Impactful Science: Earthquake Hazards and Earthscope

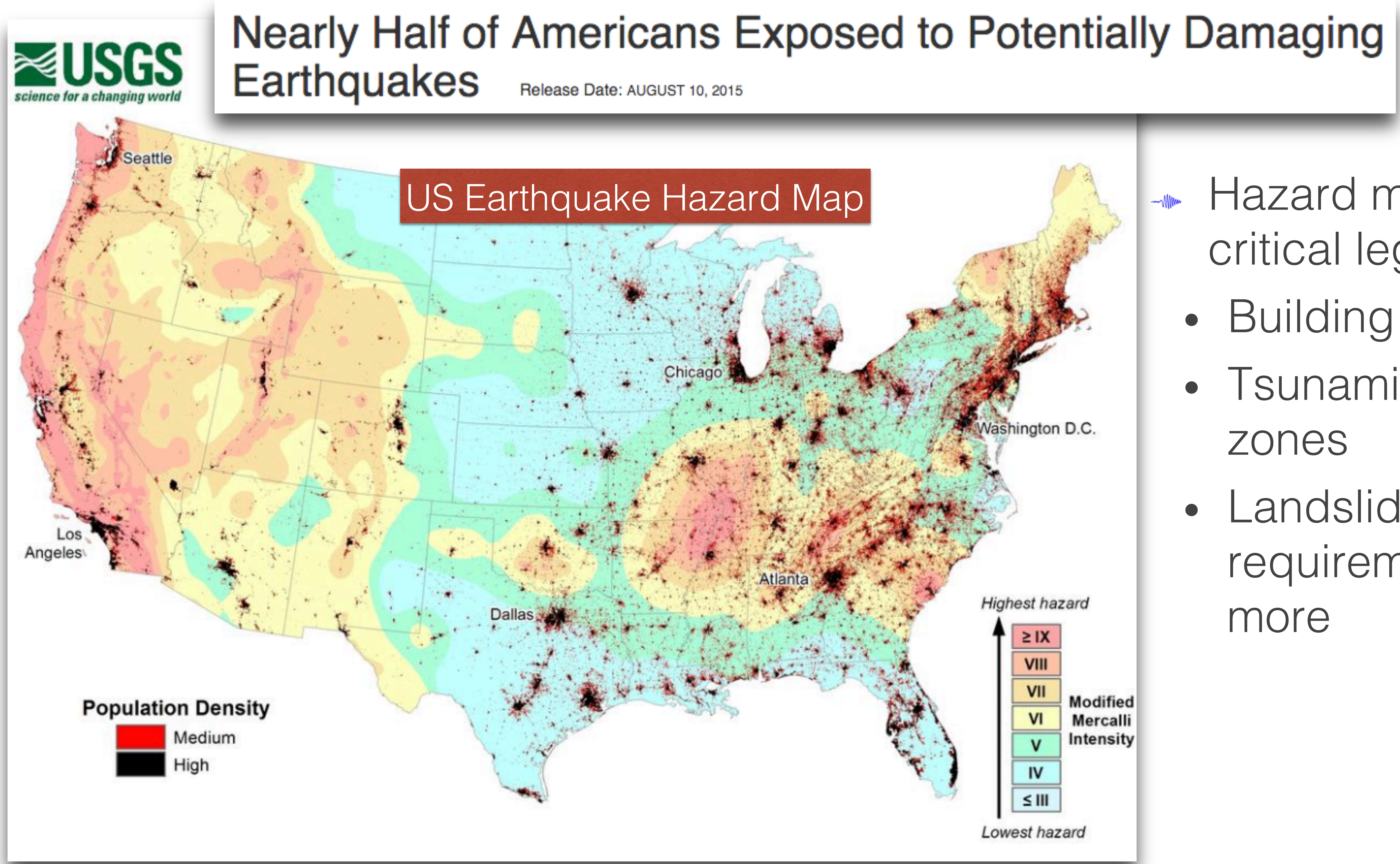
Diego Melgar
Department of Earth Sciences
University of Oregon

Society and earthquakes hazards

UNIVERSITY OF OREGON

- Fault systems are **complex**
- We understand them better than we used to
- But knowledge is still **partial**
- As geophysicists society demands **simple** answers
  - When, or how frequently, will earthquakes happen?
  - How big can they be?
  - What are their impacts?

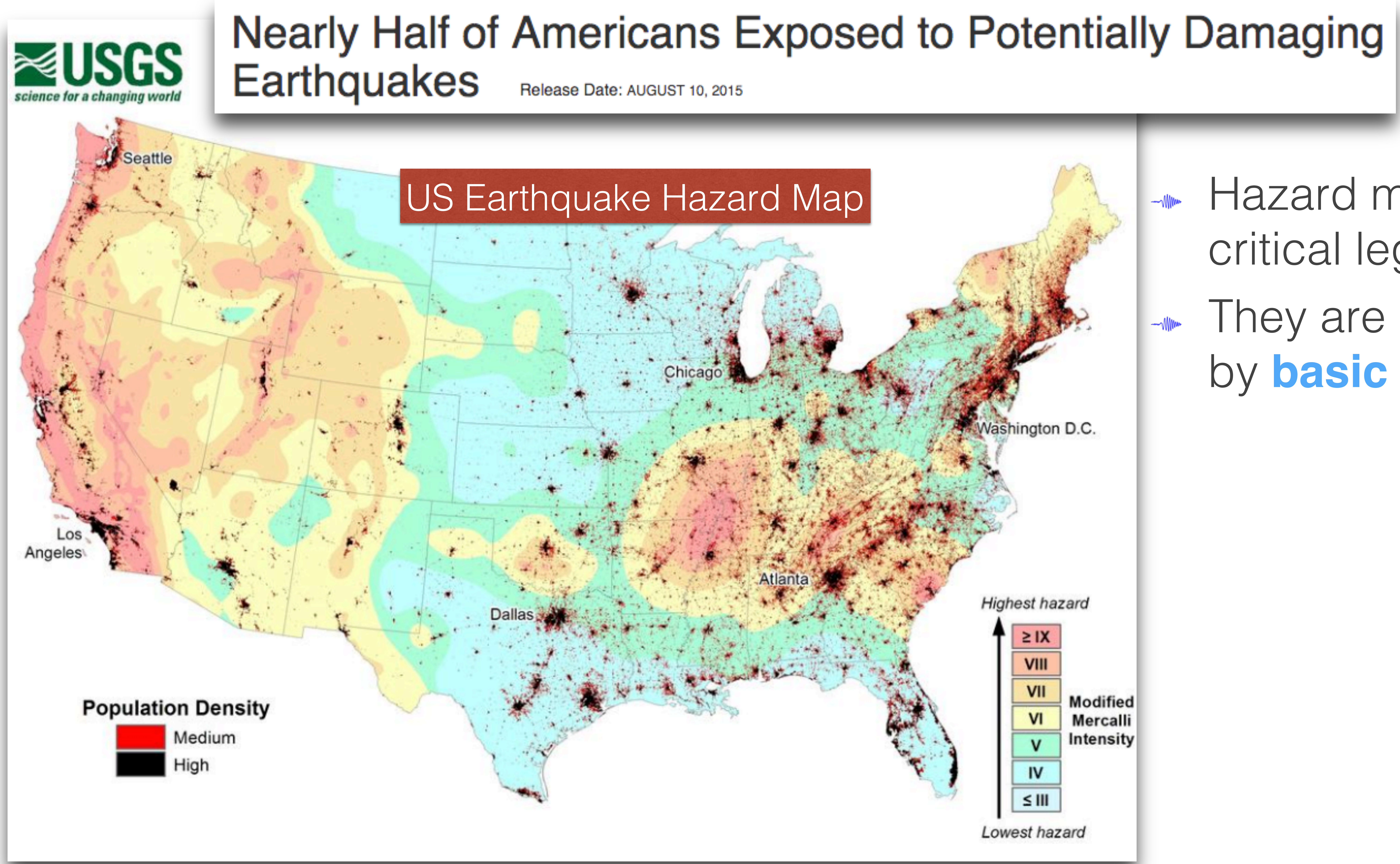
Conceptualizing hazards



- Hazard maps drive critical legislation
  - Building codes
  - Tsunami evacuation zones
  - Landslide requirements, and more

Conceptualizing hazards

UNIVERSITY OF OREGON



- Hazard maps drive critical legislation
- They are underpinned by **basic research**

