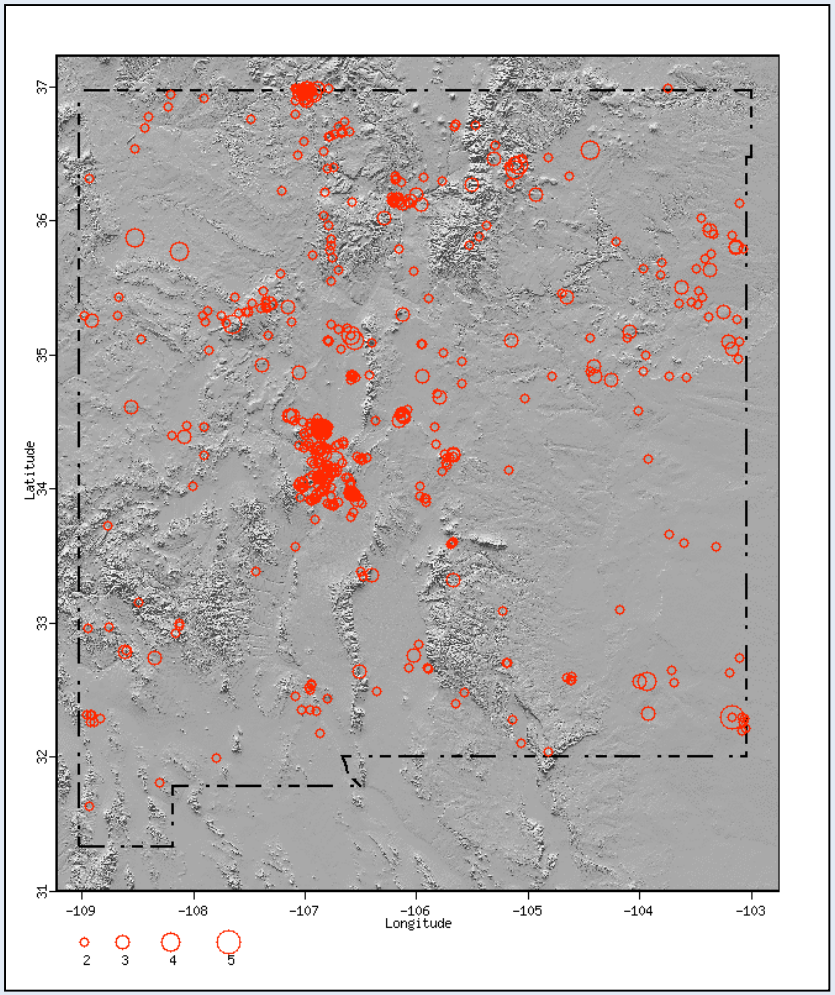
is cut by many faults. Flows of eruptive rock have taken place since the Tertiary Period; the Socorro Mountains, immediately west of Socorro, are eruptive; and very recent flows have occurred near Socorro, near San Marcial and elsewhere.

Pioneering geophysicist H.F. Reid, fresh from his seminal study of the San Francisco earthquake, researched the Socorro earthquakes and published a paper (*Reid*, 1911) in the first issue of the *Bulletin of the Seismological Society of America*. He estimated the strongest shaking to be in the immediate Socorro area and to correspond to an acceleration of approximately 15% of gravity.

