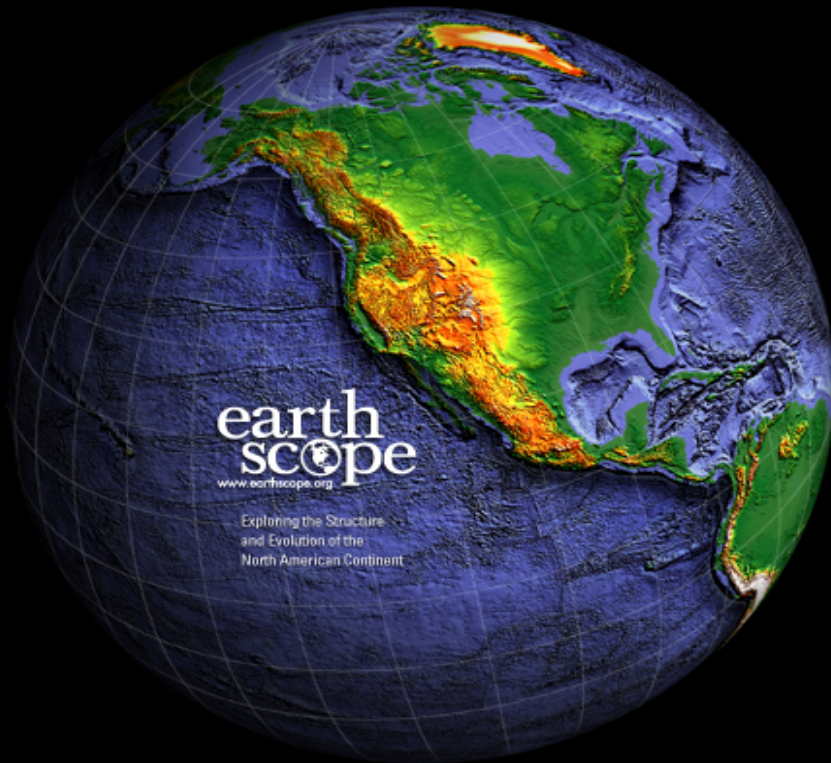


EarthScope Science Motivations

Ramon Arrowsmith

School of Earth and Space Exploration

Arizona State University



- Emphasize recent results and opportunities for geochronology
- There have been interesting papers published using geochronology related to EarthScope!

ramon.arrowsmith@asu.edu
www.earthscope.org

























Exploring the Structure and Evolution of the North American Continent:

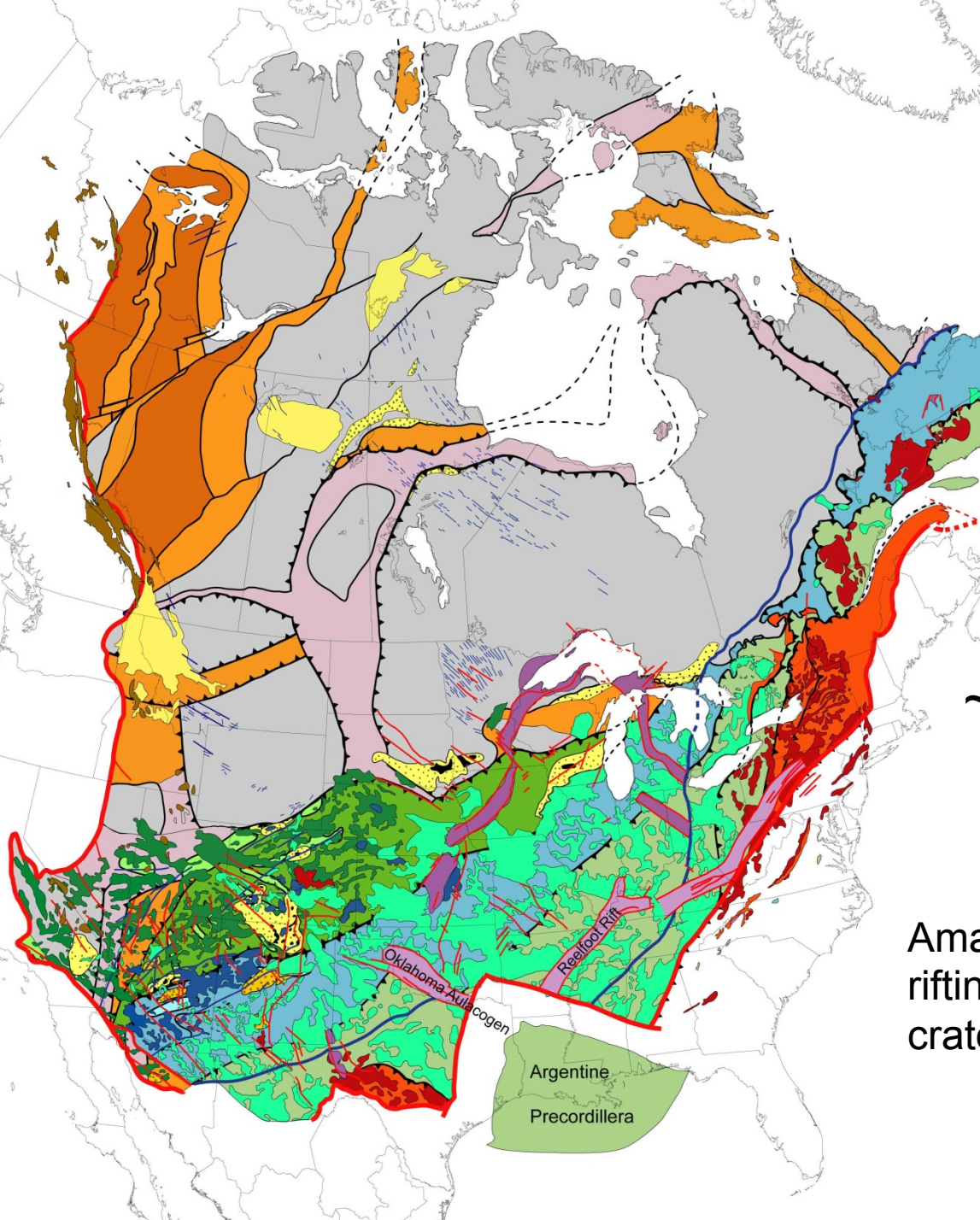
Measuring the motions and the properties that constrain the processes

~ 0.535 Ga

Amalgamation and rifting manifest in cratonic interior

-Whitmeyer and Karlstrom, 2007

-  Eastern rift basins
-  Continental rift boundary
-  <0.78 Ga Windermere Supergroup
-  Major normal faults
-  Mafic dike swarms
-  1.2-1.1 Ga Midcontinent rift system
-  1.3-0.95 Ga granitoids
-  Major thrust faults
-  1.3-1.0 Ga collisional orogens
-  1.45-1.35 Ga granitoids
-  1.55-1.35 Ga juvenile crust
-  ~1.65 Ga quartzite deposits
-  1.65-1.60 Ga granitoids
-  1.69-1.65 Ga juvenile crust
-  1.72-1.68 Ga juvenile arcs
-  ~1.70 Ga quartzite deposits
-  1.72-1.68 Ga granitoids
-  1.76-1.72 Ga juvenile crust
-  1.80-1.76 Ga juvenile arcs
-  1.9-1.8 Ga reworked Archean crust
-  2.0-1.8 Ga juvenile orogens
-  2.0-1.8 Ga juvenile arcs
-  2.5-2.0 Ga miogeoclinal sediments
-  >2.5 Ga Archean crust



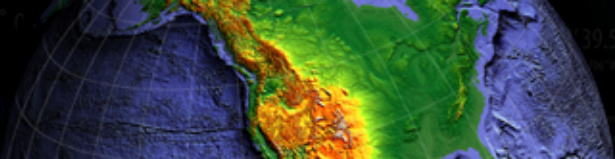
(Whitmeyer and Karlstrom, 2007)

Exploring the Structure and Evolution of the North American Continent:

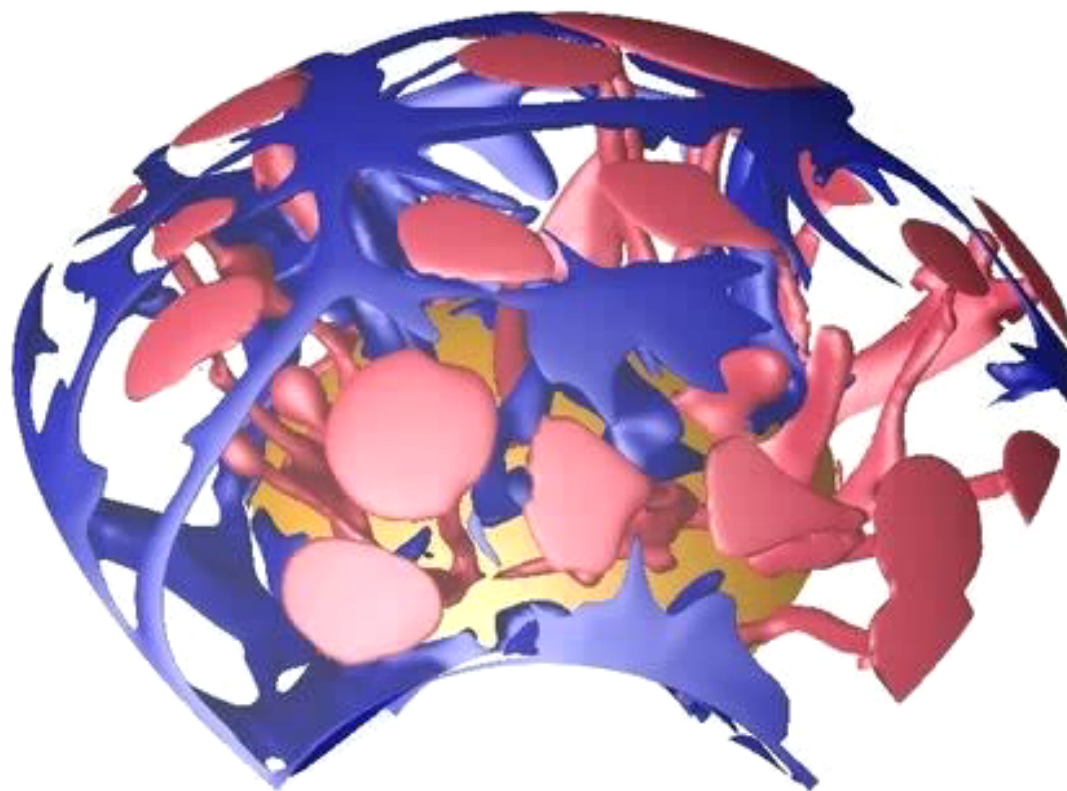
Measuring the motions and the properties that constrain the processes

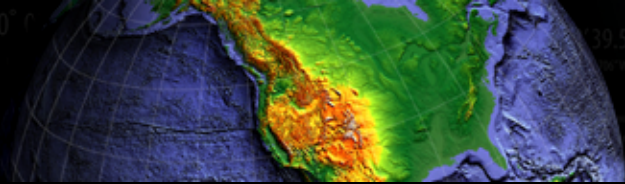


Interactive Geology Project, CU Boulder
<http://igp.colorado.edu/animations.html>
Professor Ron Blakey, Colorado Plateau Geosystems



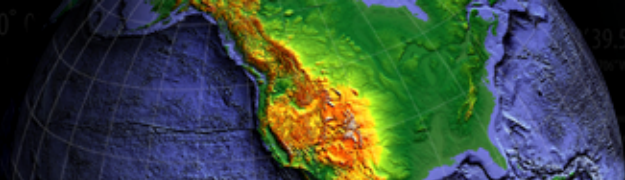
Geologic, geochronologic,
and geophysical data are
needed to test