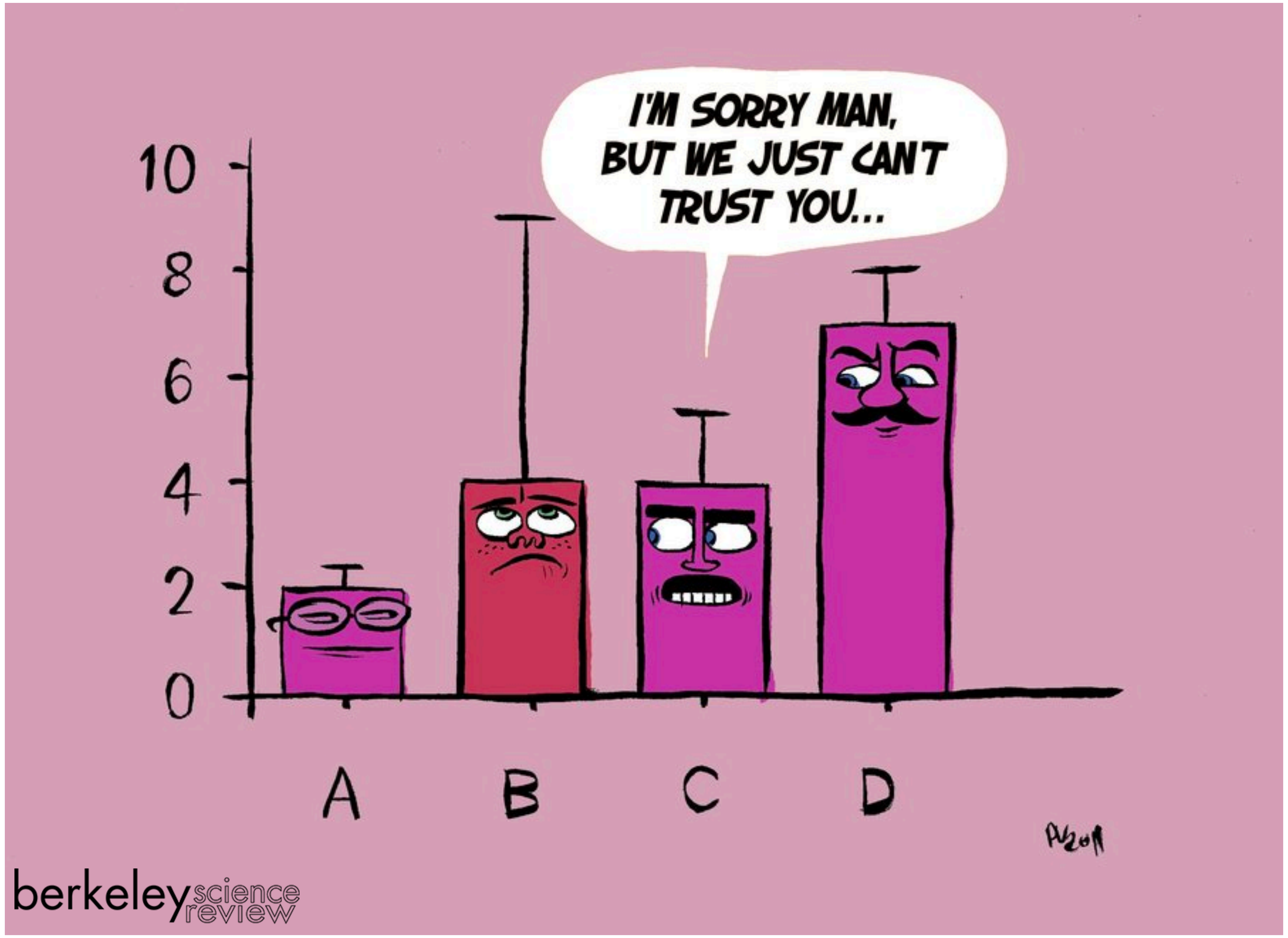
Conceptualizing hazards

UNIVERSITY OF OREGON

- This requires converting **uncertain** knowledge into **absolute** statements

  - You need **this much** concrete and rebar
  - The school **cannot be** within X km from the shore

- This is contrary to scientific epistemology, we never know an **absolute** truth.

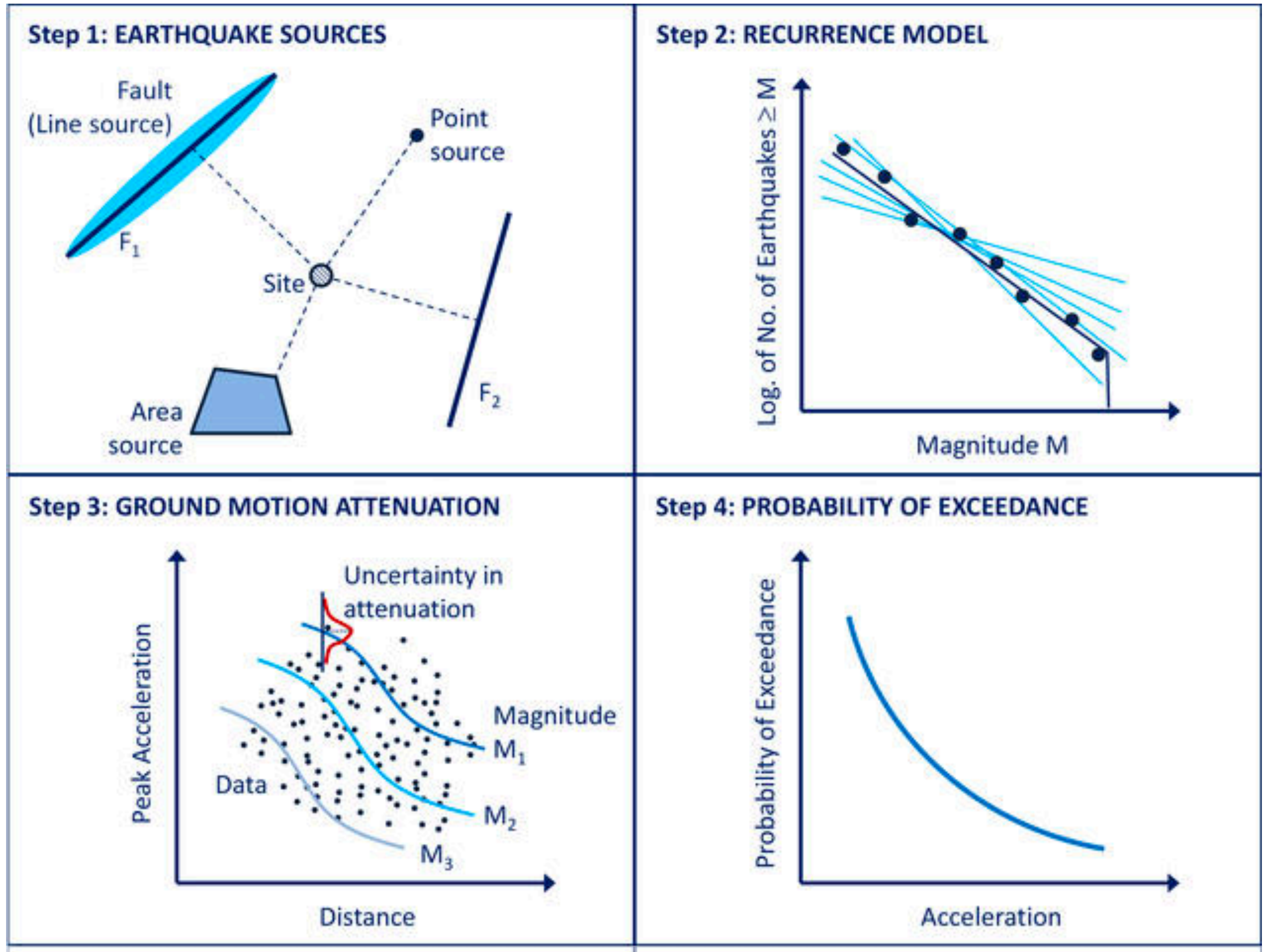


Conceptualizing hazards

- We are left with **two choices**:
  - **Paralysis**: admit our fallibility and do nothing
  - Or, formalisms that **maximize information** content of our imperfect knowledge

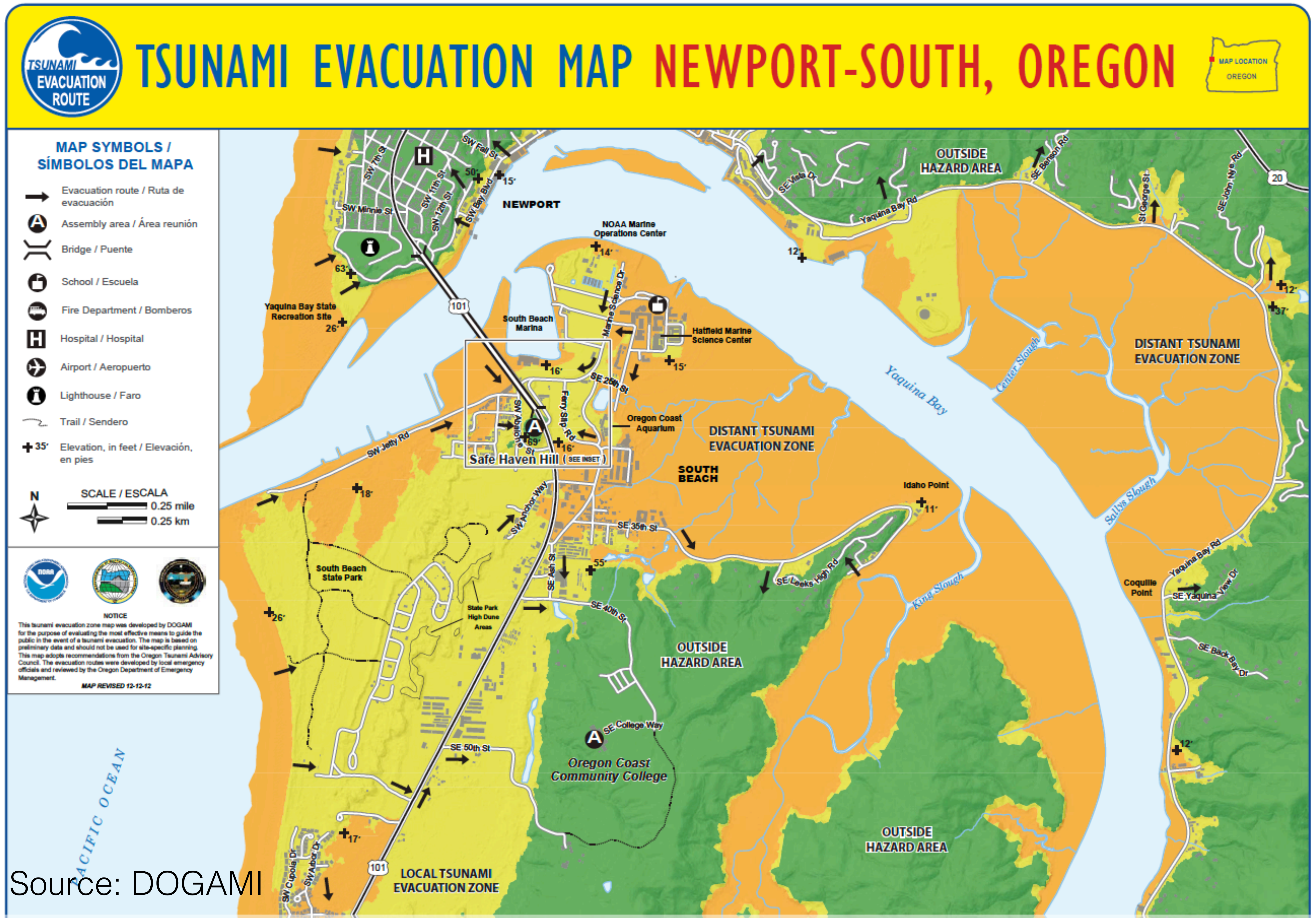
Conceptualizing hazards

Probabilistic Seismic Hazard Analysis



Source: FEMA

Scenario Driven Tsunami Evacuation Maps



Source: DOGAMI

How has basic science influenced hazards?