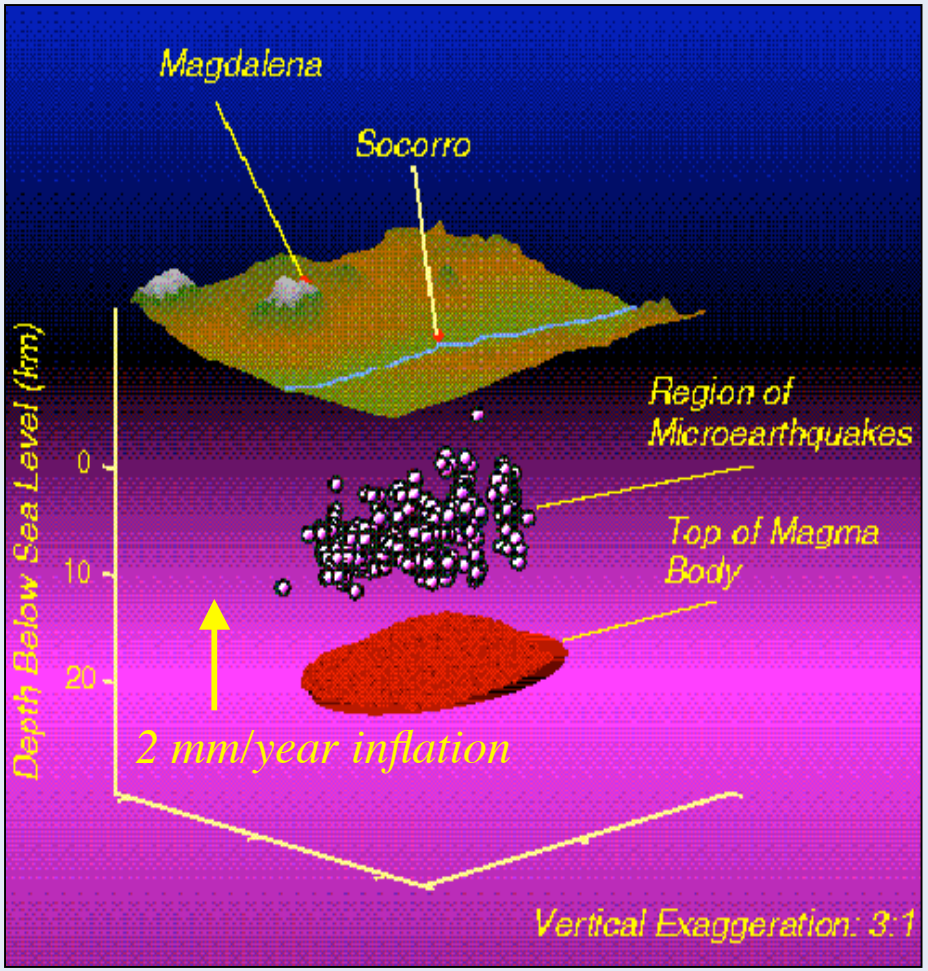
InSAR image (Fialko, 2001), showing a stacked uplift space-based image using 14 radar images of the Socorro Magma Body recorded between 1992 and 2000. The vertical uplift is 2-4 mm/year. The two outlines shown are estimated Socorro magma body boundaries estimated from microearthquakes by Reinhart and Sanford (1981; solid) and Balch et al. (1998; dashed)