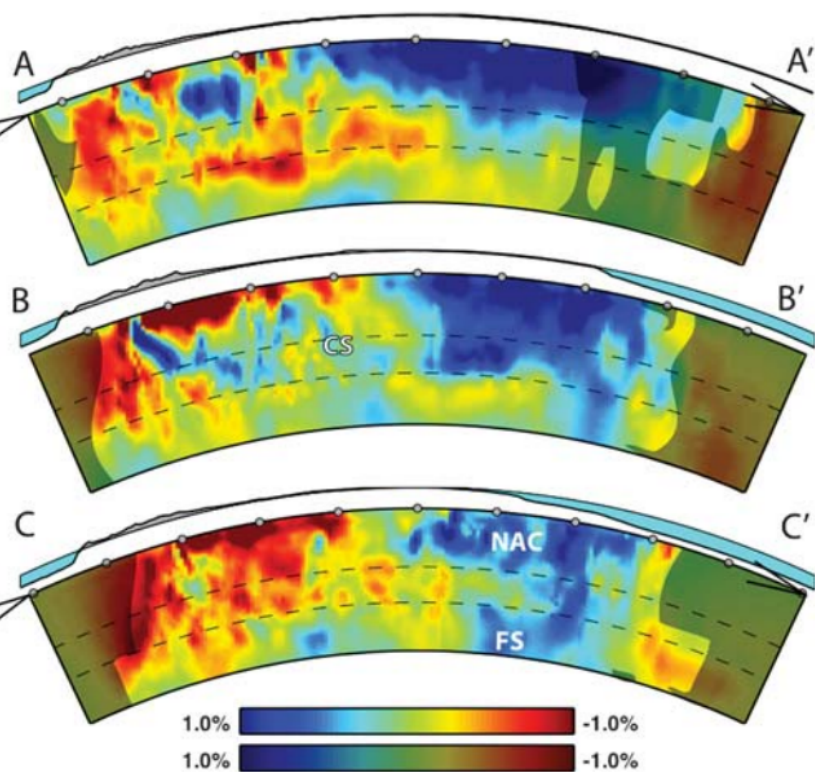
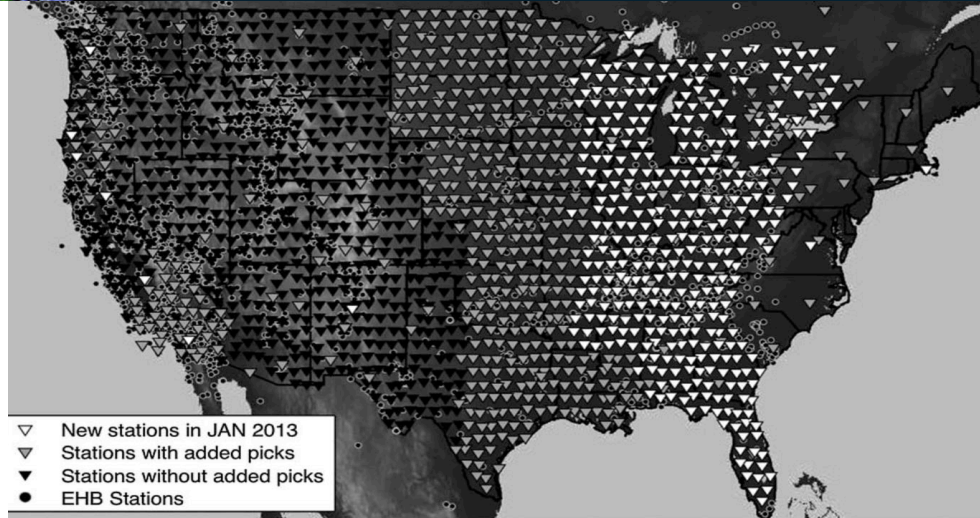