The Cascadia
Subduction Zone

Is Cascadia active? A brief history

UNIVERSITY OF OREGON

Earthquake Hazards on the Cascadia Subduction Zone

THOMAS H. HEATON AND STEPHEN H. HARTZELL

Science AAAS Vol. 236, No. 4798 (Apr. 10, 1987), pp. 162-168

Radiocarbon test of earthquake magnitude at the Cascadia subduction zone

Brian F. Atwater*, Minze Stuiver† & David K. Yamaguchi‡

NATURE · VOL 353 · 12 SEPTEMBER 1991

Tree-ring dating the 1700 Cascadia earthquake

NATURE | VOL 389 | 30 OCTOBER 1997

David K. Yamaguchi
Department of Environmental Health, University of Washington, Box 354695, Seattle, Washington 98195, USA
e-mail: yamaguch@u.washington.edu
Brian F. Atwater
US Geological Survey, Department of Geological Sciences, University of Washington, Box 351310, Seattle, Washington 98195, USA
Daniel E. Bunker
Tree-Ring Laboratory, Lamont-Doherty Earth Observatory, Palisades, New York 10964, USA
Boyd E. Benson
GeoEngineers Inc., 8410 154th Avenue N.E., Redmond, Washington 98052, USA
Marion S. Reid
The Nature Conservancy, 2060 Broadway, Suite 230, Boulder, Colorado 80302, USA

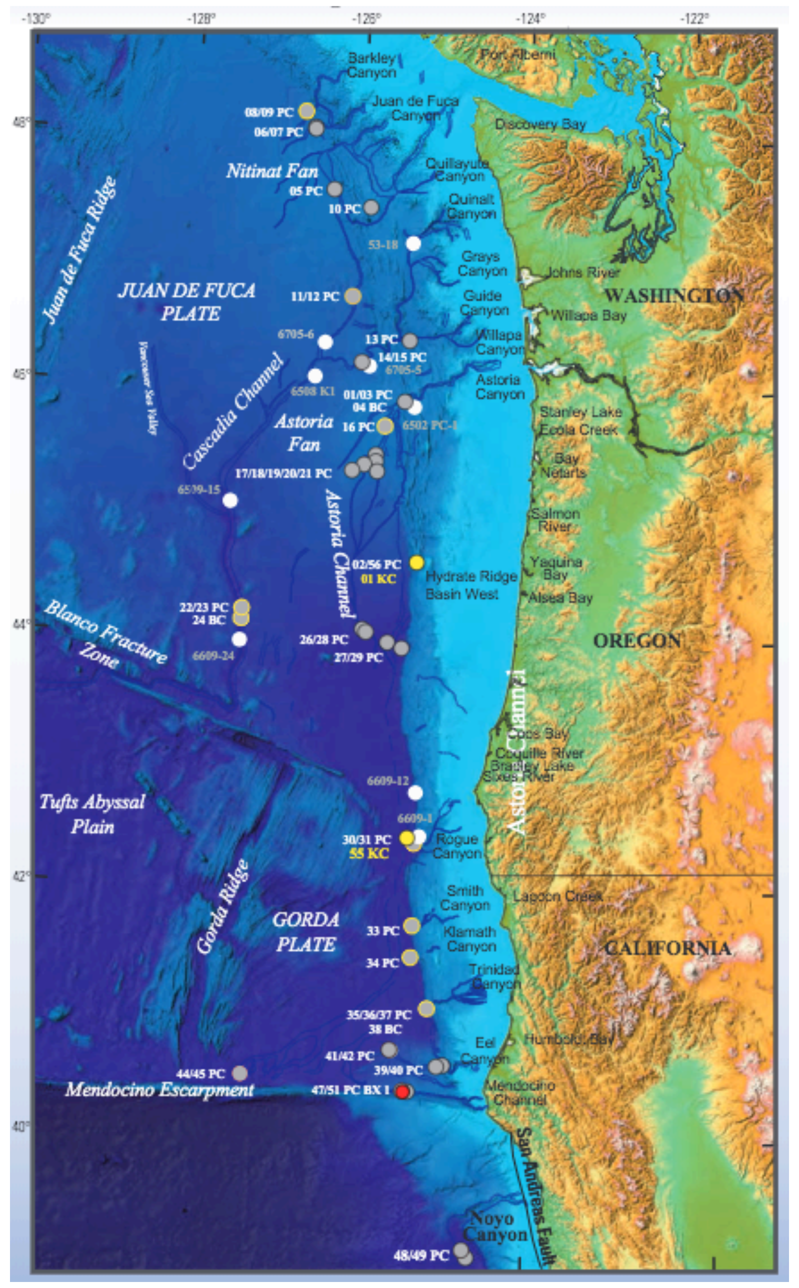
Turbidite Event History—Methods and Implications for Holocene Paleoseismicity of the Cascadia Subduction Zone

By Chris Goldfinger, C. Hans Nelson, Ann E. Morey, Joel E. Johnson, Jason R. Patton, Eugene Karabanov, Julia Gutiérrez-Pastor, Andrew T. Eriksson, Eulàlia Gràcia, Gita Dunhill, Randolph J. Enkin, Audrey Dallimore, and Tracy Vallier

Professional Paper 1661–F

U.S. Department of the Interior
U.S. Geological Survey

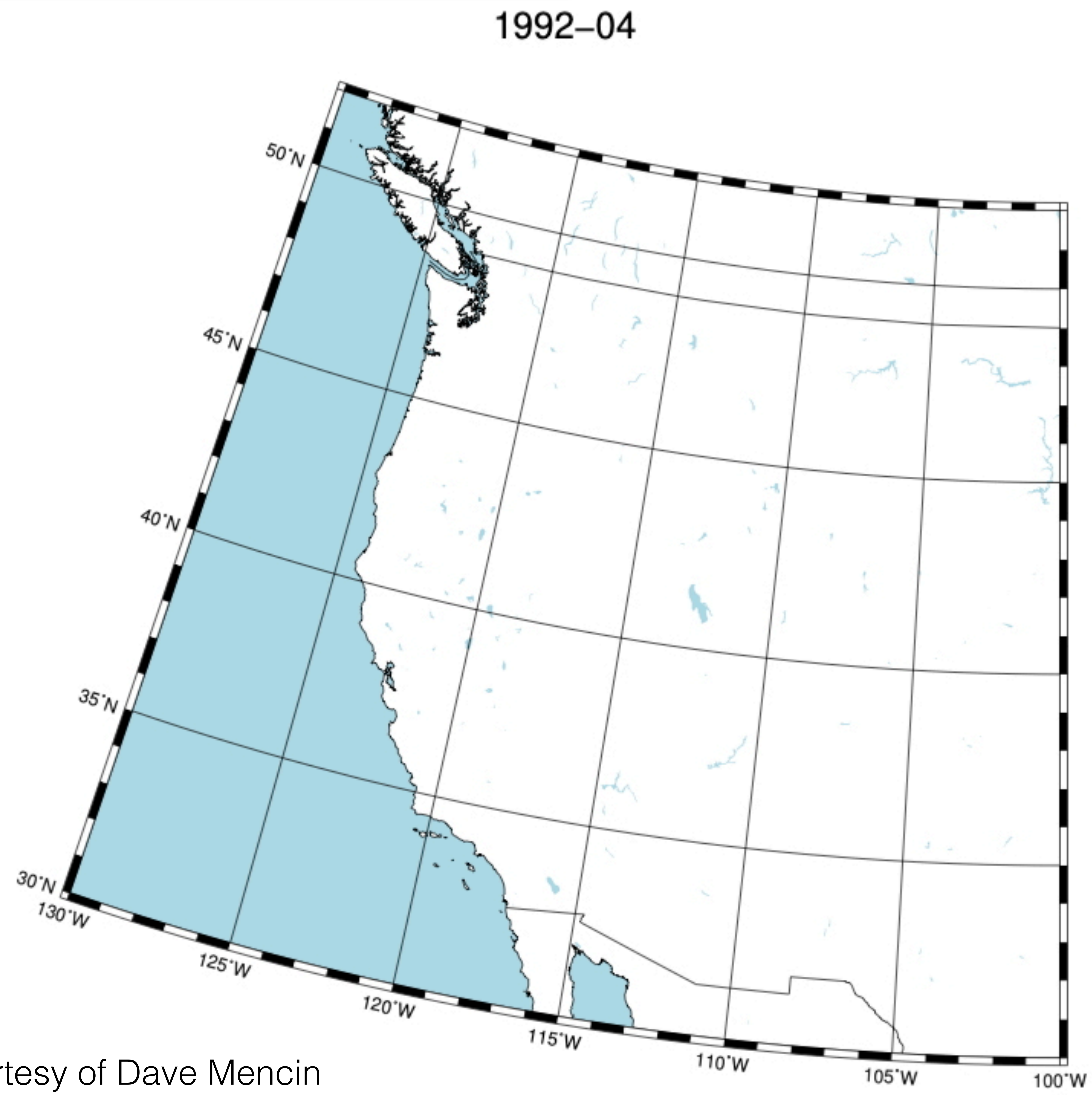
2001



Cascadia's motion

- **1278** PBO stations built out to supplement local networks
- Direct measurements of plate **deformation**
- **Where** are the faults and are they **locked** or not?