The Socorro Magma Body is Responsible for Much of NM's Seismic Activity…

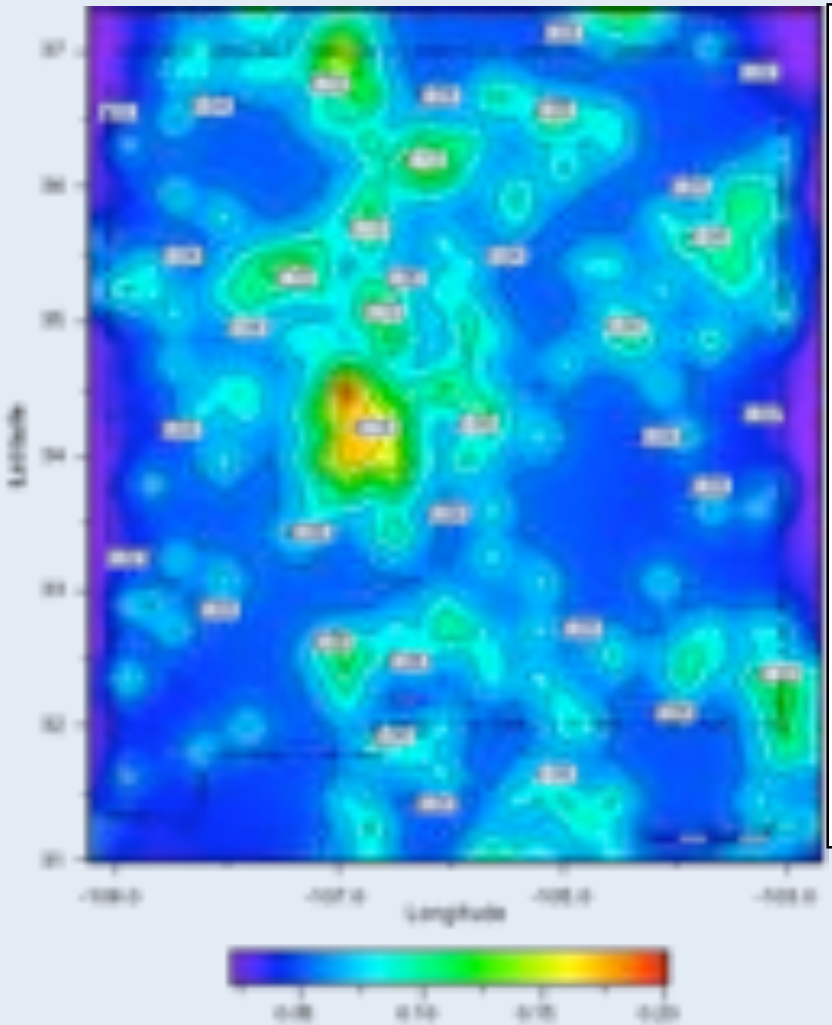


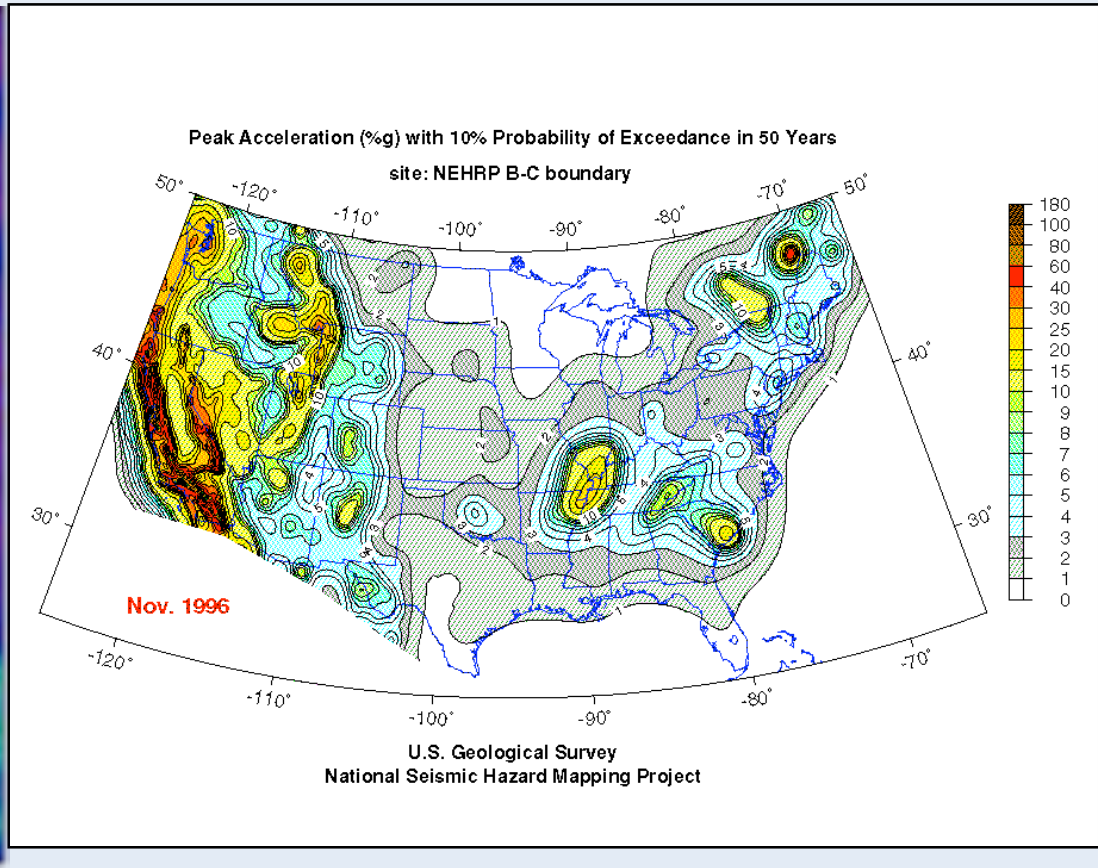
Earthquakes in NM, 1962-present.