An EarthScope Science Sampler

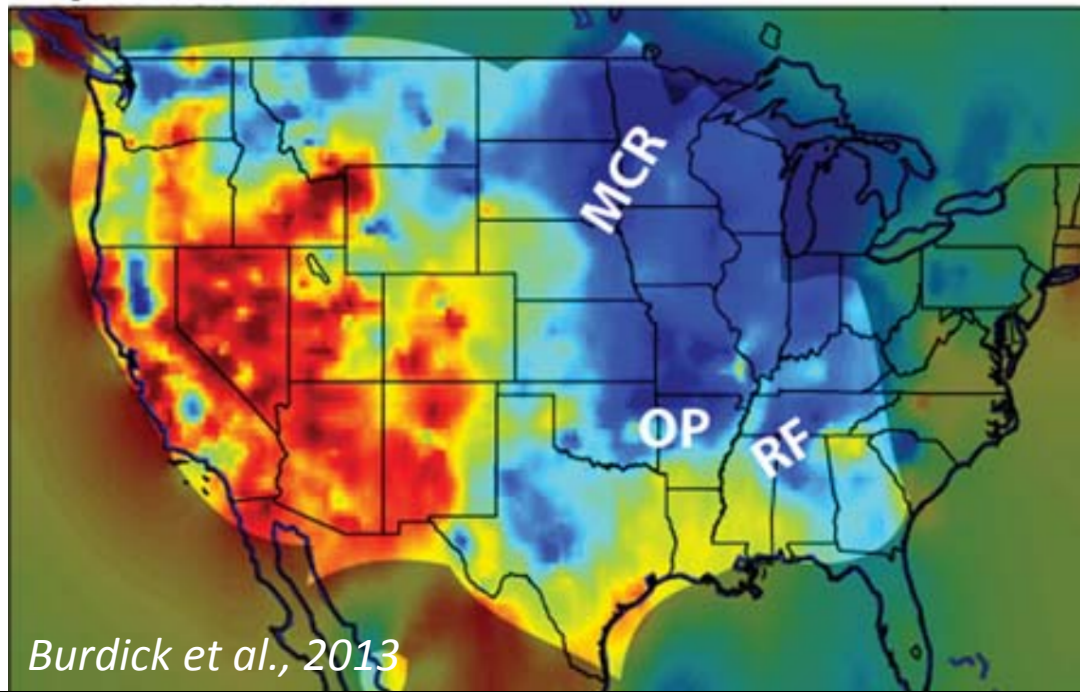




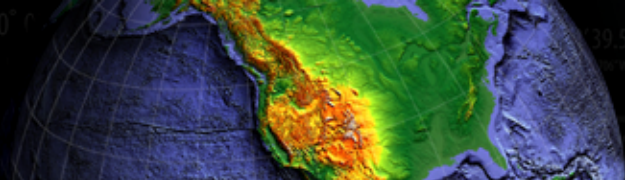
AMAZING IMAGES OF EARTH'S INTERIOR



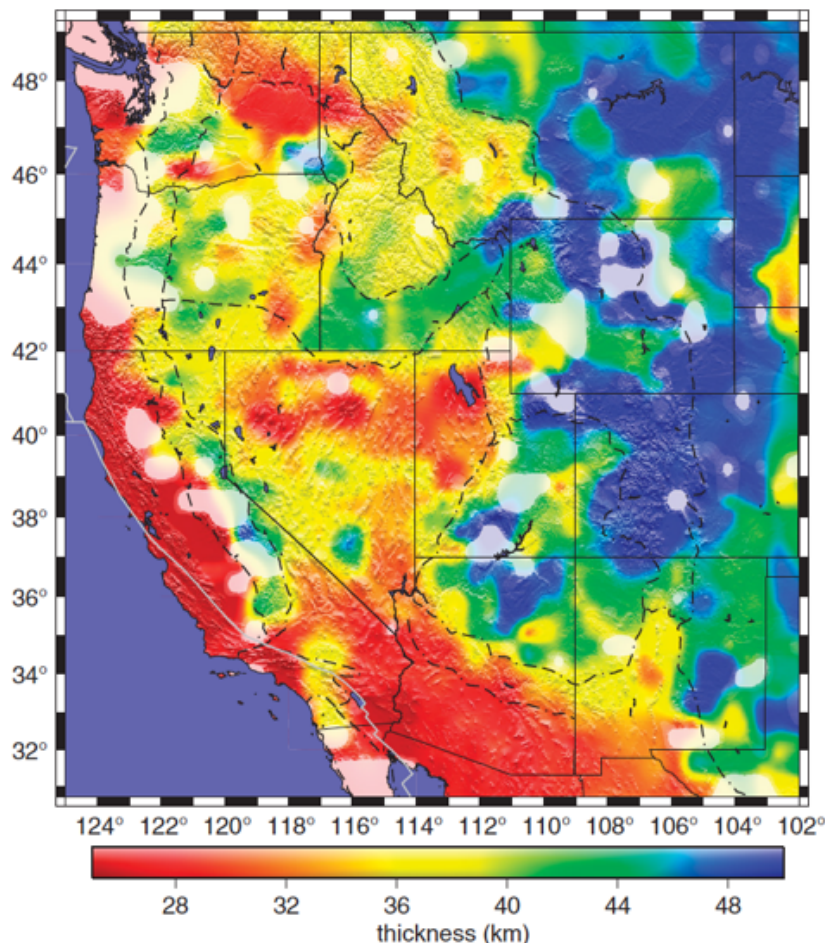
Depth 100 km



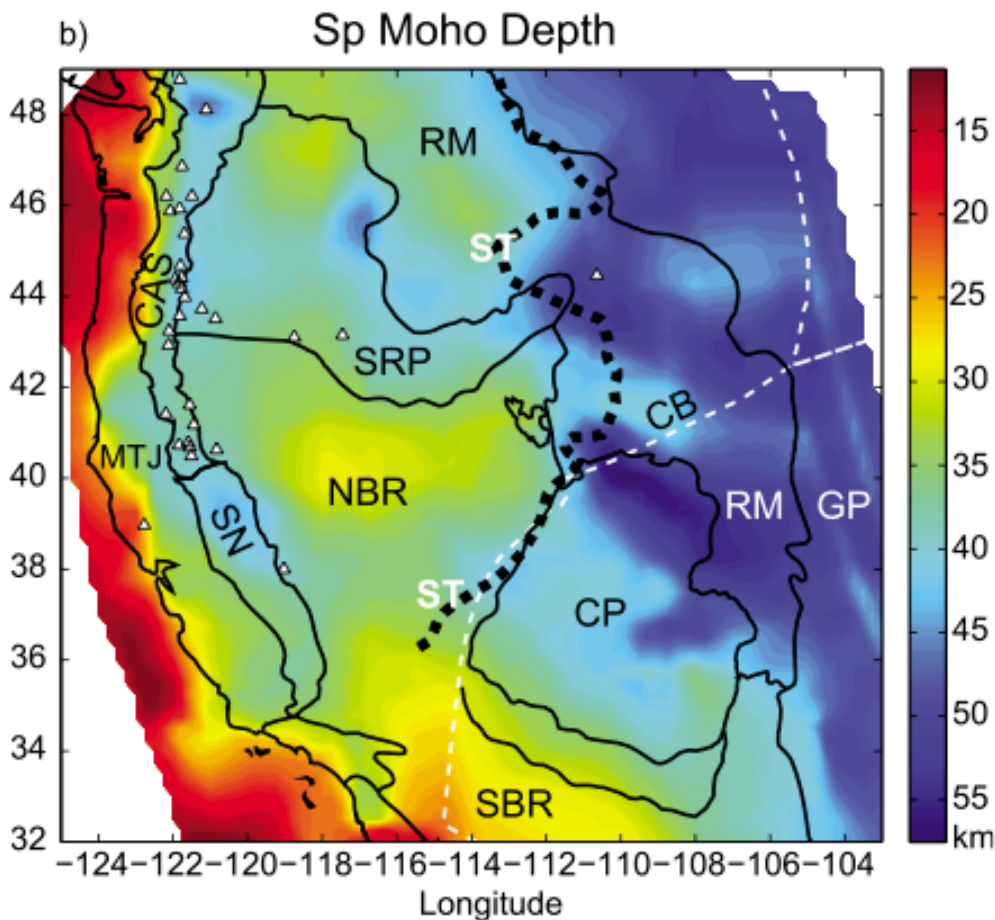
Burdick et al., 2013



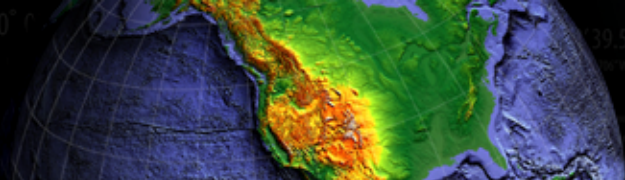
CRUSTAL THICKNESS FROM RECEIVER FUNCTIONS



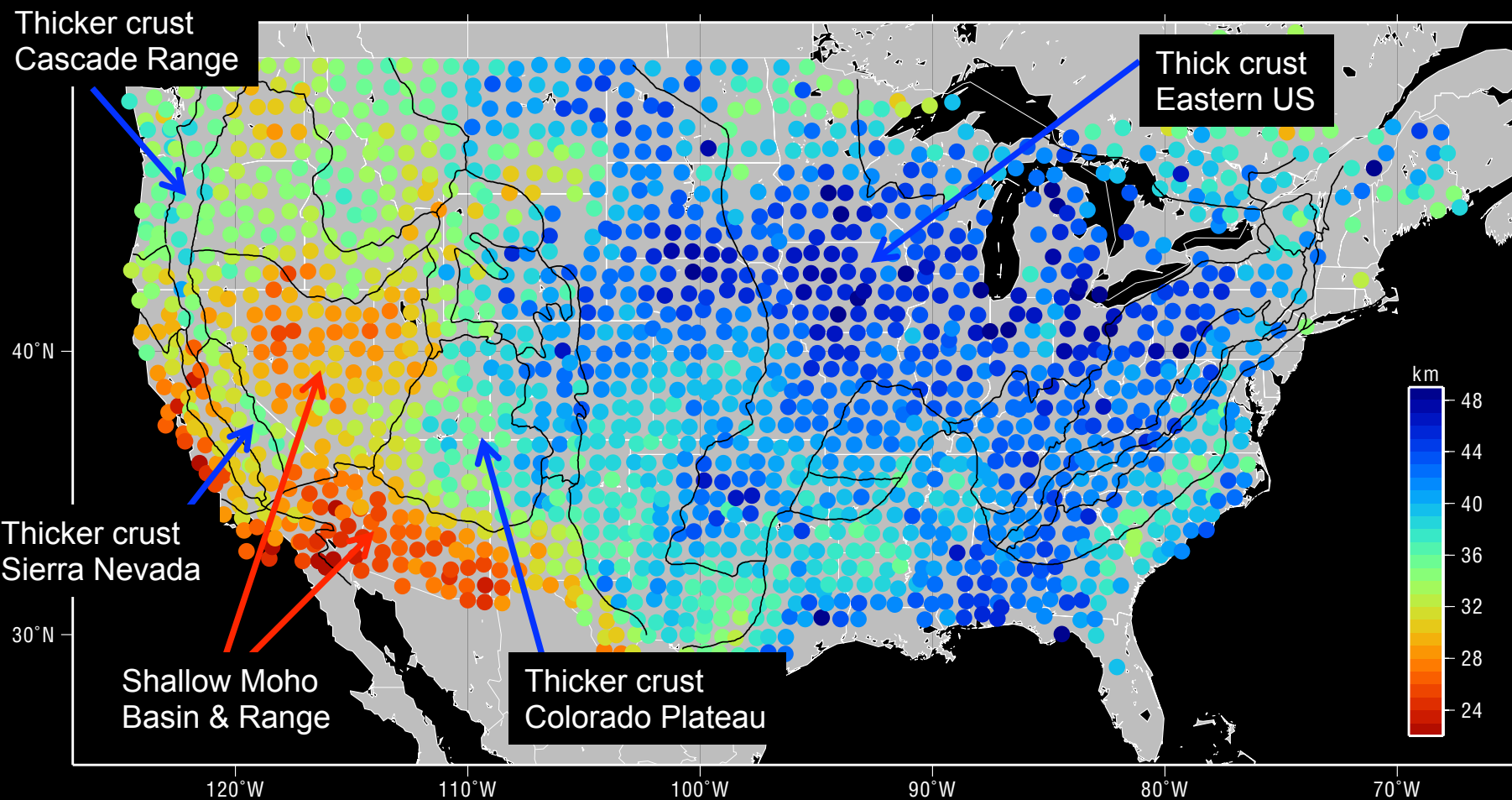
Gilbert, 2012

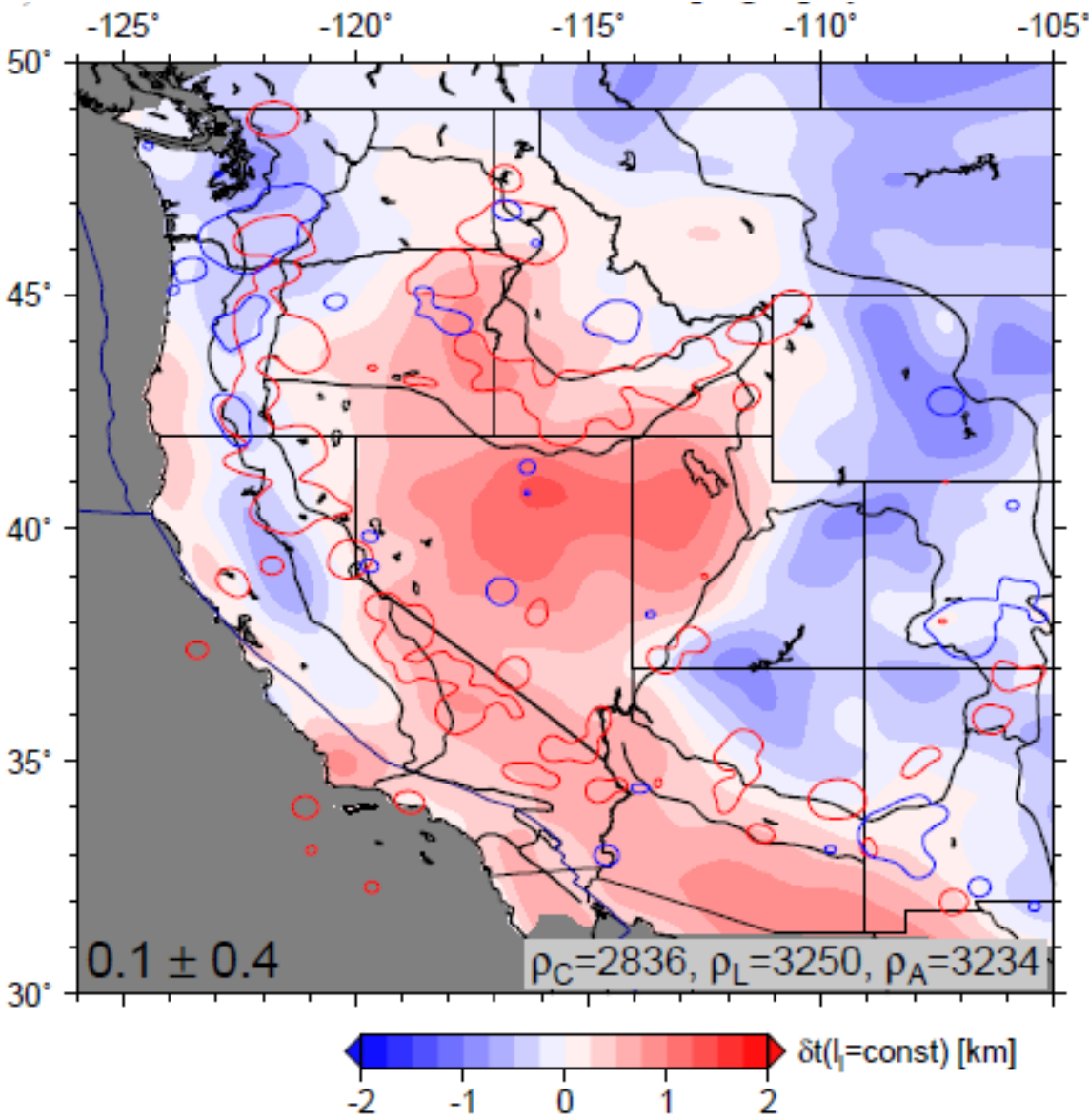
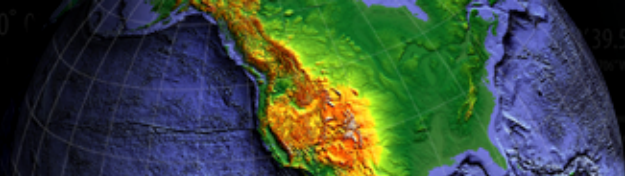


Levander & Miller, 2012



CRUSTAL THICKNESS FROM P_n STATION TIME TERMS





STATIC AND DYNAMIC SUPPORT OF TOPOGRAPHY

Topographic elevations not explained by variable crustal thickness. Lithospheric thickness variation hard to image and does not seem to explain either.

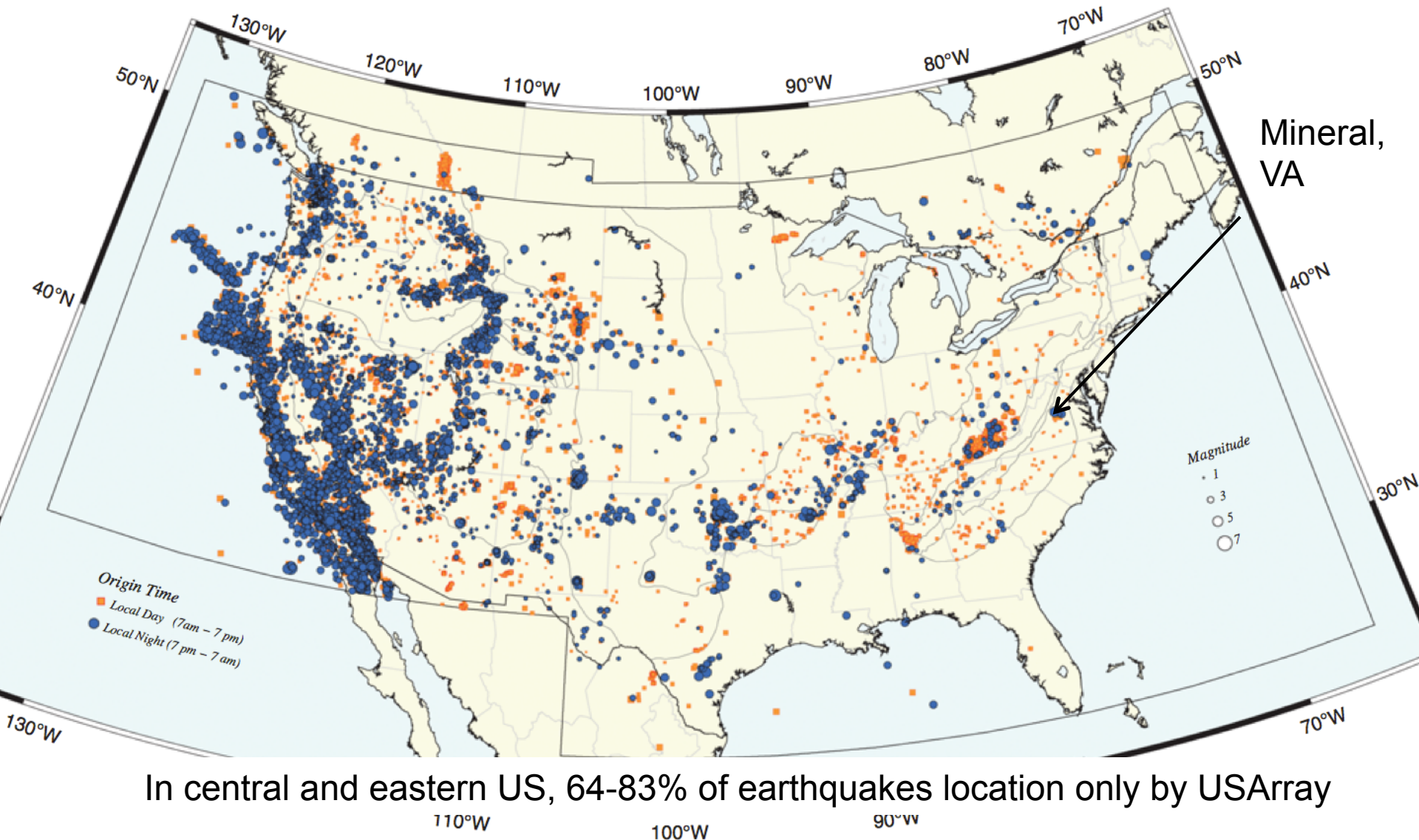
->important interactions between vigorous upper mantle convection and intraplate deformation

Becker, Faccenna, Humphreys, Lowry, & Miller, EPSL 2013

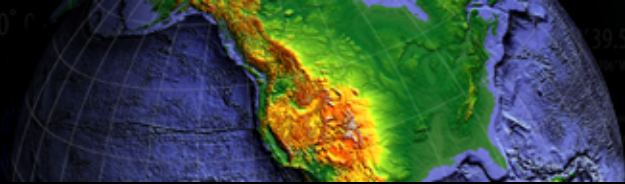
Earthquakes located by USArray

Luciana Astiz
University of California, San Diego

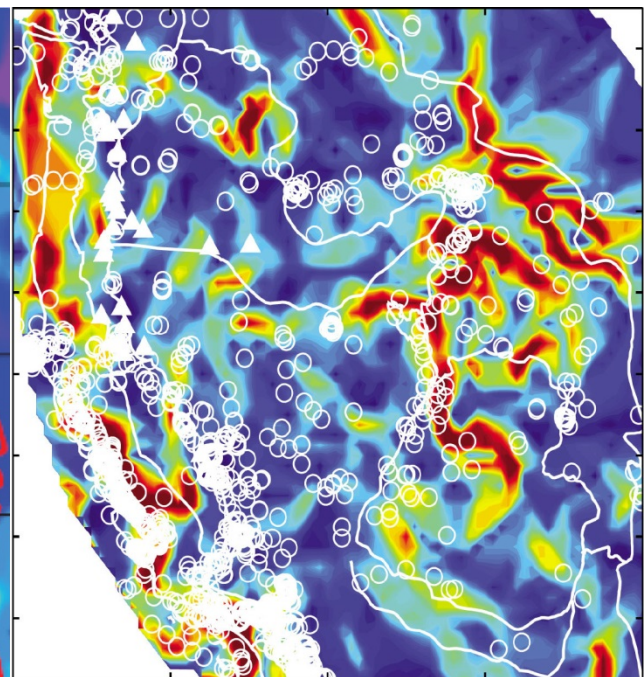
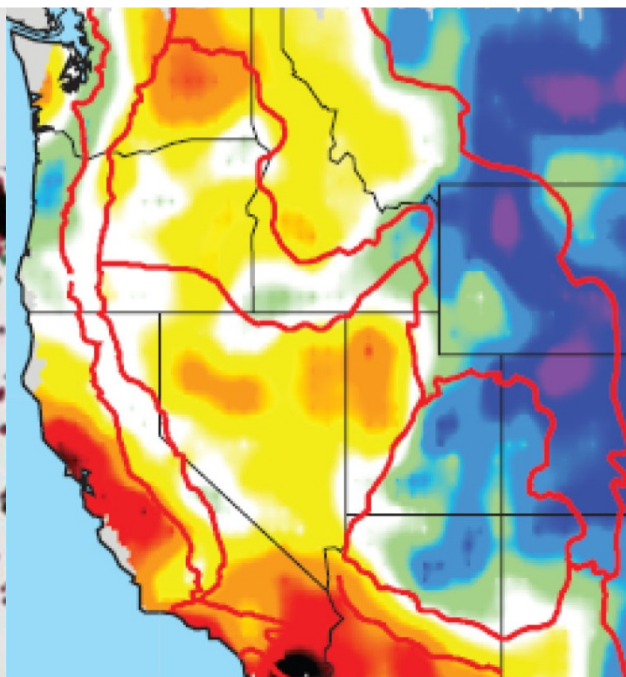
Local Day/Night seismicity in the ANF Bulletin from April 2004 to November 2013