PBO GPS station buildout



Courtesy of Dave Mencin

Cascadia's landward movement

- Is Cascadia **locked**?
    - **Yes!**

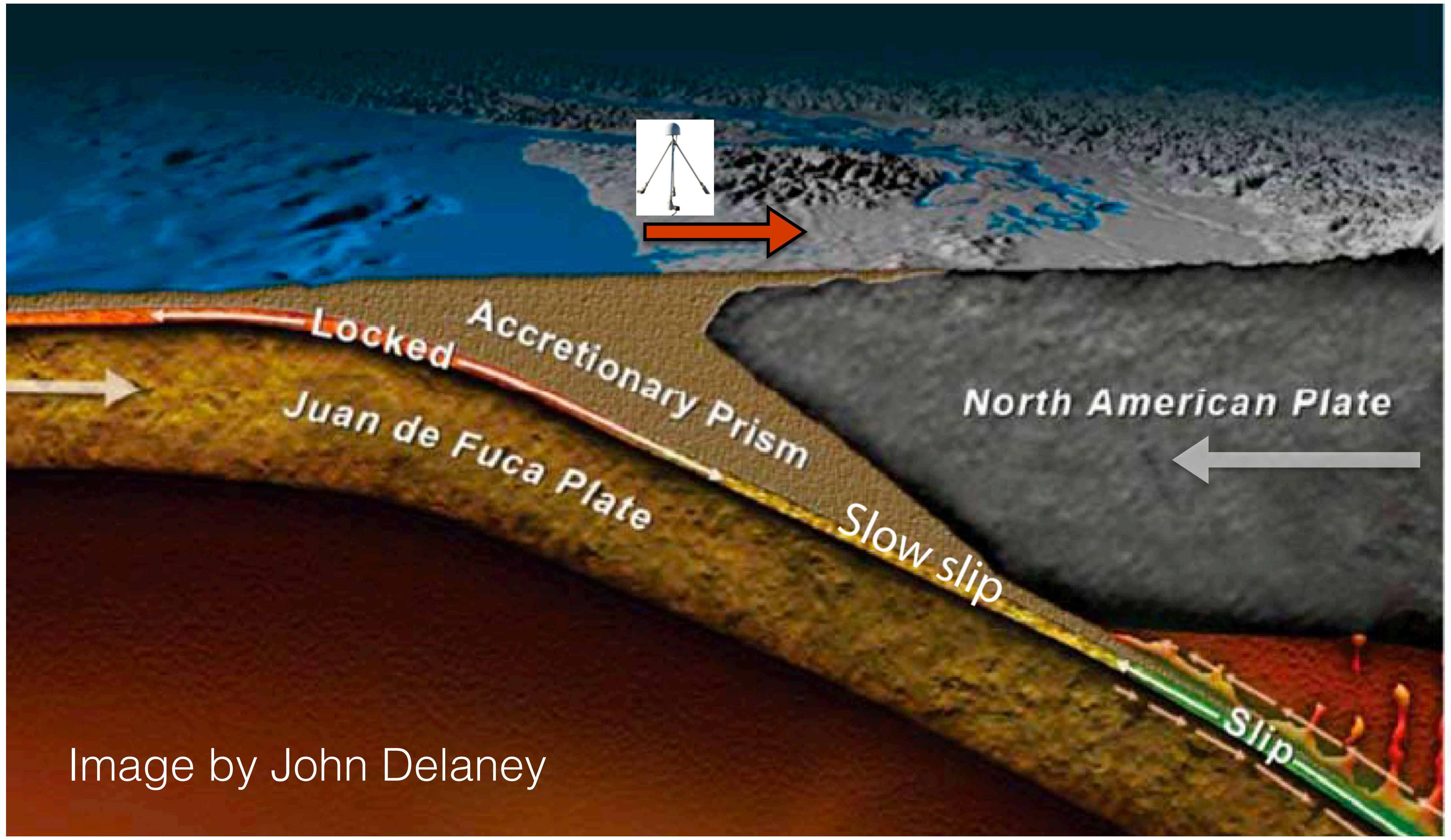
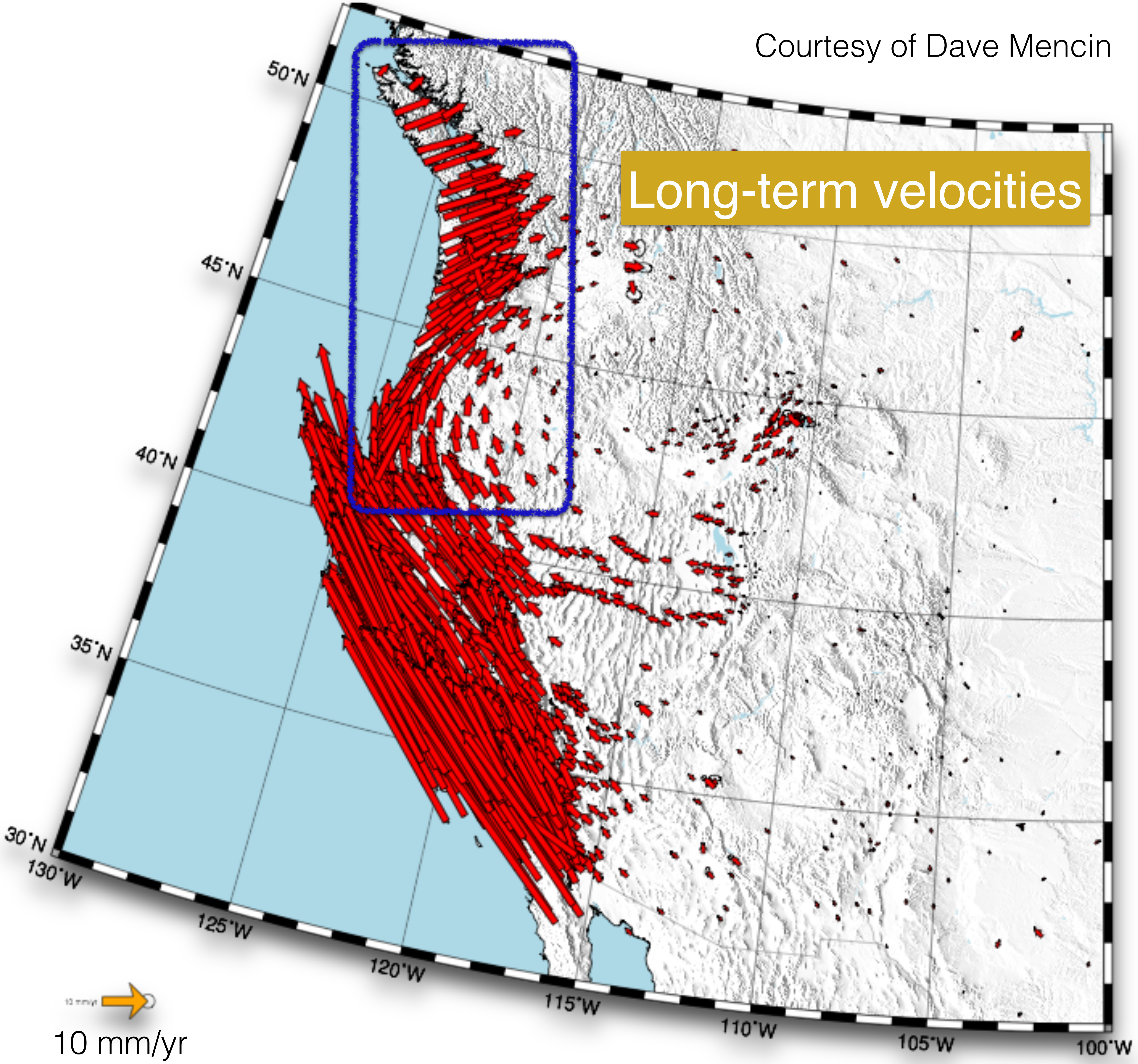


Image by John Delaney



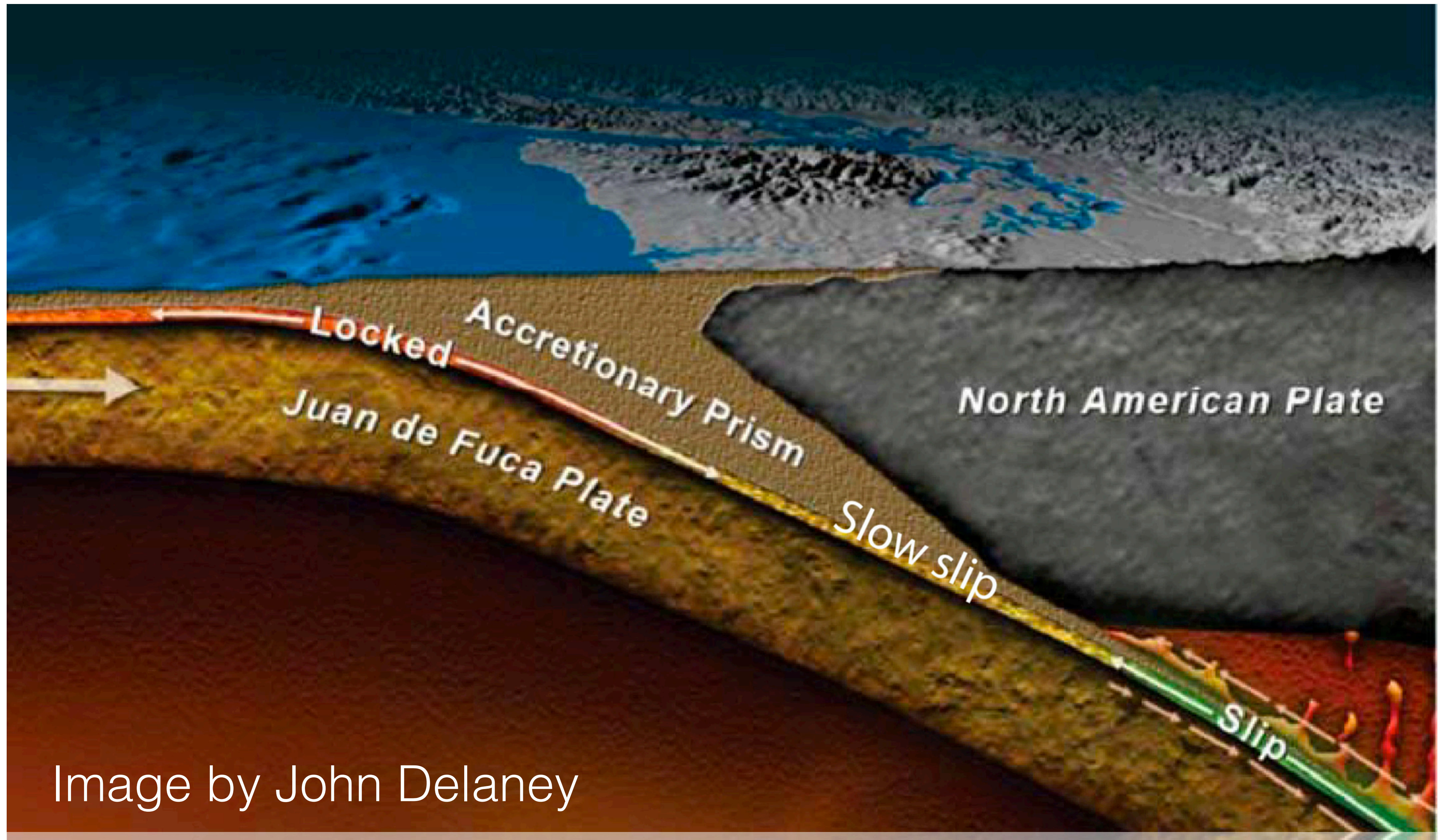
Is Cascadia active? The geodetic perspective