Earthquakes near Socorro.

Aster, Sanford, et al.

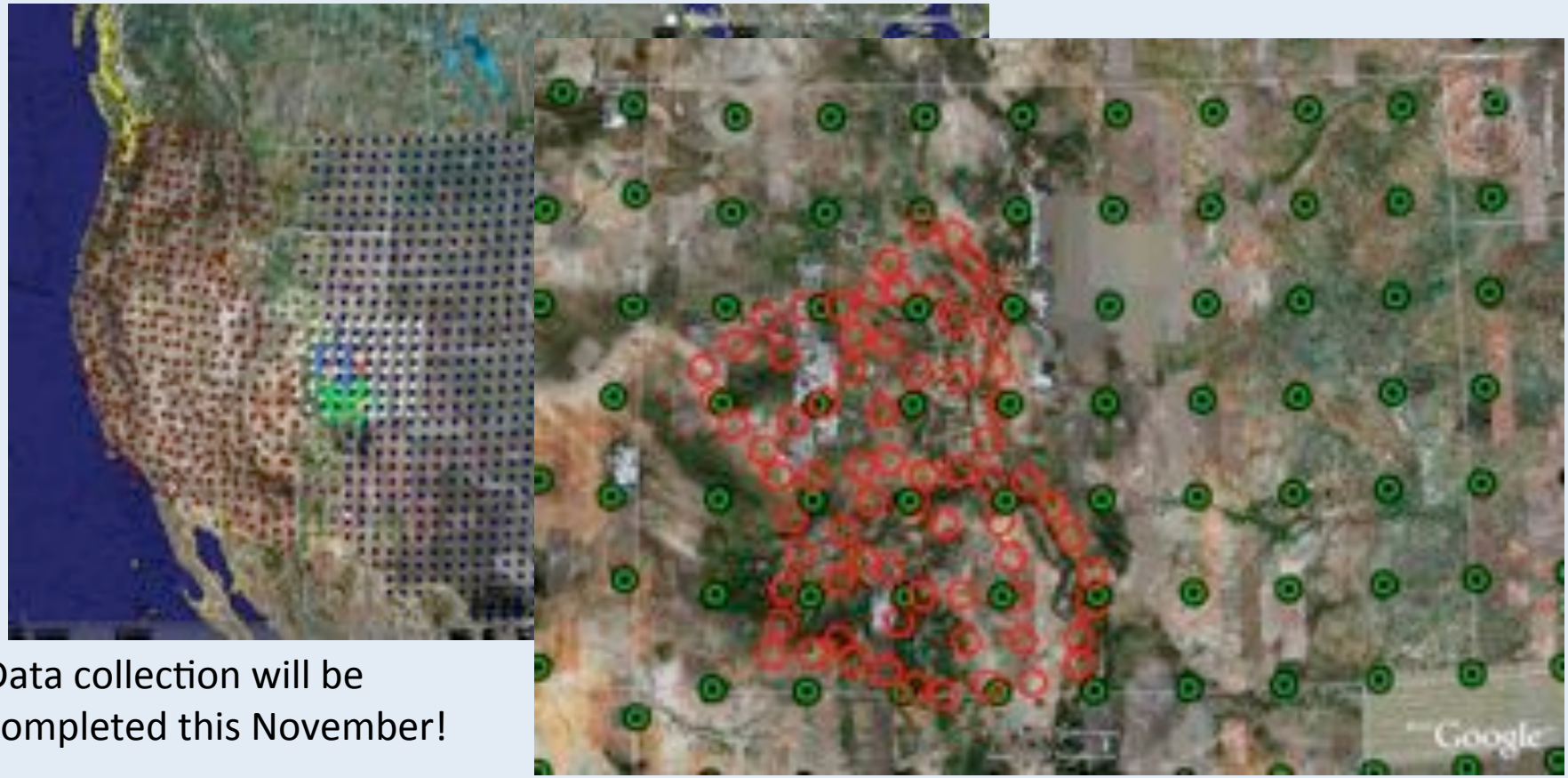




Probabilistic ground shaking predictions for earthquake-causcd acceleration (10% probability of exceedance in 50 years), estimated for New Mexico (*left*; *Lin and Sanford*, 2000) and for the conterminous U.S. (*right*; U.S. Geological Survey, 1996). Estimates incorporate hazard from Holocene faults and background seismicity.