In central and eastern US, 64-83% of earthquakes location only by USArray



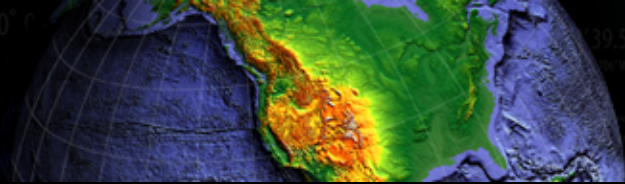
SEISMICITY CORRELATES WITH GRADIENTS IN CRUSTAL STRUCTURE



Astiz et al., 2014

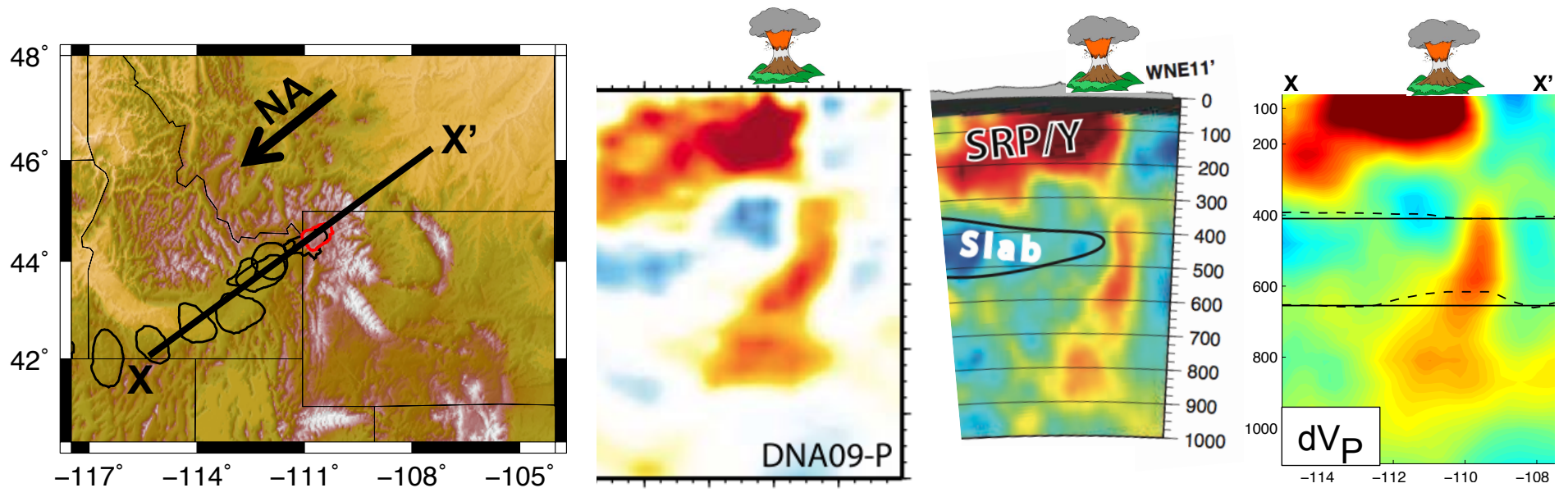
Shen & Ritzwoller, 2014

Levander & Miller, 2012

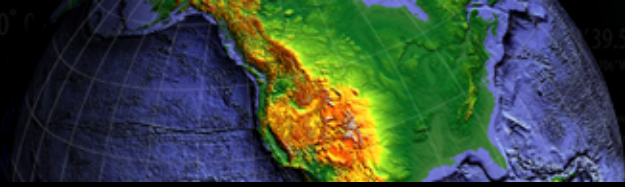


USARRAY TOMOGRAPHY BENEATH YELLOWSTONE

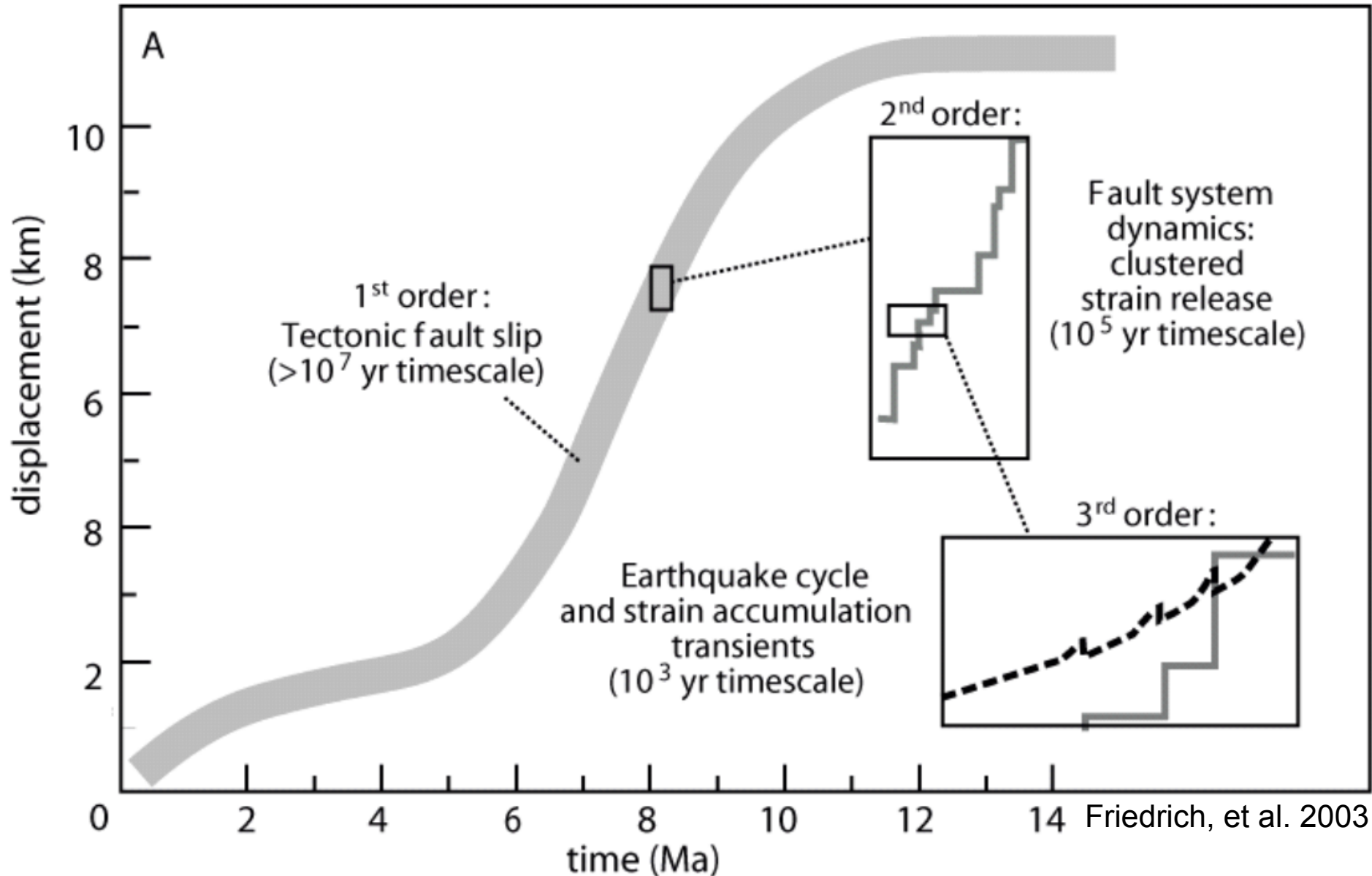
A vertically heterogeneous low-velocity anomaly extending into the lower mantle in the USArray tomography models.

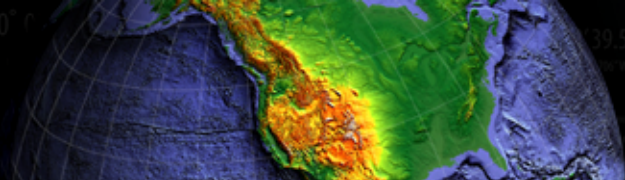


Obrebski et al. (2010) James et al. (2011) Schmandt et al. (2012)