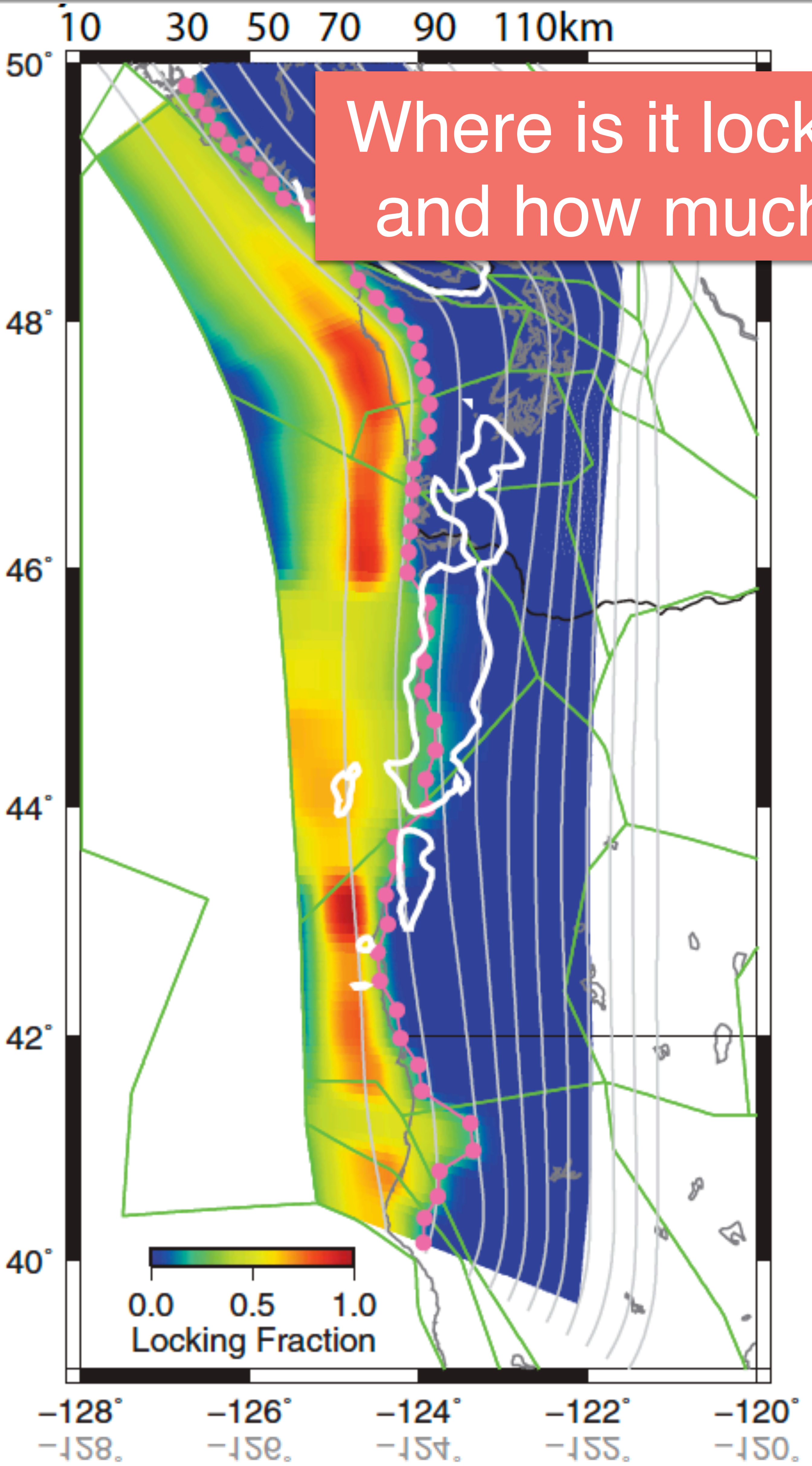
Geochemistry, Geophysics, Geosystems

RESEARCH ARTICLE
10.1002/2013GC005172

Central Cascadia subduction zone creep

Gina M. Schmalzle[1,2], Robert McCaffrey[3], and Kenneth C. Creager[1]





Is Cascadia active? The geodetic perspective

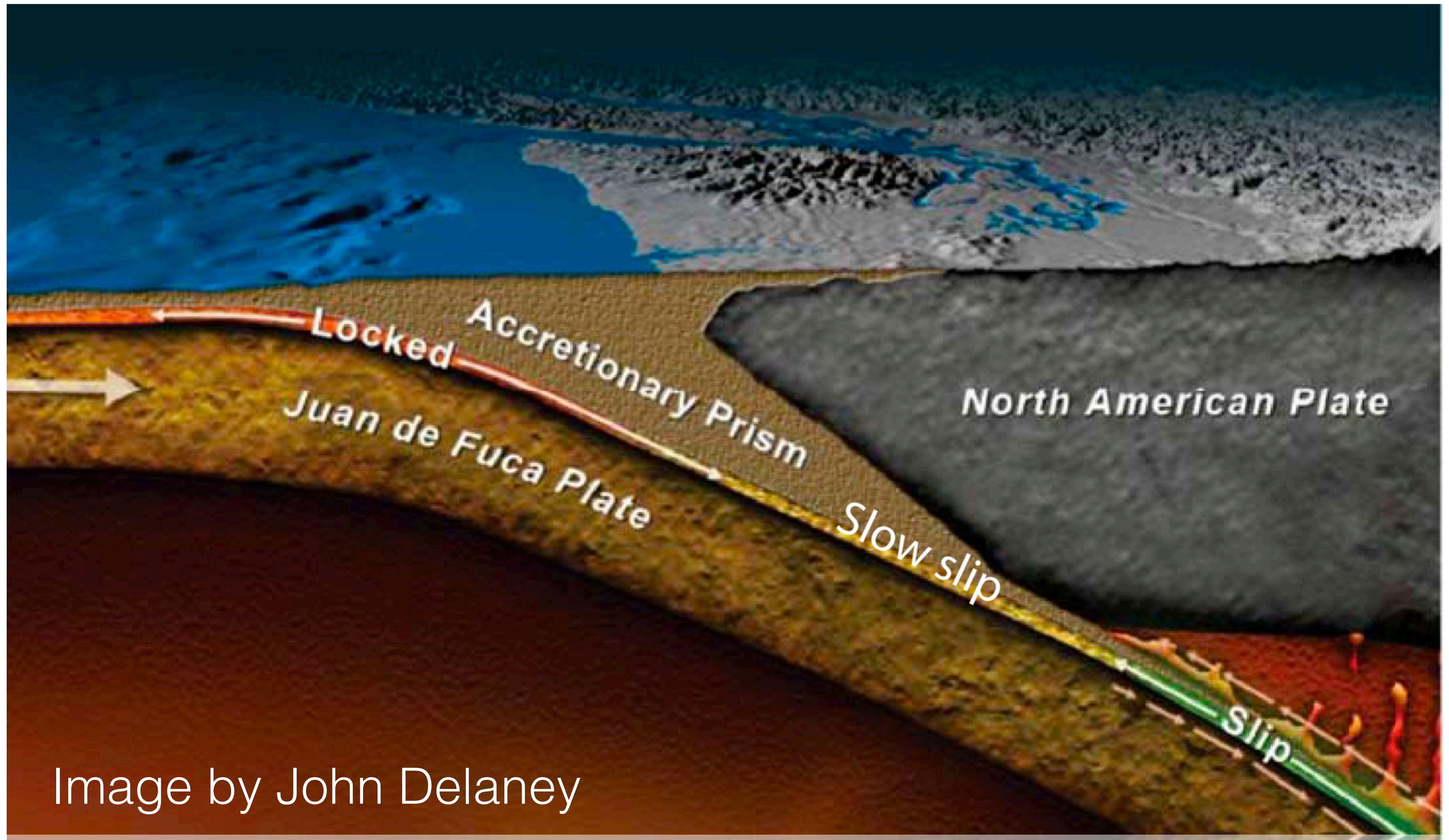
UNIVERSITY OF OREGON

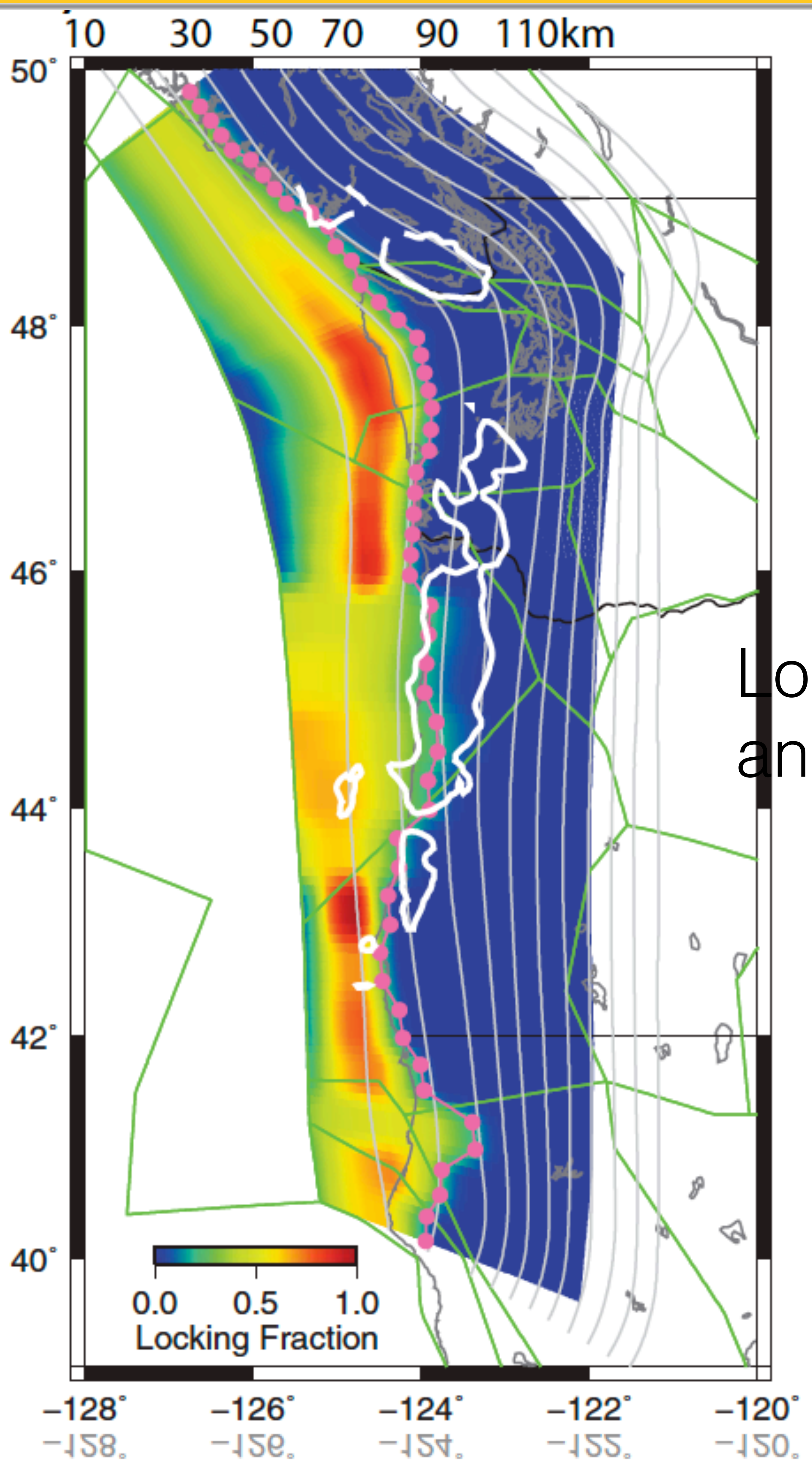
Geochemistry, Geophysics, Geosystems

RESEARCH ARTICLE
10.1002/2013GC005172

Central Cascadia subduction zone creep

Gina M. Schmalzle[1,2], Robert McCaffrey[3], and Kenneth C. Creager[1]