Example ongoing project: RISTRA (Rio Grande Rift Seismic Transect)

CREST Experiment (NMT, UNM, UWY, PSU, LANL, …).

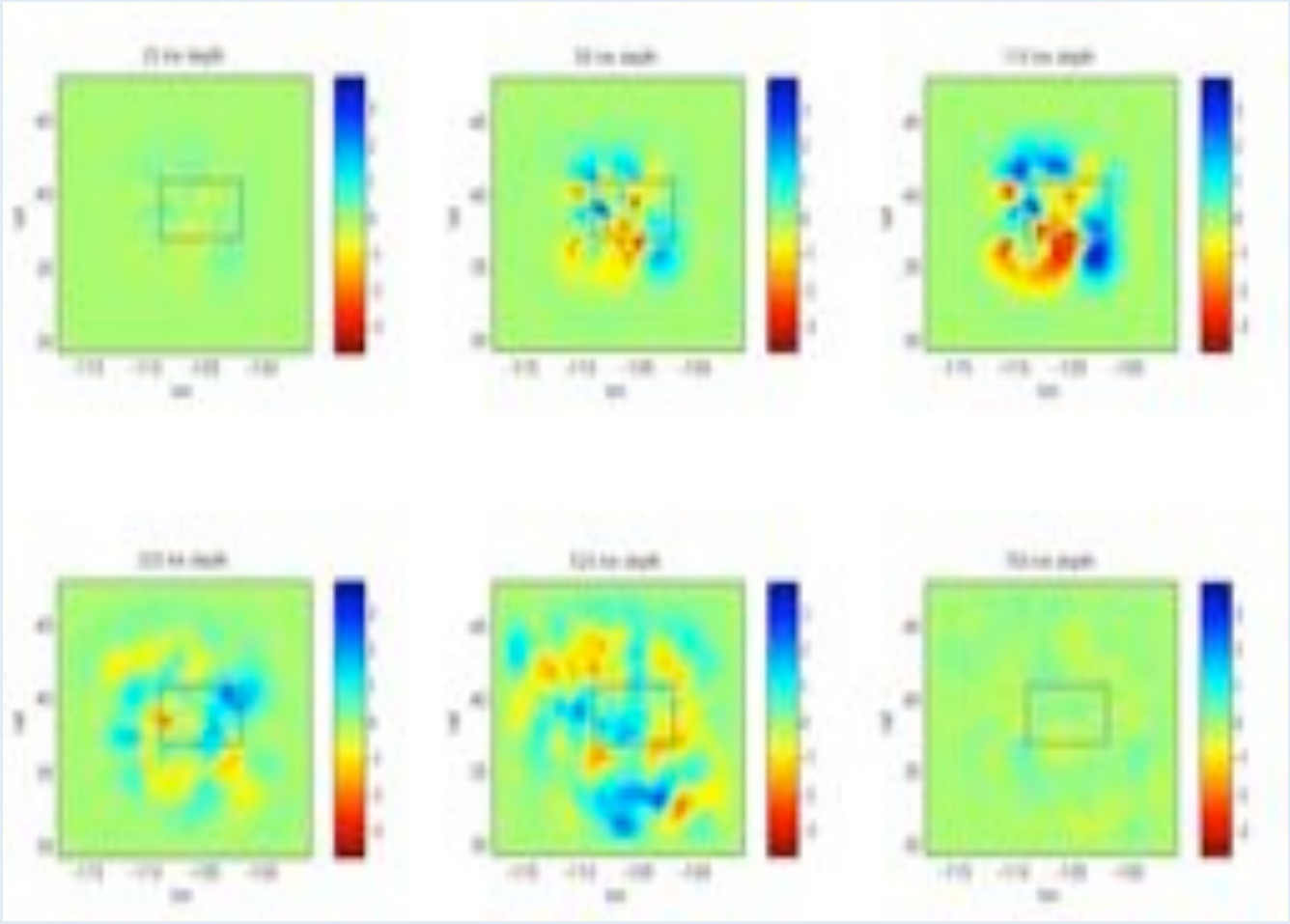


Data collection will be completed this November!