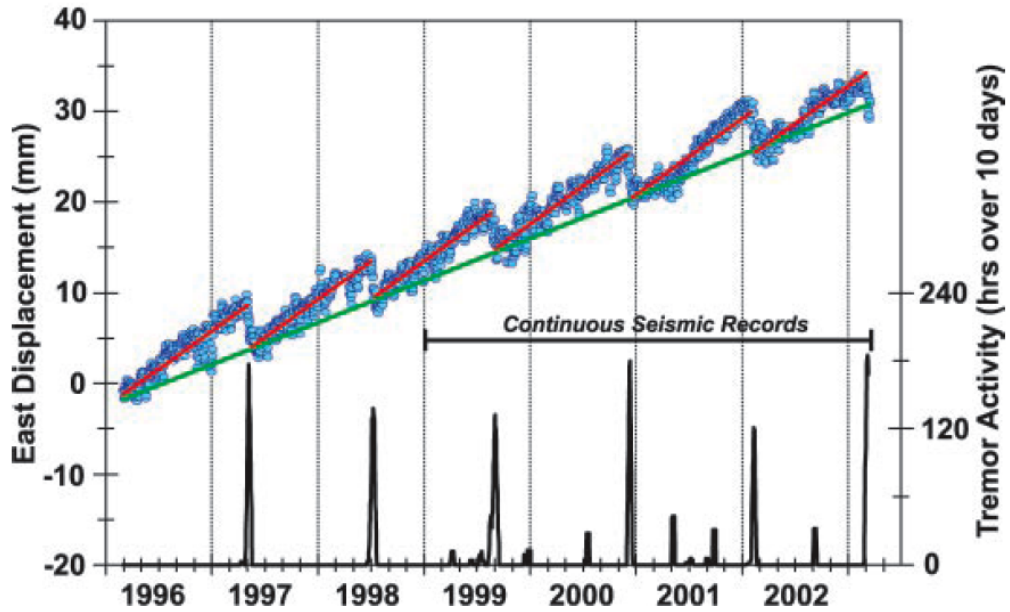


Earth Deformation at periods of 10^1 to 10^7 yr





Earthquakes, tremor and aseismic slip in Cascadia



Rogers and Dragert, 2003

What
Where
When
Why

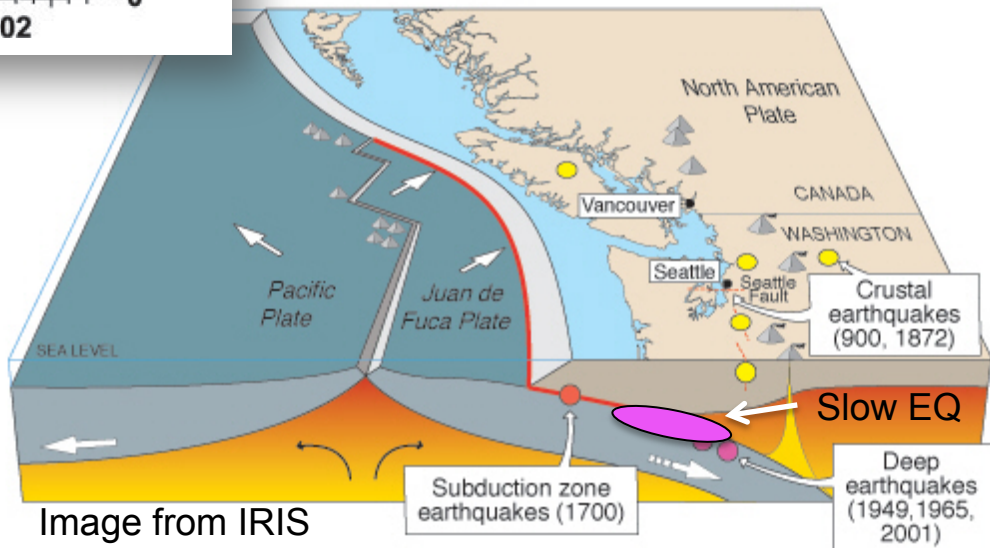
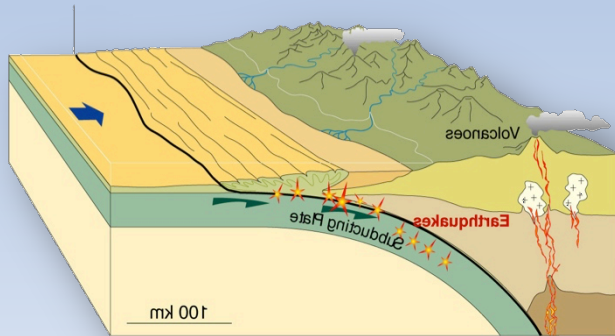
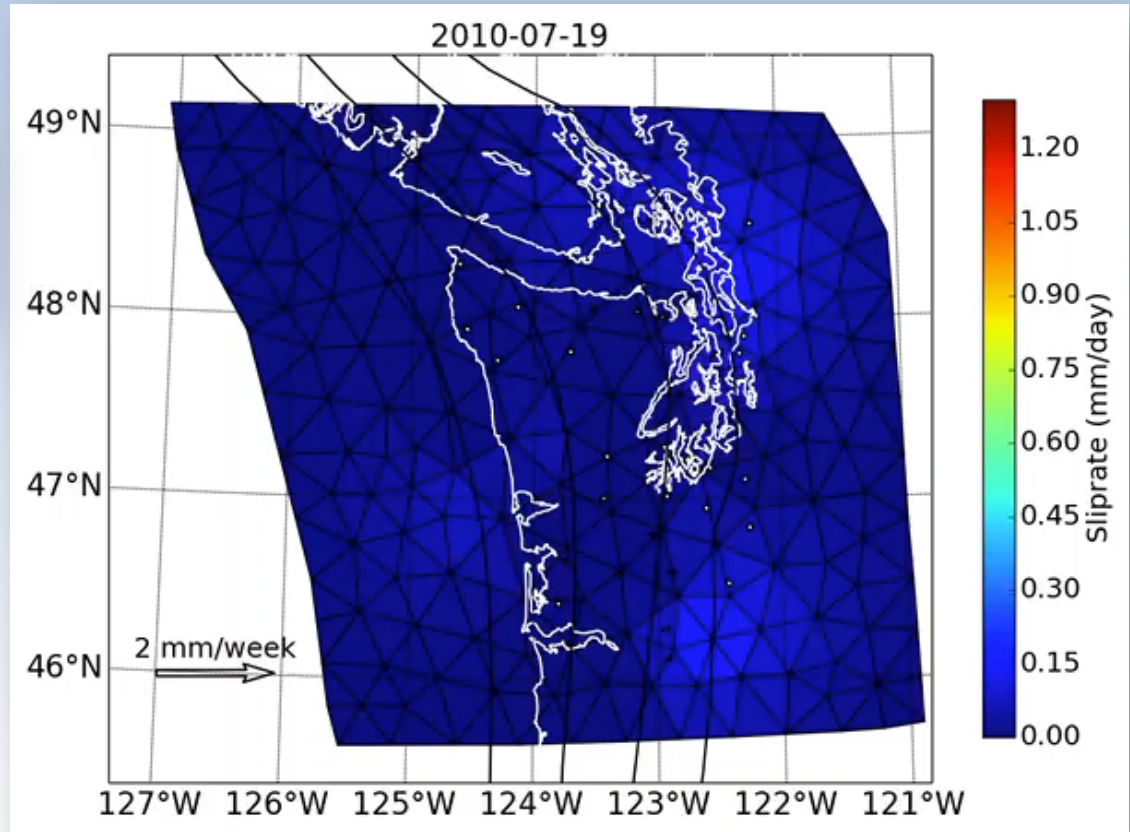


Image from IRIS

New Algorithms: Automated transient detection using sparsity based approaches



Transient slip rate and tremor vs time



$$\begin{bmatrix} \text{blue line} \\ \text{green wavy line} \\ \text{purple wavy line} \\ \text{red wavy line} \\ \text{cyan wavy line} \end{bmatrix} \begin{bmatrix} m_0 \\ m_1 \\ \vdots \\ m_{p-1} \end{bmatrix} = \begin{bmatrix} d_0 \\ d_1 \\ \vdots \\ d_{N-1} \end{bmatrix}$$

$$\mathbf{m} = \underset{\mathbf{m}}{\operatorname{argmin}} \|\mathbf{d} - \mathbf{Gm}\|_2^2 + \lambda \|\mathbf{m}\|_0$$

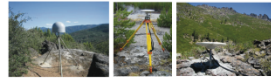
A Geodetic Strain Rate Model for the Pacific-North American Plate Boundary, Western United States

Corné Kreemer¹
 William C. Hammond¹
 Geoffrey Blewitt¹
 Austin A. Holland²
 Richard A. Bennett²

¹Nevada Bureau of Mines and Geology,
 University of Nevada Reno
²Department of Geological Sciences,
 University of Arizona
 2012

SUMMARY

The map presents a model of recent strain rates across the Pacific-North American (PNA) plate boundary of the western United States. The model includes the spatial distribution of deformation rates across the Pacific-North American plate boundary from the San Andreas fault system to the Sierra Nevada range, and includes a model of geodetic strain rates. We use GPS observations to constrain the model and compare it to a geodetic strain rate model derived from GPS observations. The model shows that strain rates are highest in the Sierra Nevada range and lowest in the San Andreas fault system. The model also shows that strain rates are highest in the Sierra Nevada range and lowest in the San Andreas fault system.

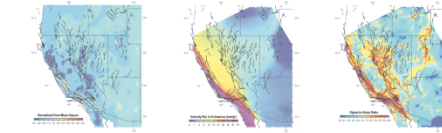


GPS DATA

The GPS stations were compiled specifically for this study. The GPS stations were compiled specifically for this study. The GPS stations were compiled specifically for this study. The GPS stations were compiled specifically for this study.

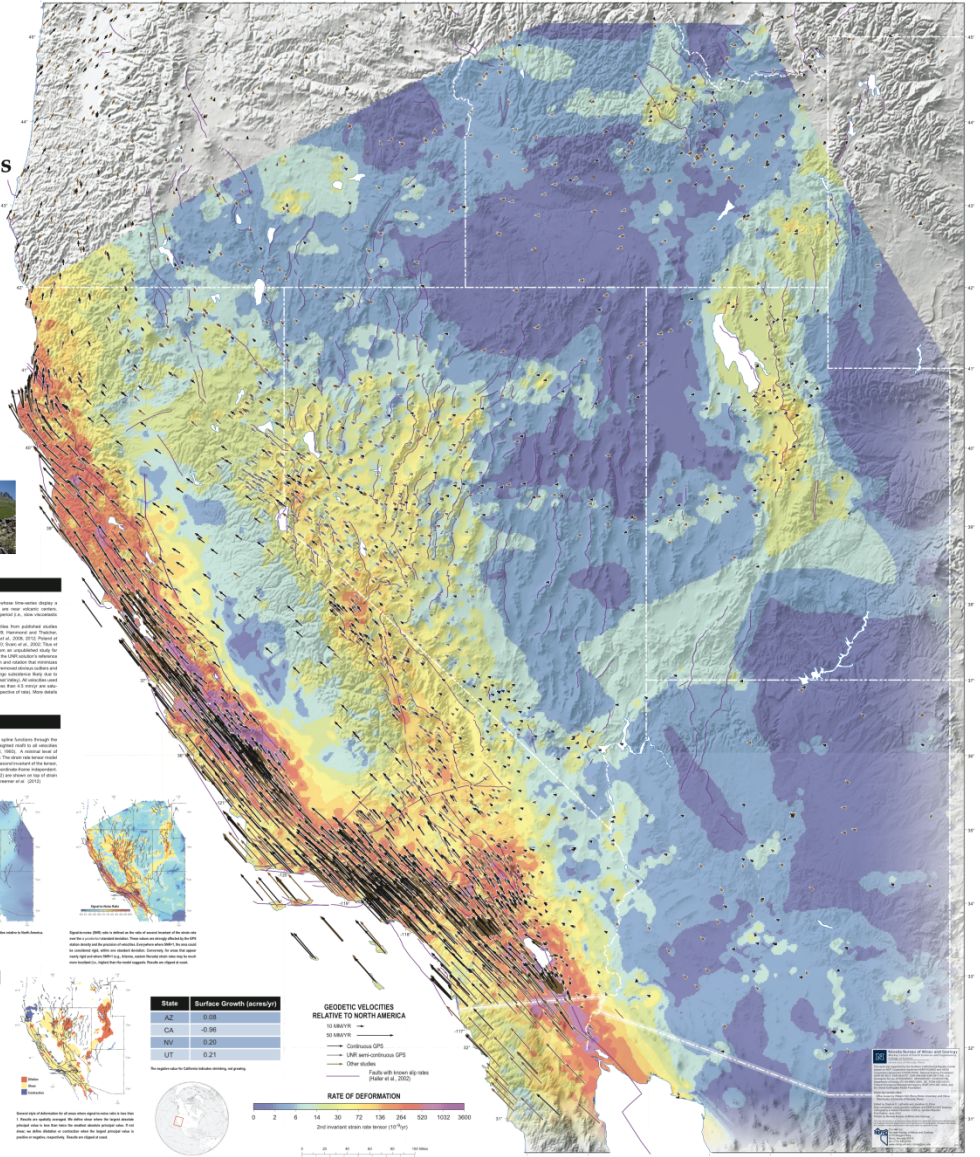
MODELING DETAILS

For the strain rate model, we included GPS stations with available vertical data. We used the GPS stations with available vertical data. We used the GPS stations with available vertical data. We used the GPS stations with available vertical data.



BIBLIOGRAPHY

We refer to the following publications for background information on GPS observations and strain rate modeling. We refer to the following publications for background information on GPS observations and strain rate modeling. We refer to the following publications for background information on GPS observations and strain rate modeling.

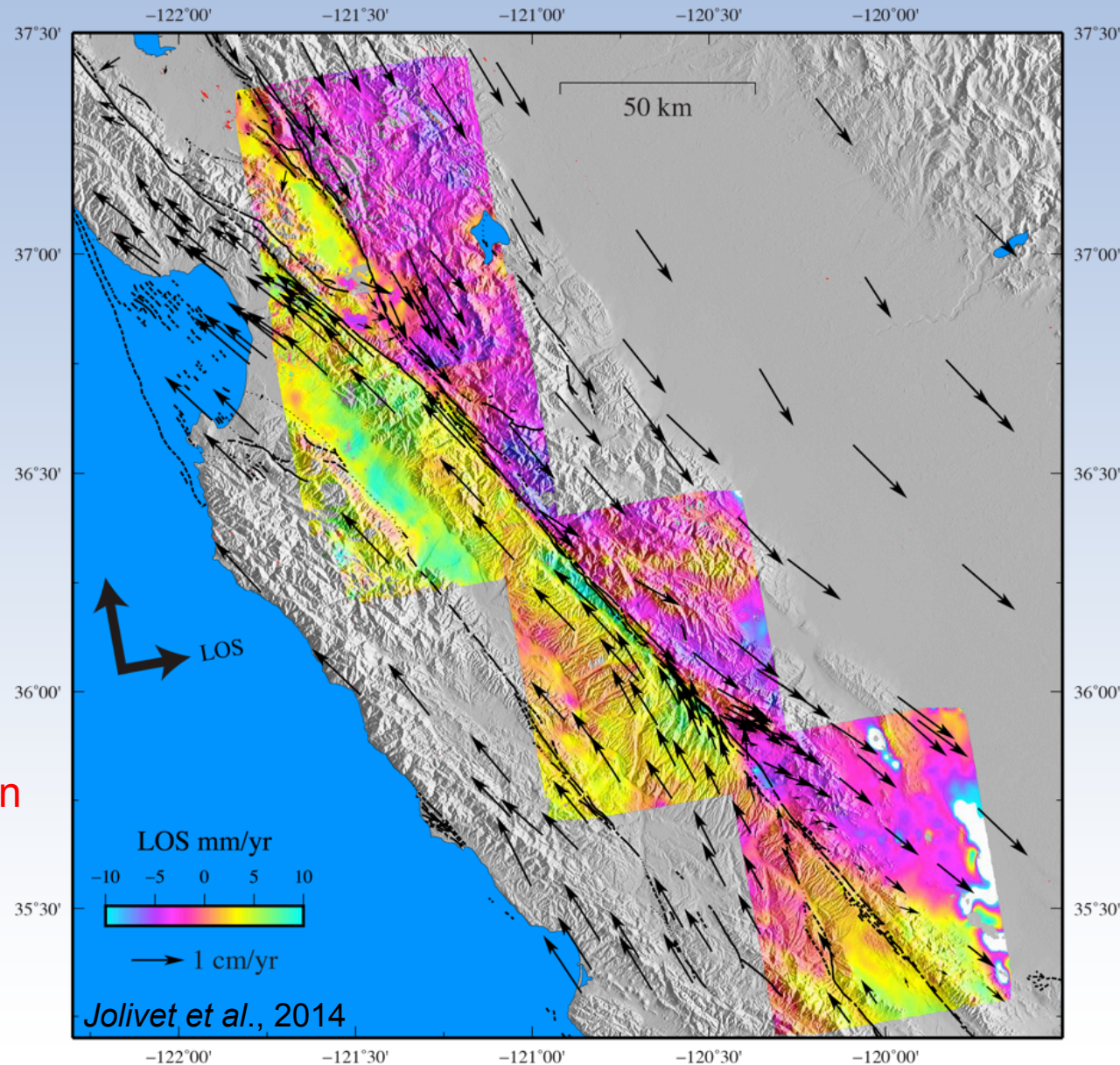


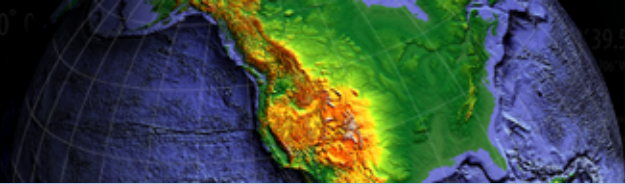
Kinematics, dynamics & structure of the San Andreas Fault

- Low strain accumulation across the Central SAF
- Previous ruptures don't overlap with creeping regions.
- Transition from creeping to locked is smooth in the north but abrupt in the south.