Locking is **heterogenous** and **segmented**

Is Cascadia active? The geodetic perspective

UNIVERSITY OF OREGON

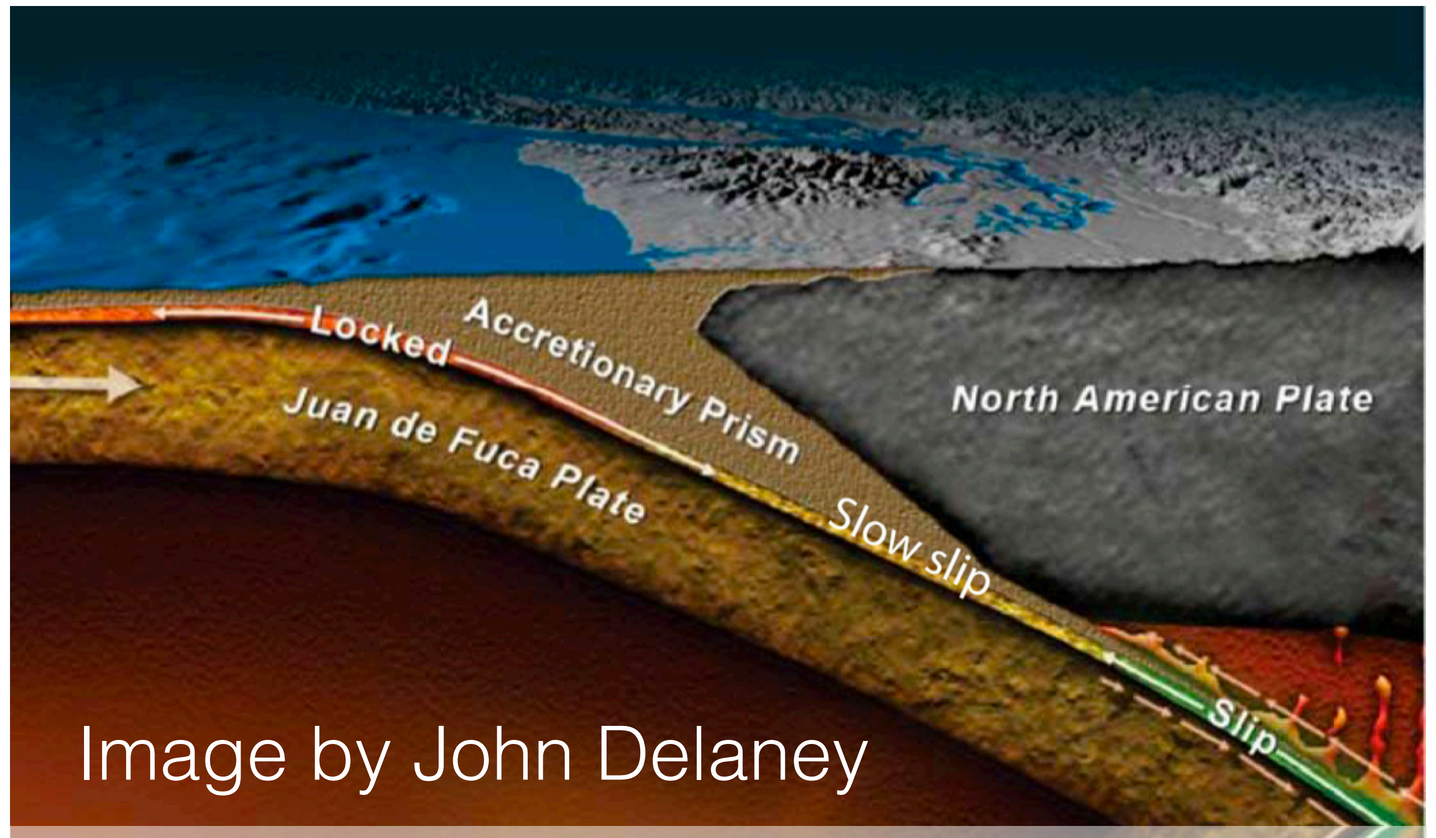
Geochemistry, Geophysics, Geosystems

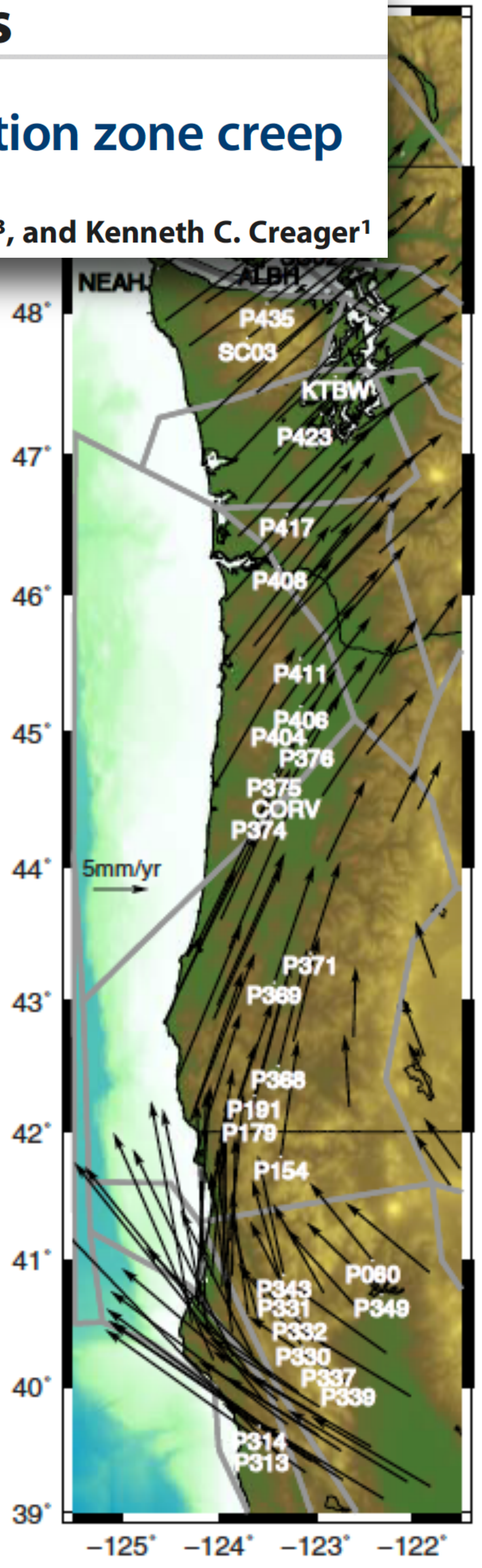
RESEARCH ARTICLE

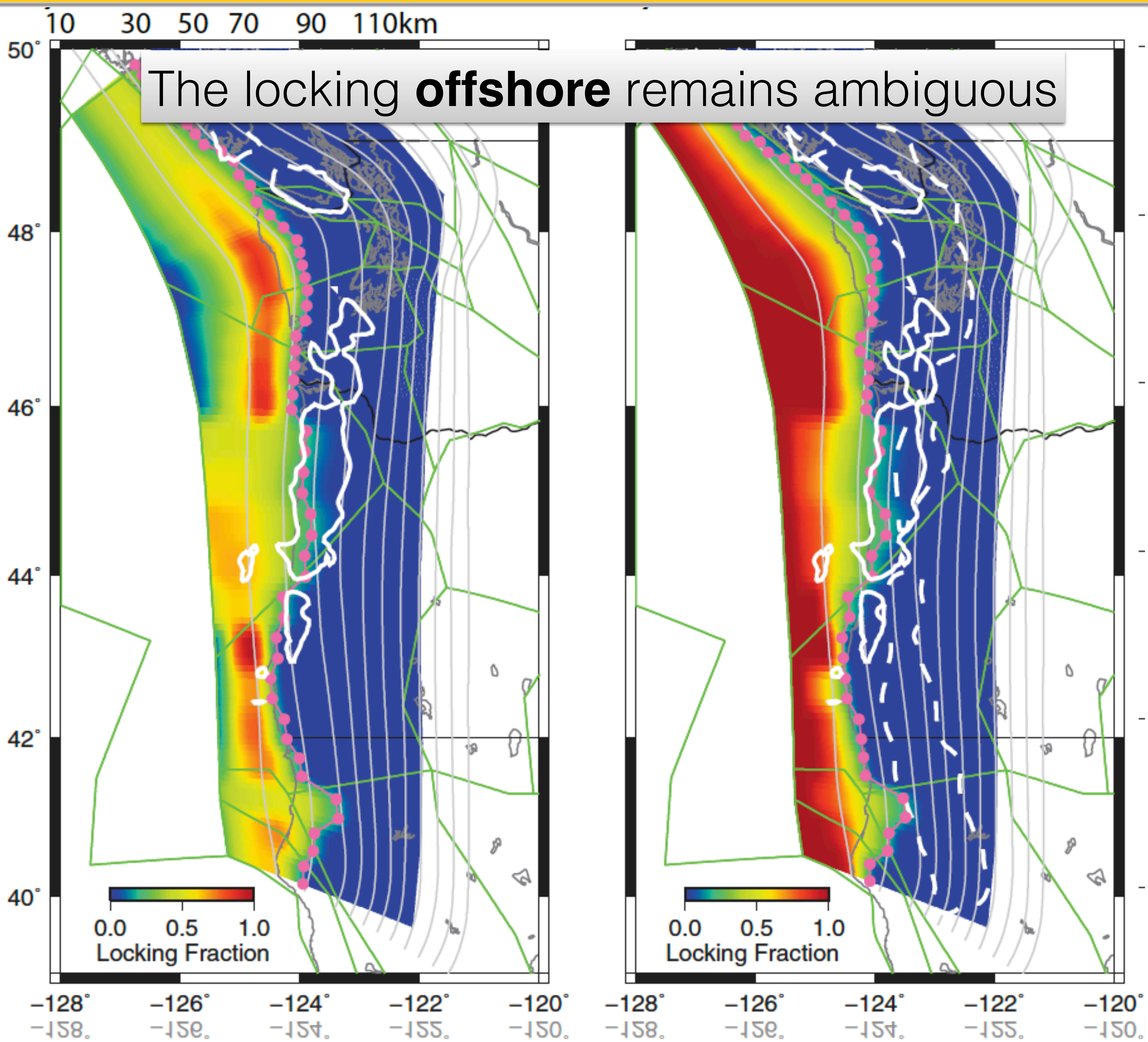
10.1002/2013GC005172

Central Cascadia subduction zone creep

Gina M. Schmalzle[1,2], Robert McCaffrey[3], and Kenneth C. Creager[1]







Why this pattern and is it a long term feature?