Resolving crustal thickness and mantle structure of the Aspen Anomaly:

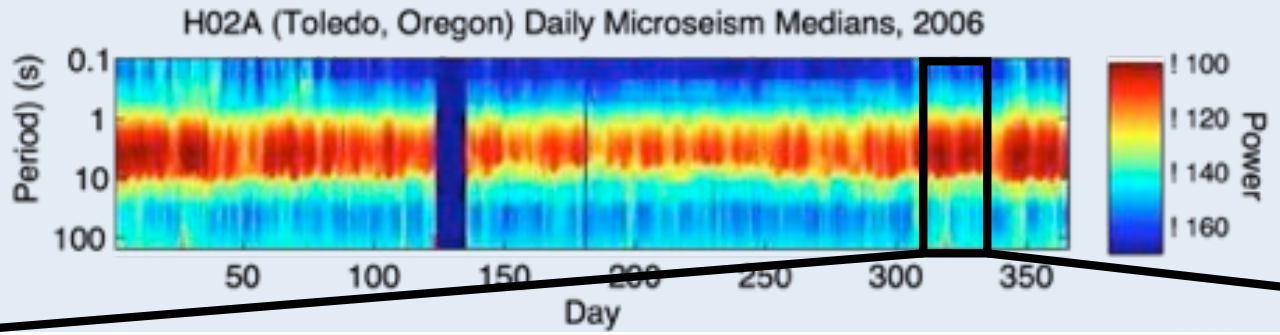
- 59 IRIS PASSCAL broadband stations (2008- 2009; red circles) coordinated with the ~70-km-spacing USArray stations.
- The composite deployment hosts ~70 stations for fine-scale 3-d imaging of the Aspen Anomaly (embedded in the sparser USArray deployment).
- Will produce 3-d seismic images with resolution comparable to that achieved in the passive source components of the 2-d RISTRA study.

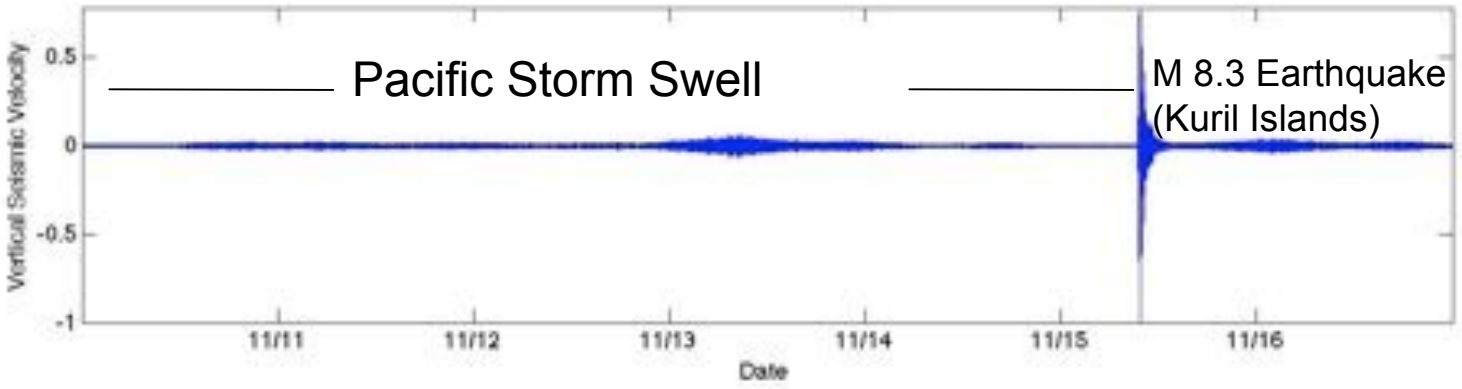
Mantle Structure under CREST (as of 10:00 pm yesterday)