Data
 Satellite radar: ALOS
 GPS: PBO, BARD

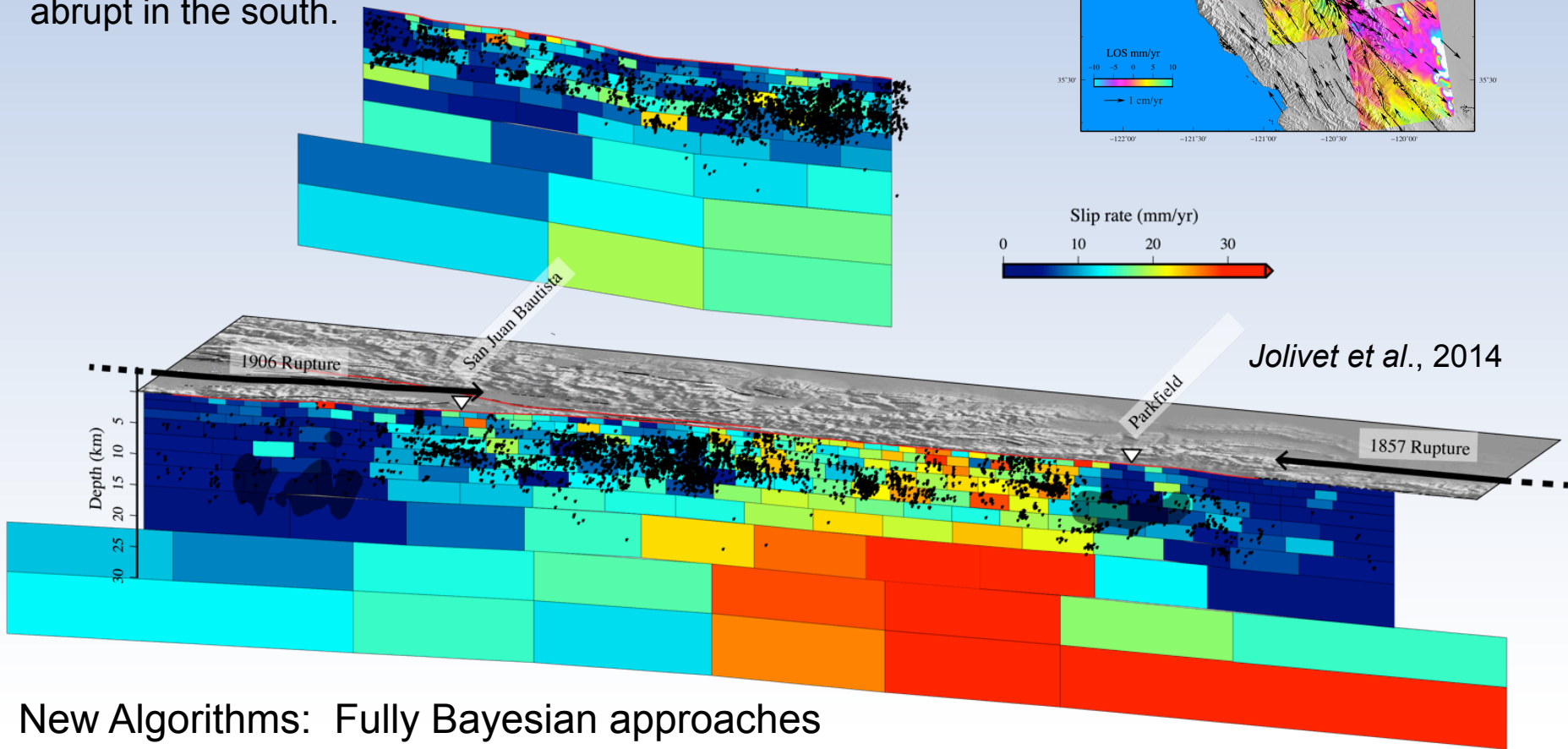
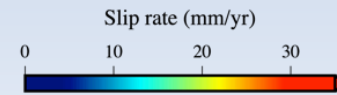
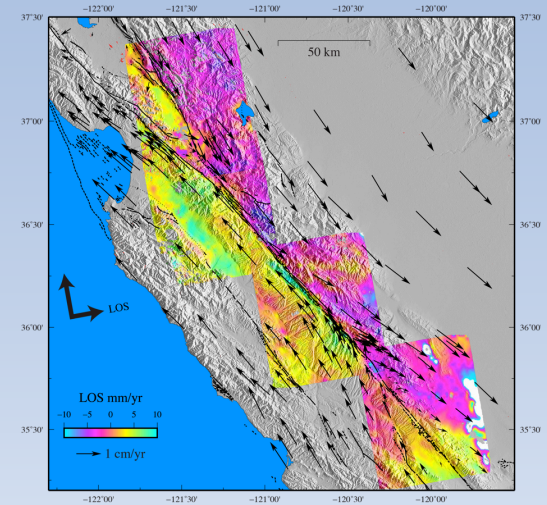
Mapping interseismic strain accumulation by merging GPS and repeat satellite radar imaging



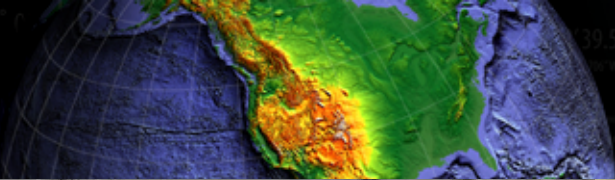


Kinematics, dynamics & structure of the San Andreas Fault

- Low strain accumulation across the Central SAF
- Previous ruptures and creeping regions don't overlap.
- Transition from creeping to locked is smooth in the north but abrupt in the south.

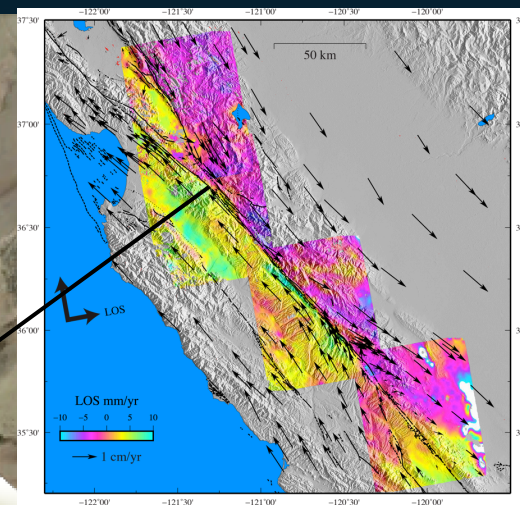
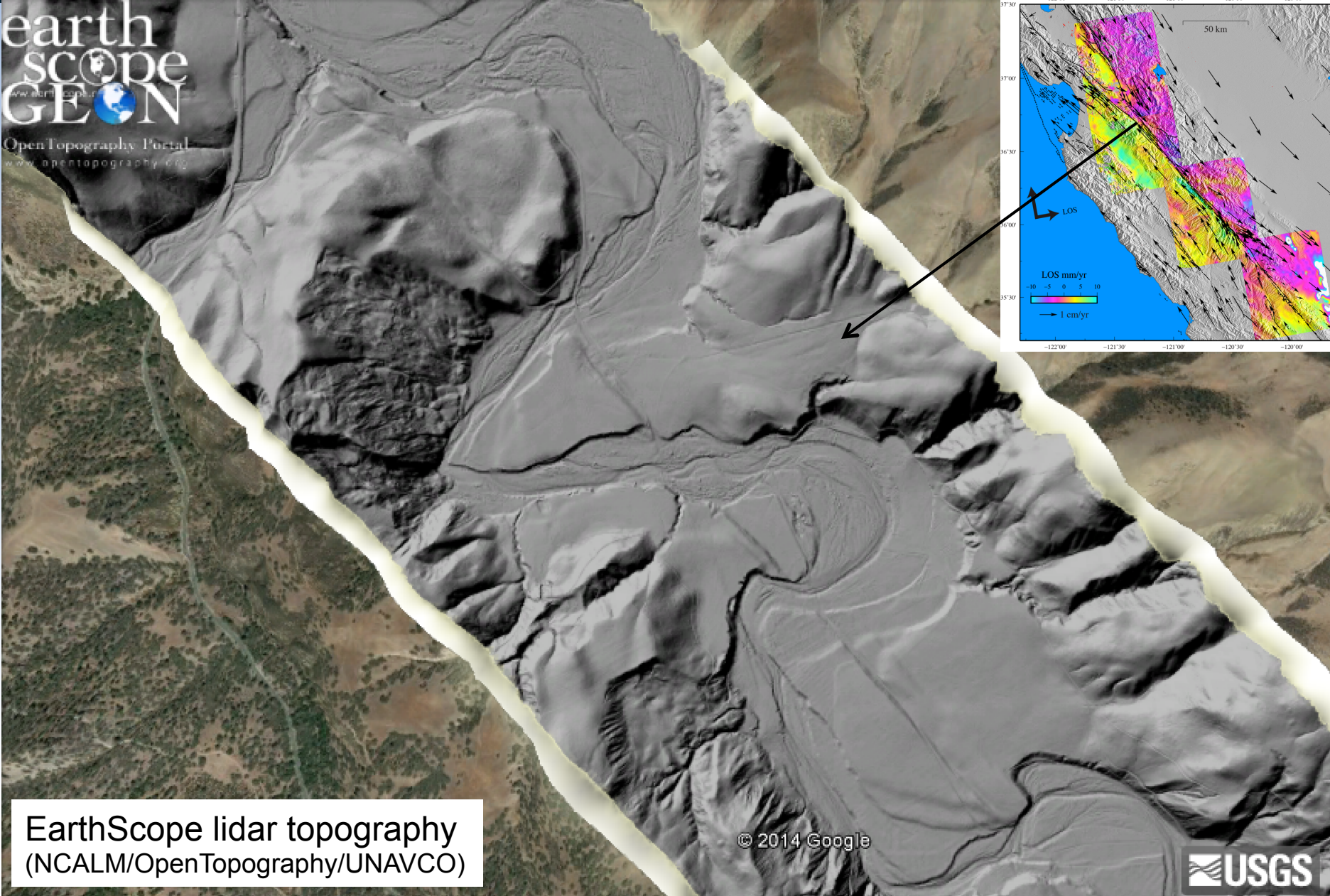