Tomography reveals buoyant asthenosphere accumulating beneath the Juan de Fuca plate

William B. Hawley,[1,2]* Richard M. Allen,[1,2] Mark A. Richards[1]

Science, 2017

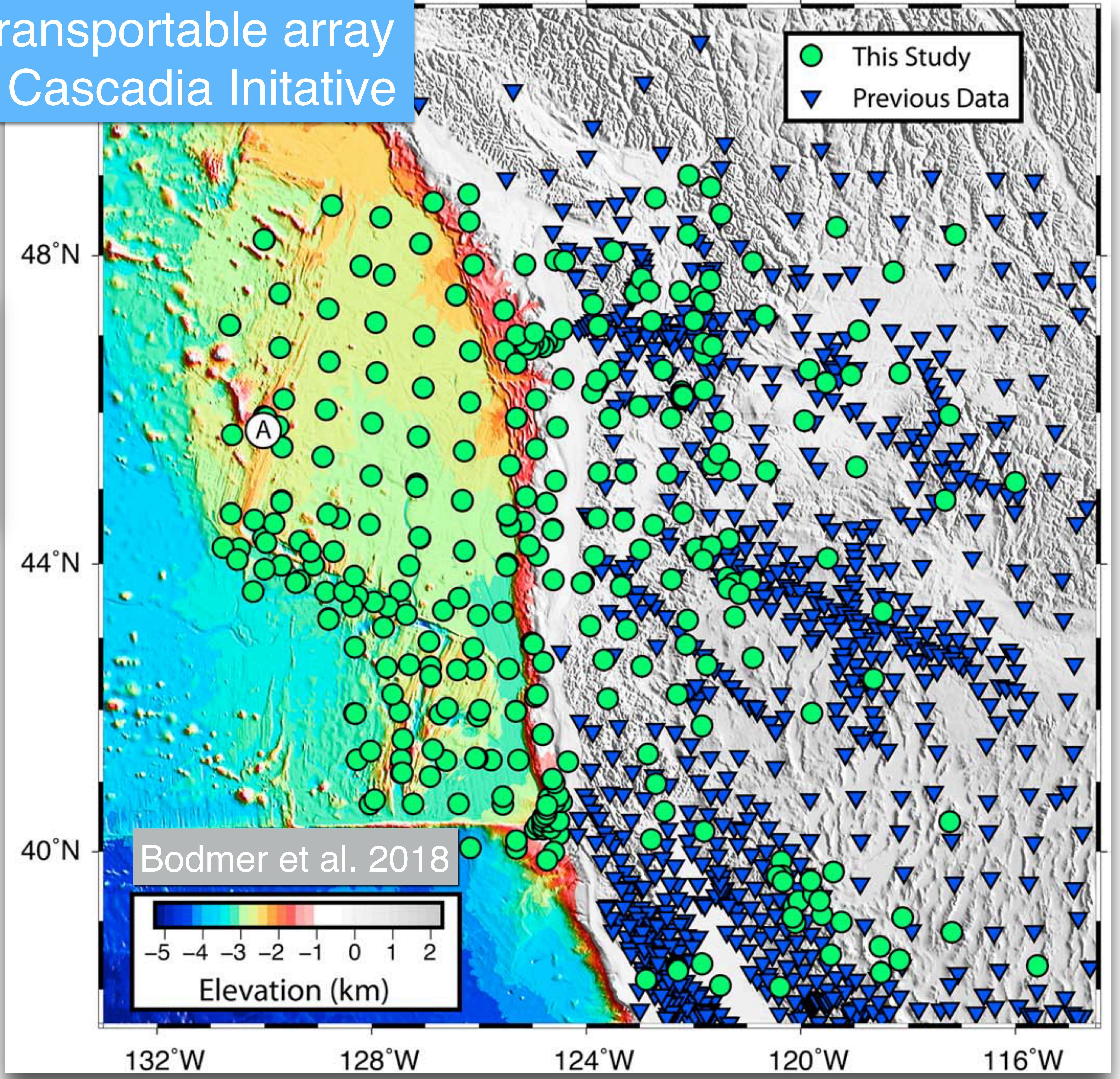
Buoyant Asthenosphere Beneath Cascadia Influences Megathrust Segmentation

Miles Bodmer[1], Douglas R. Toomey[1], Emilie E. E. Hooft[1], and Brandon Schmandt[2]

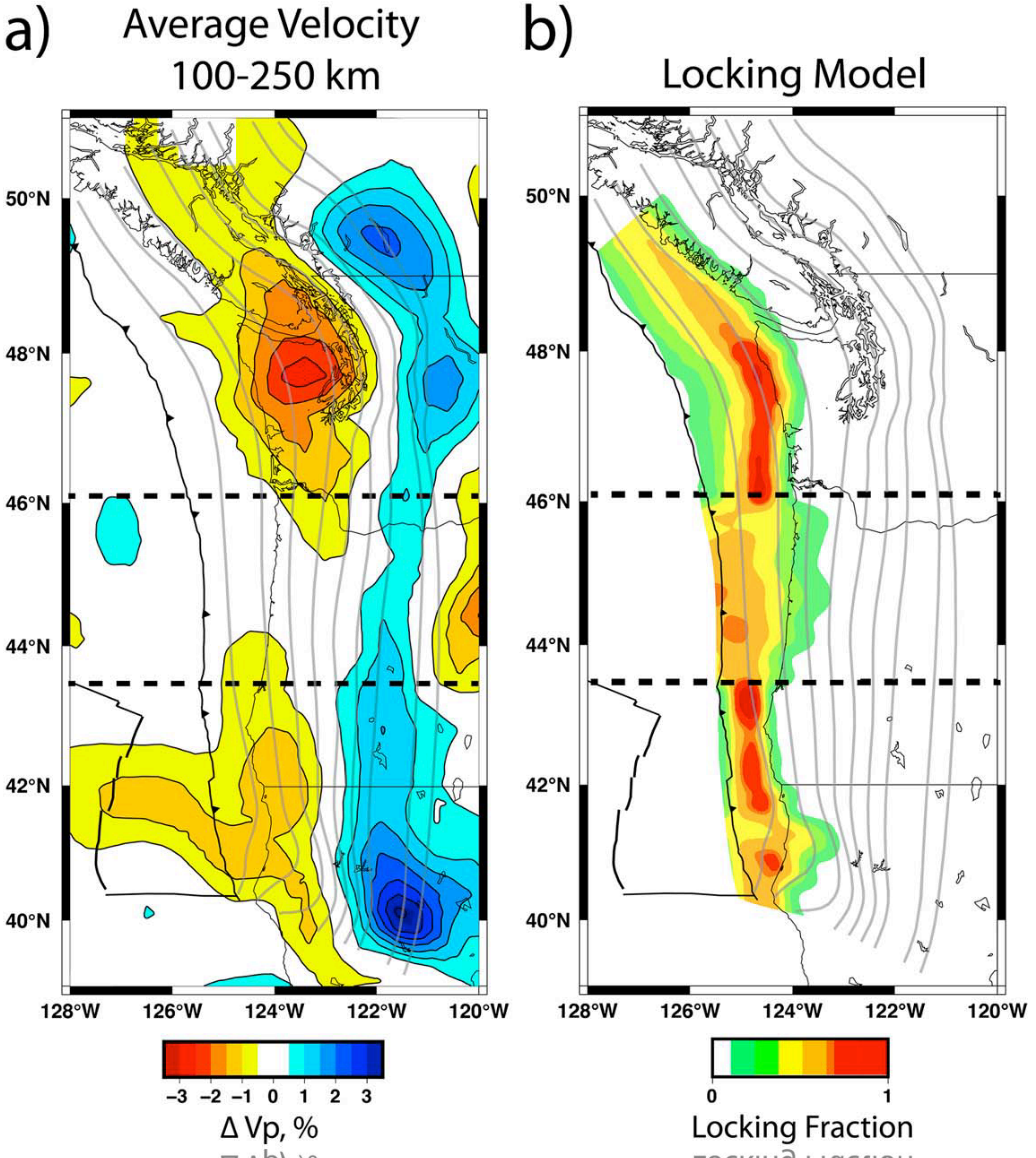
[1]Department of Earth Sciences, University of Oregon, Eugene, OR, USA, [2]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, USA