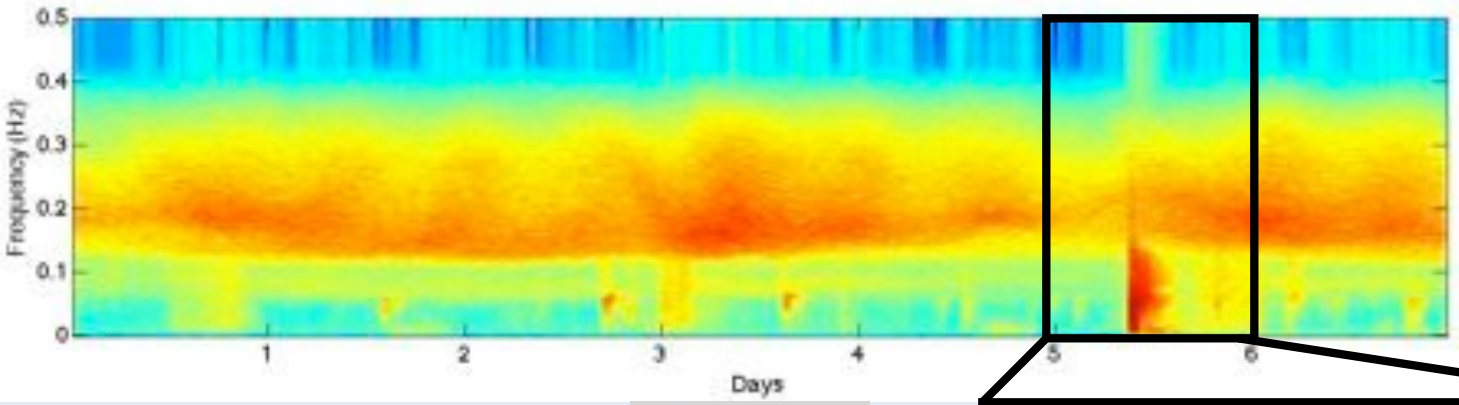


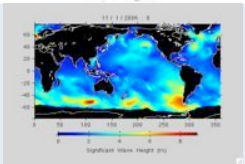
J. MacCarthy

Example ongoing project: Analyzing Earth's Microseism (talk this evening)









3600 x speed

Some things Happening Right Now with EarthScope in our Region…

•Scientists from UNM and the University of Colorado are collecting new GPS Geodesy data to see how fast the Rio Grande Rift is spreading.

•New Mexico Tech/UNM/University of Wyoming students and researchers have deployed a state-of-the-art network of seismometers in Southern Colorado (from Aspen to the NM border) embedded in USArray to study the history and present-day dynamics of the Colorado Rockies and northern Rio Grande Rift (CREST).

•USArray is now in our region, recording seismic activity (and providing unprecedented new data for deep seismic imaging and other science that will keep researchers occupied for at least decades). Key questions include understanding the deep 3-d structure of the Rio Grande Rift, southern Rocky Mountains, and Colorado Plateau.

•A University of Texas/Baylor group is using the EarthScope FA/TA to study the "Artesia Anomaly" discovered during RISTRA, where upper mantle appears to be sinking back into the deep Earth near the edge of the Rio Grande Rift system.

•Systematic large-scale 3-d mapping of the mantle by several national groups (e.g., Oregon, Berkeley, U. Colorado, …) is ongoing in the region as USArray sweeps through.

so… stay tuned for new discoveries!

A few final words…

- We are truly in the middle of a "golden age" of Earth discovery; uncovering the detailed history and processes that affect the planet from surface to core.
- Seismology provides by far the most detailed imaging of the deep Earth, and EarthScope is the most ambitious seismic imaging experiment in the history of Earth science.
- The mantle is rife with fascinating structures and its processes couple strongly with the crust and our most iconic landforms.
- As educators, we are in a position to dramatically reshape popular conceptions on how the Earth works at a new level of completeness and understanding for our audiences.