New Algorithms: Fully Bayesian approaches

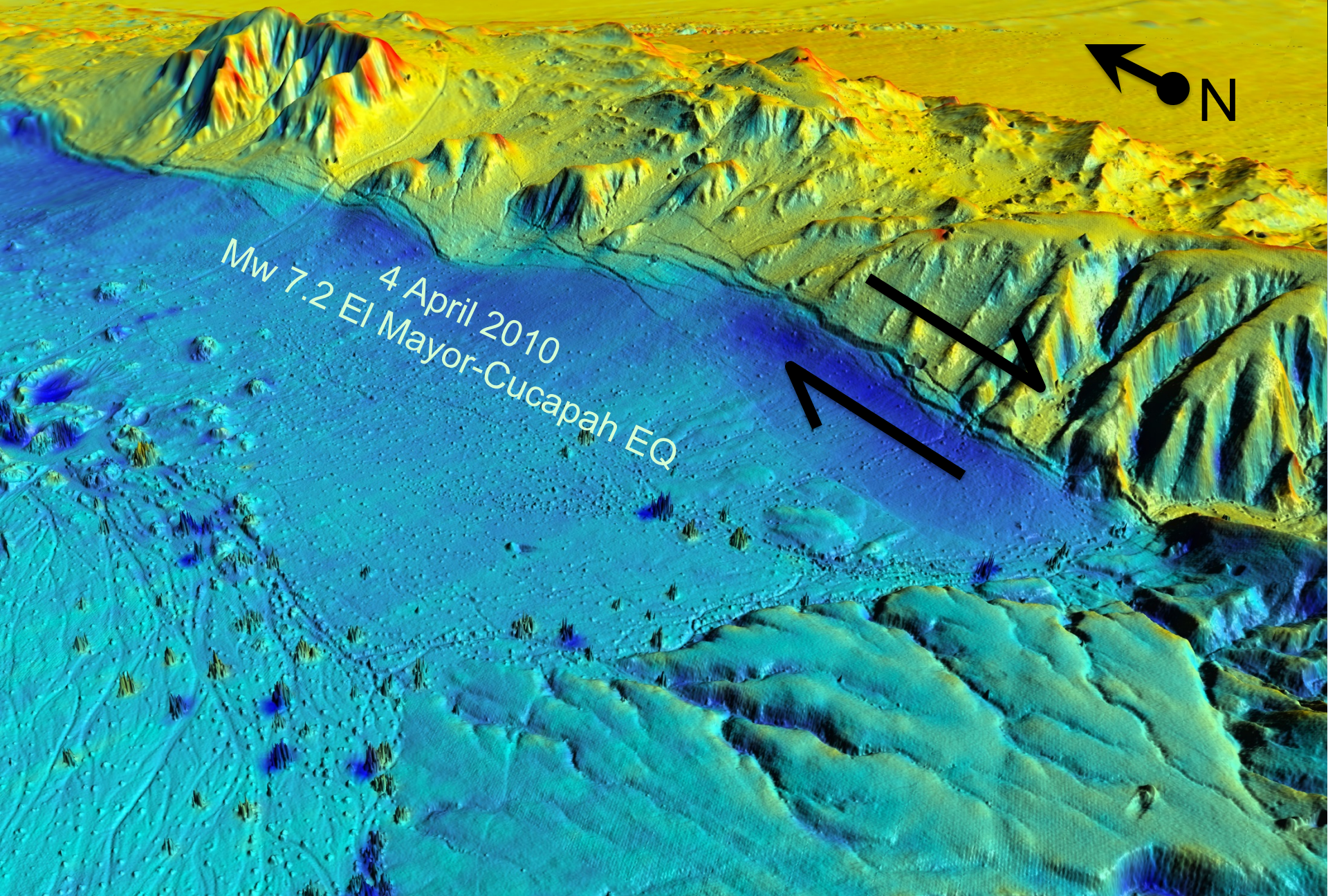


Kinematics, dynamics & structure of the San Andreas Fault

earth scope
GEON
OpenTopography Portal
www.opentopography.org



EarthScope lidar topography
(NCALM/OpenTopography/UNAVCO)



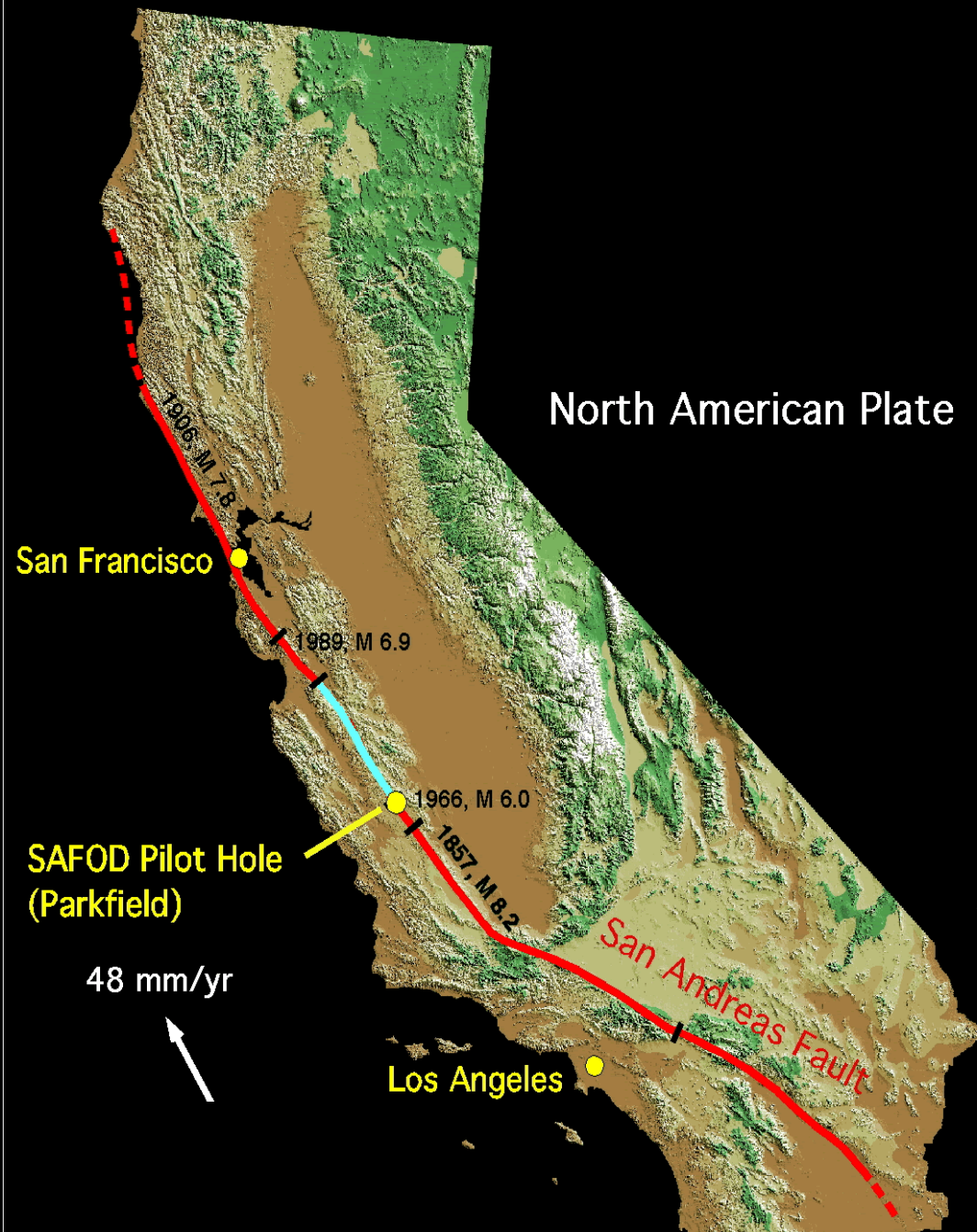
Using LIDAR to detect detailed fault offsets

Oskin, et al., 2012

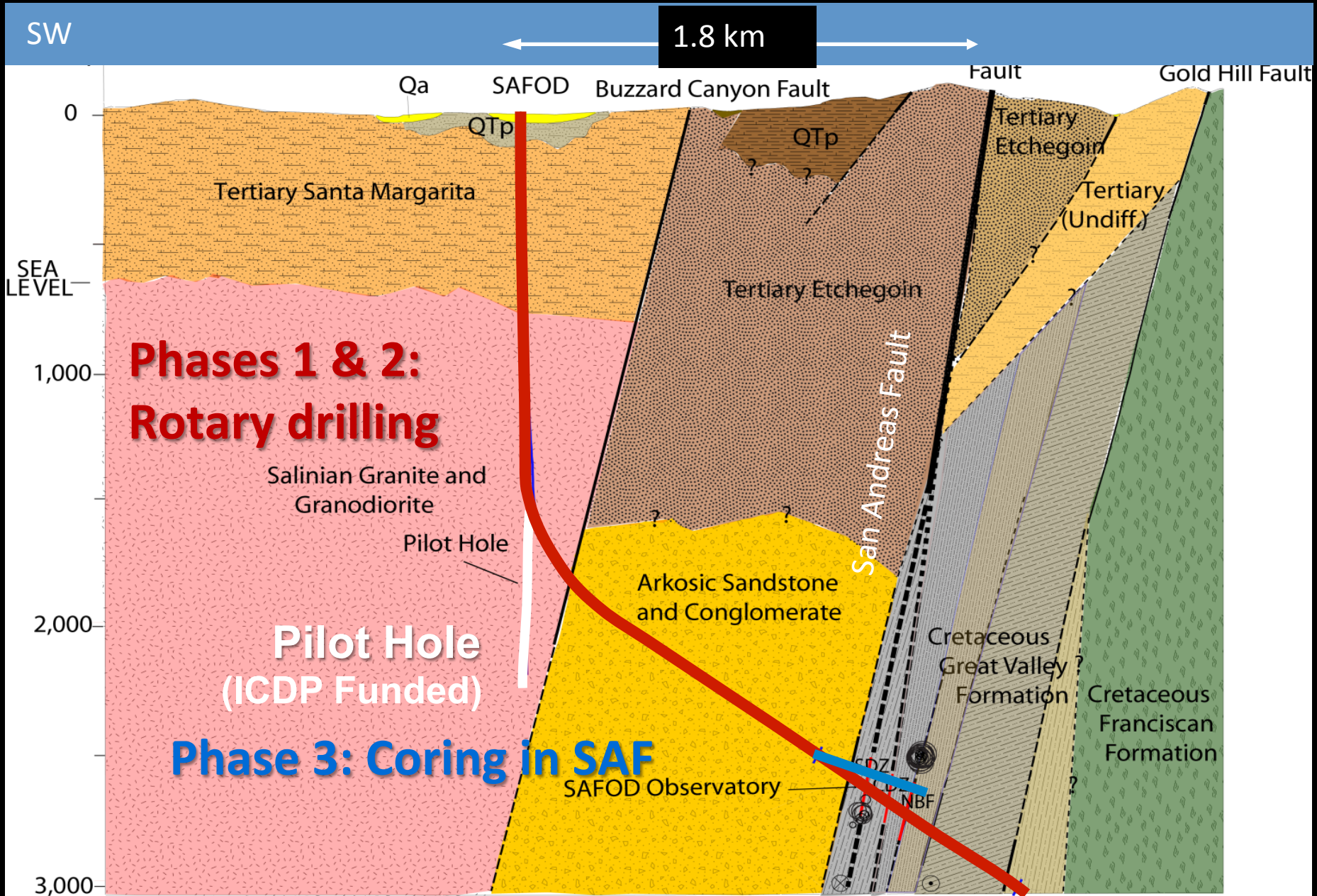
What is the strength of a plate boundary fault at seismogenic depth?

Is it 100-200 MPa,
 $\mu \approx 0.6$, or 10-20 MPa,
 $\mu \leq 0.2$?

SAFOD: Determine physical and chemical processes controlling deformation and earthquake generation within an active plate-bounding fault zone

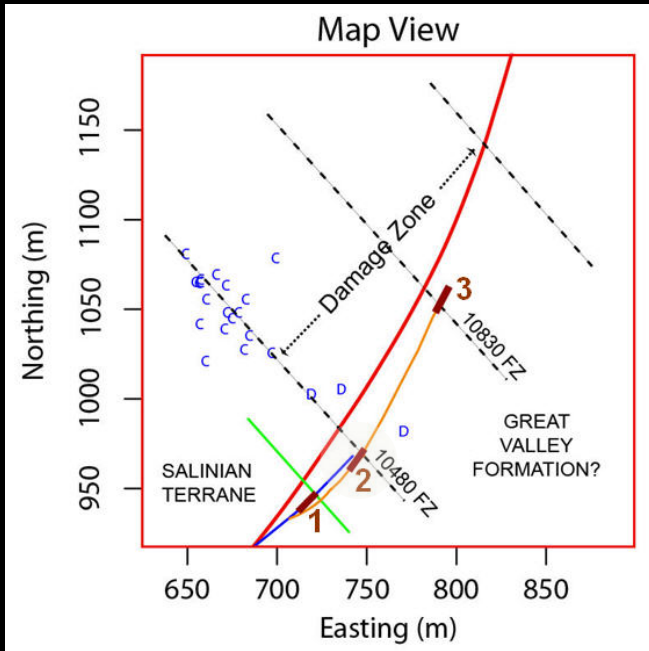


SAFOD Geology and Drilling Plan



Phase 3 Coring: Interval 2 - Across 10,480' Fault

Talc + Serpentine Found in Cuttings from 10,480 and 10,830 faults (see Solum et al, 2006; Moore and Rymer, 2007) → Mineralogical control on fault strength?



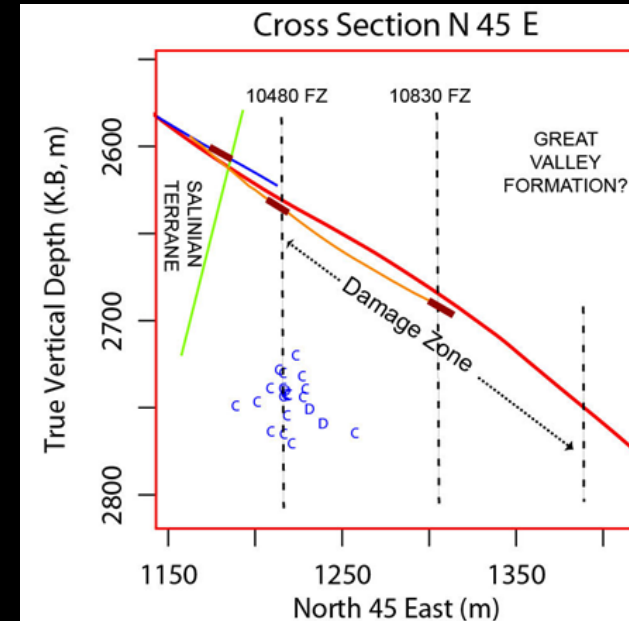
Casing Deformation Zone: Fault Gouge Layer (1.5 m thick)

Highly sheared serpentinite layer with fragmented calcite veins

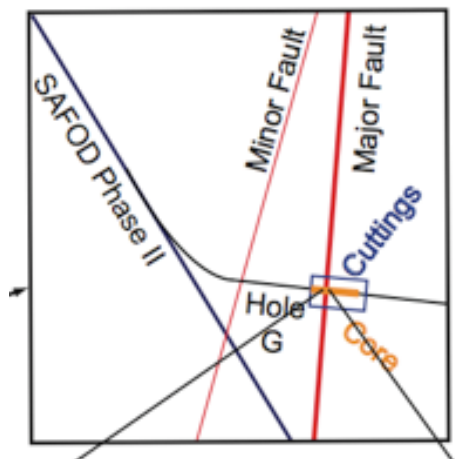
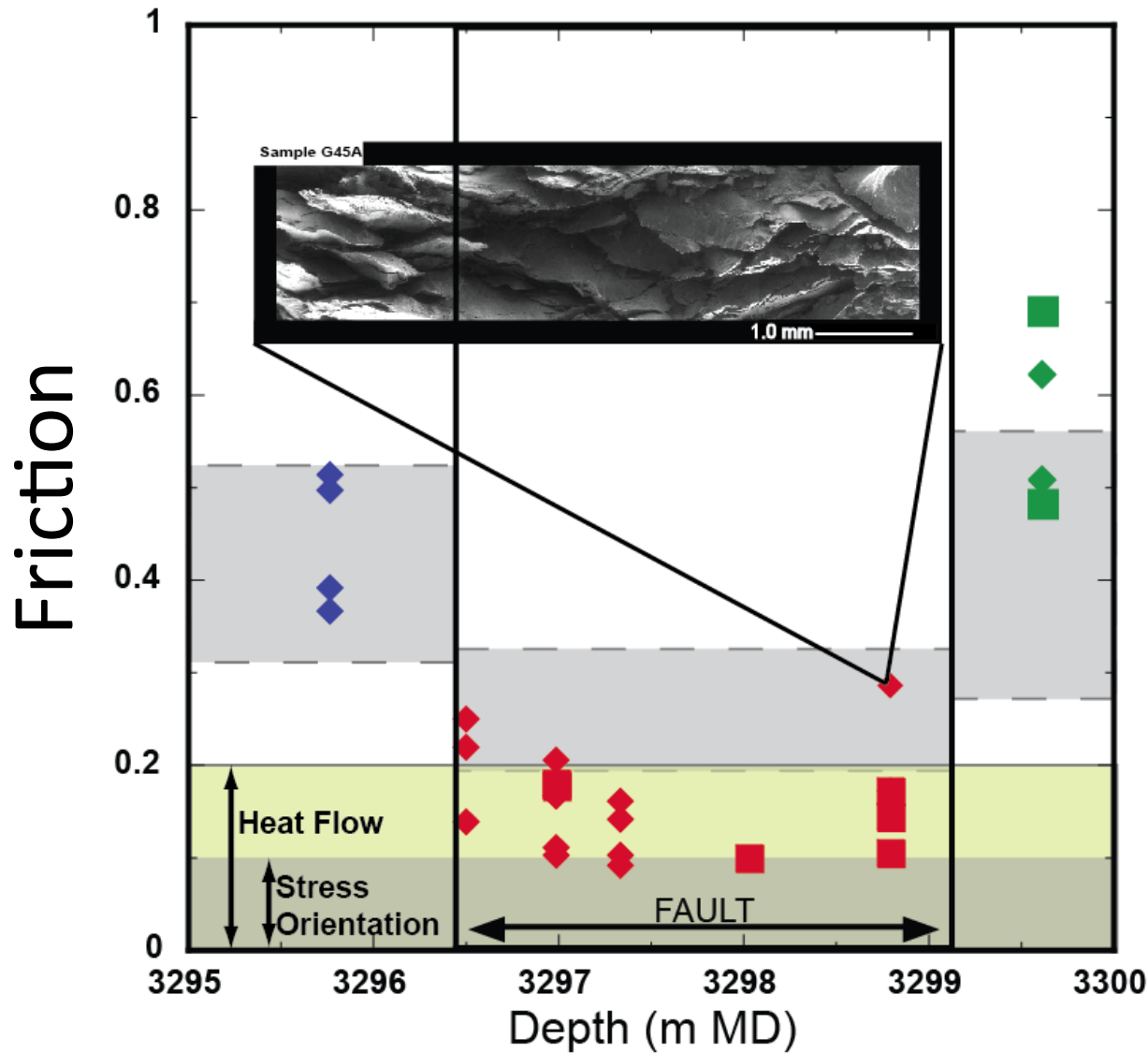
Foliated fault gouge with serpentinite and sandstone porphyroclasts

Foliated gouge with serpentinite and sandstone porphyroclasts

Serpentinite cut by white (calcite) veins

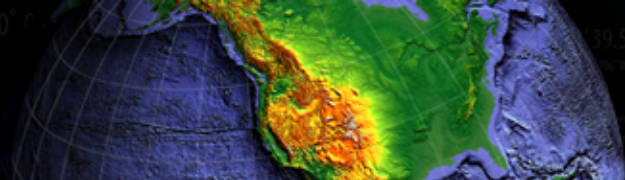


Frictional Strength, SAFOD Phase III Core



Carpenter, Marone, and Saffer, 2011

Carpenter, Saffer and Marone, 2012



San Andreas Fault is Profoundly Weak

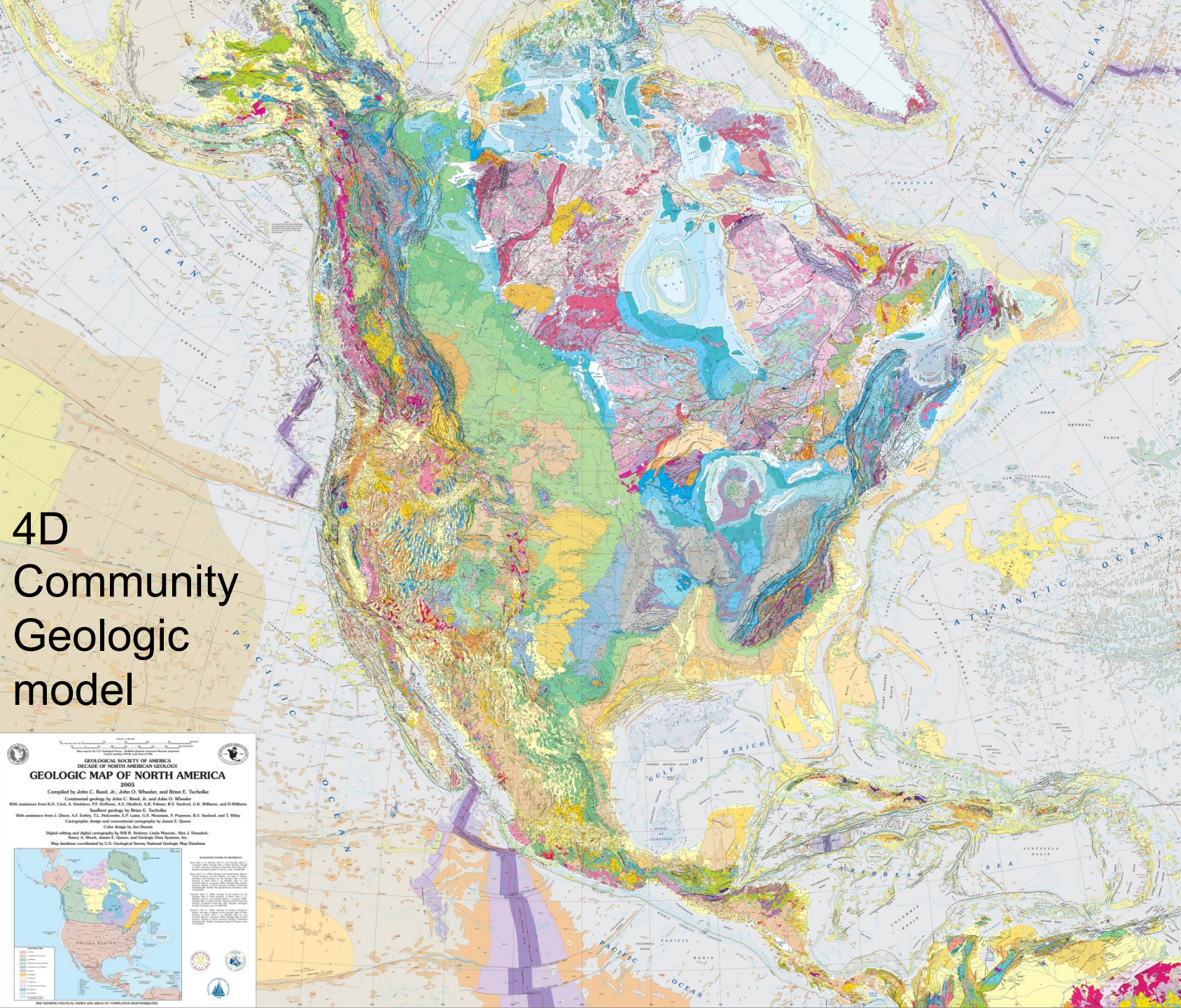
- Weakness is due to properties of fault gouge, not fluid pressure.
- Fault zone is narrow.
- Drilling laid to rest decades of debate about weakness and structure of fault zone.




What is next?

- What do we want to be doing in 2020?
- Build on the scientific, technical, and broader impact successes of EarthScope
- New partnerships





4D Community Geologic model


 **GEOLOGICAL SOCIETY OF AMERICA**
DECADE OF NORTH AMERICAN GEOLOGY
GEOLOGIC MAP OF NORTH AMERICA
2005

Compiled by John C. Reed, Jr., John O. Wheeler, and Brian E. Turchette
Continental geology by John C. Reed, Jr. and John O. Wheeler
With assistance from K.D. Coia, A. Davidson, P.J. Hoffman, A.V. Gaudin, A.R. Palmer, B.V. Swenson, C.K. Williams, and H. Williams
Seafloor geology by Brian E. Turchette
With assistance from J. Dixon, A.J. Enay, T.L. Hollister, G.P. Laine, C.K. Mooreman, P. Popescu, B.V. Swenson, B.V. Swenson, and T. Wilby
Cartographic design and conventional cartography by James E. Queen
Color design by Jan Steiner

Digital editing and digital cartography by Bill R. Suttner, Linda Mearns, Nan J. Donath,
Henry A. Stock, James E. Queen, and George Dine System, Inc.
Map database contributed by U.S. Geological Survey National Geologic Map Database

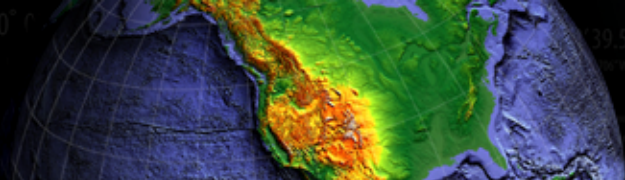
BRIDGE CODES OF REFERENCE
The map uses the following bridge codes to identify geological features:
C1 - Continental geology
S1 - Seafloor geology
C2 - Structural geology
C3 - Paleogeography
C4 - Paleogeography
C5 - Paleogeography
C6 - Paleogeography
C7 - Paleogeography
C8 - Paleogeography
C9 - Paleogeography
C10 - Paleogeography
C11 - Paleogeography
C12 - Paleogeography
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C96 - Paleogeography
C97 - Paleogeography
C98 - Paleogeography
C99 - Paleogeography
C100 - Paleogeography

MAP BOUNDARY, NATIONAL NAMES AND SCALES OF COORDINATION RESPONSIBILITIES



A Big Idea: Subduction Zone Observatory





Understanding Subduction Zones

- Subduction Zone Observatories
 - IRIS-UNAVCO collaboration to spearhead an international effort
- Leverages a history of technical interchange and collaboration: GSN, Polar, GLISN, Polenet, TA, PBO, Reference Network, COCONet, TlalocNet
- Builds from the existing backbone and engagement of regional partners
- Basic research and societal relevance and impact
- Multidisciplinary
 - Seismology, geodesy, volcanology, atmospheric . . .
- A legacy of EarthScope beyond 2018?
 - SAGE and GAGE proposals; community meetings