Geophys. Res. Lett, 2018

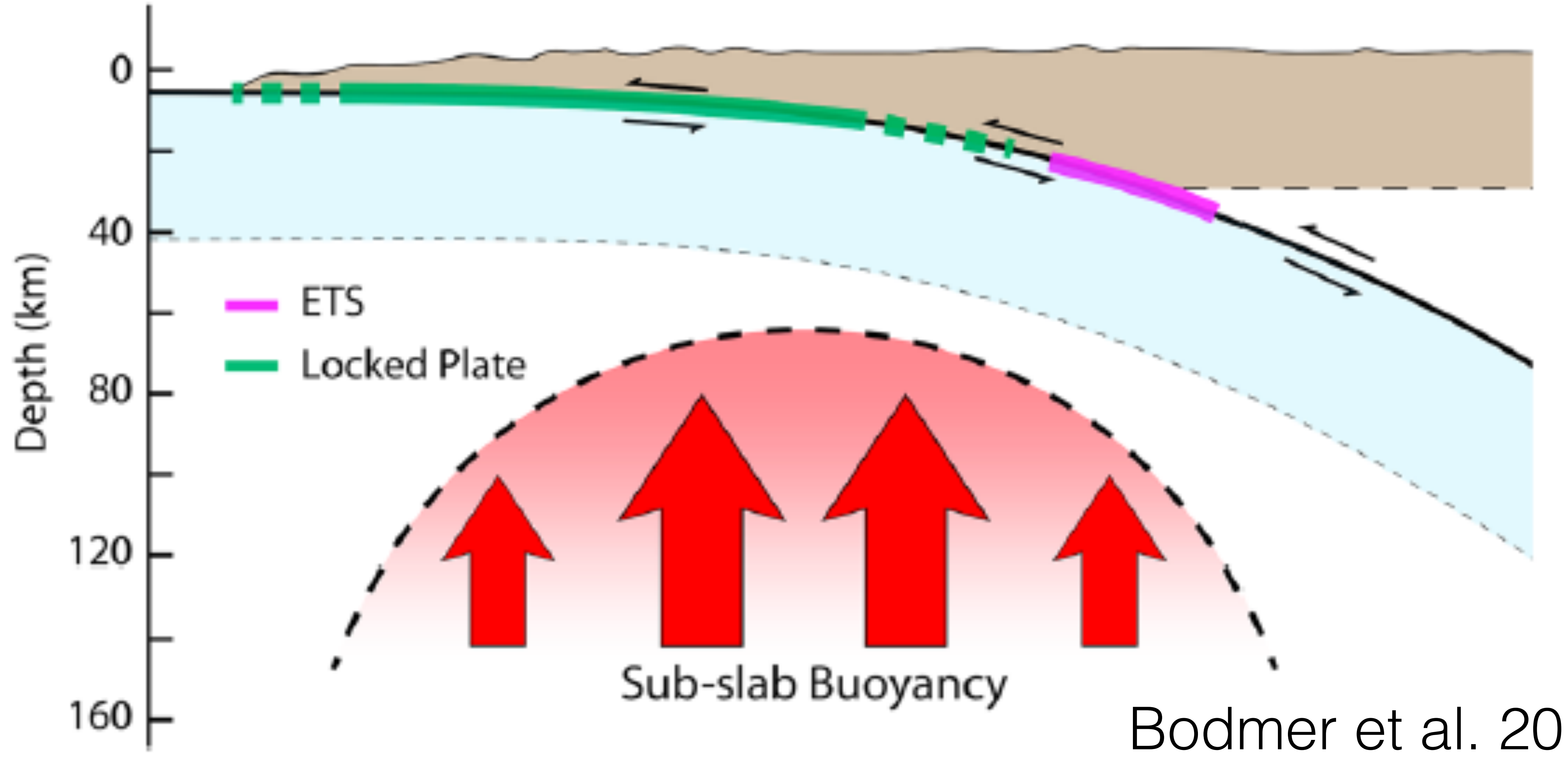
Transportable array & Cascadia Initative



Why this pattern and is it a long term feature?

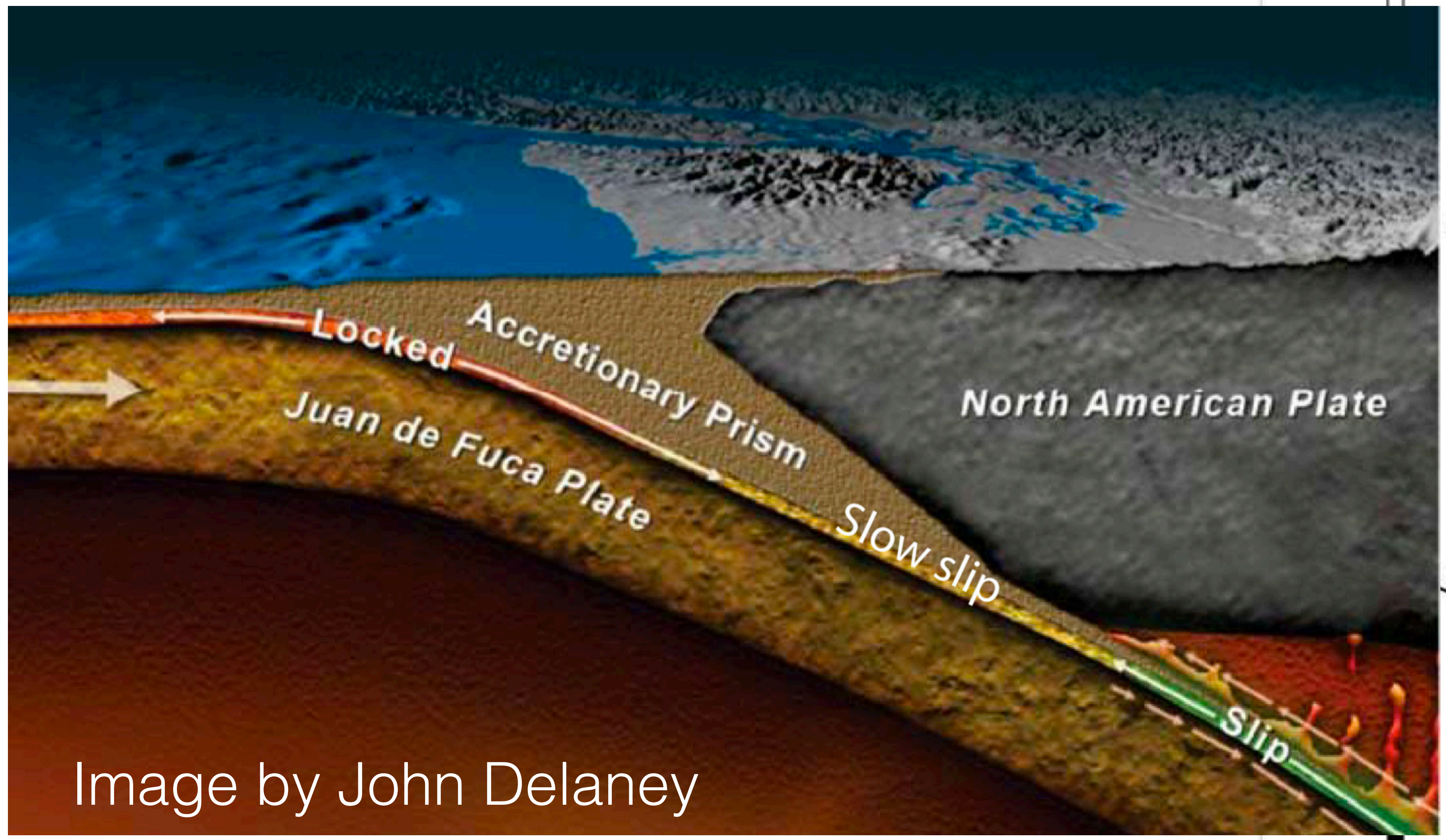


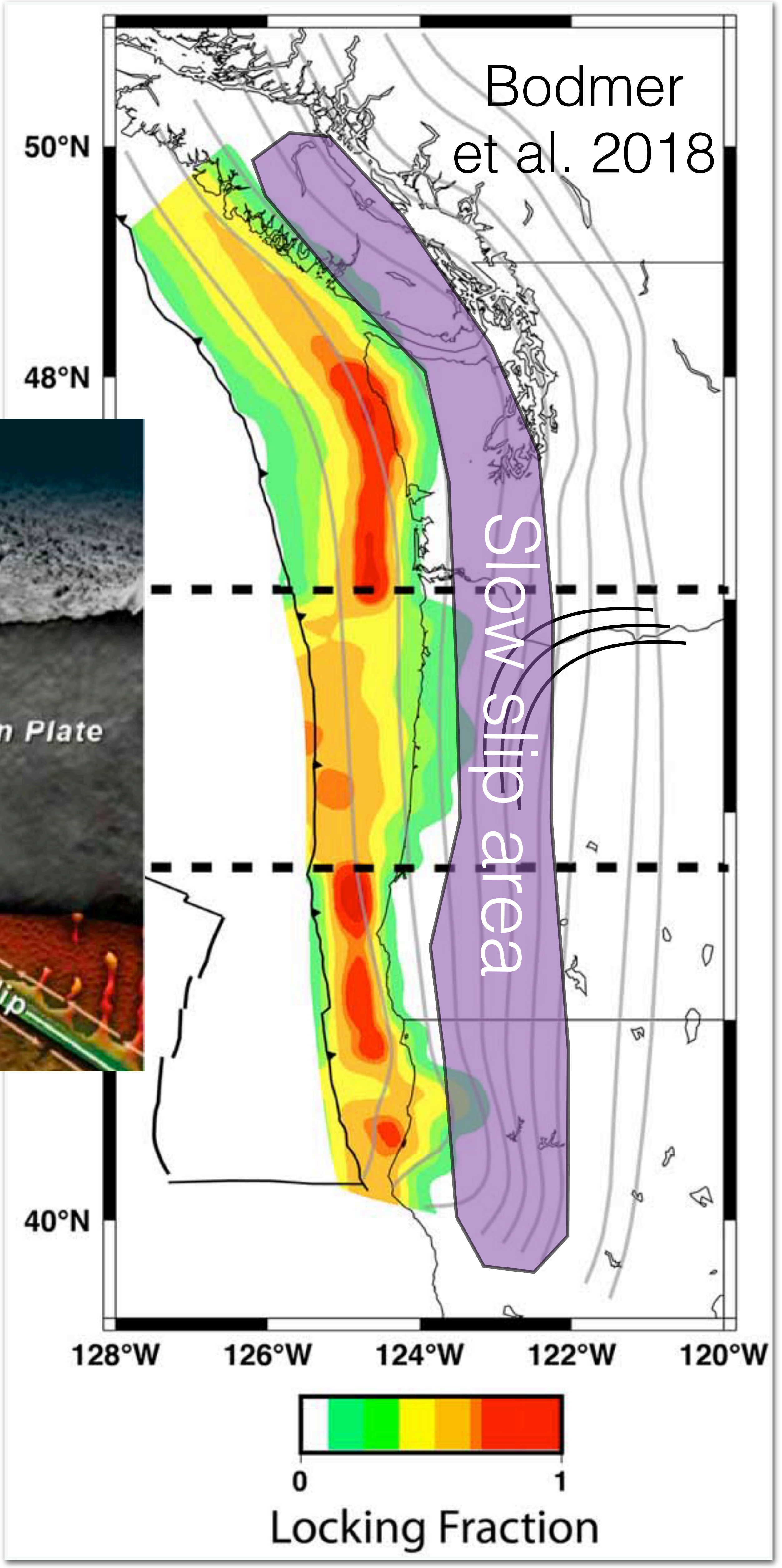
A physical mechanism for locking

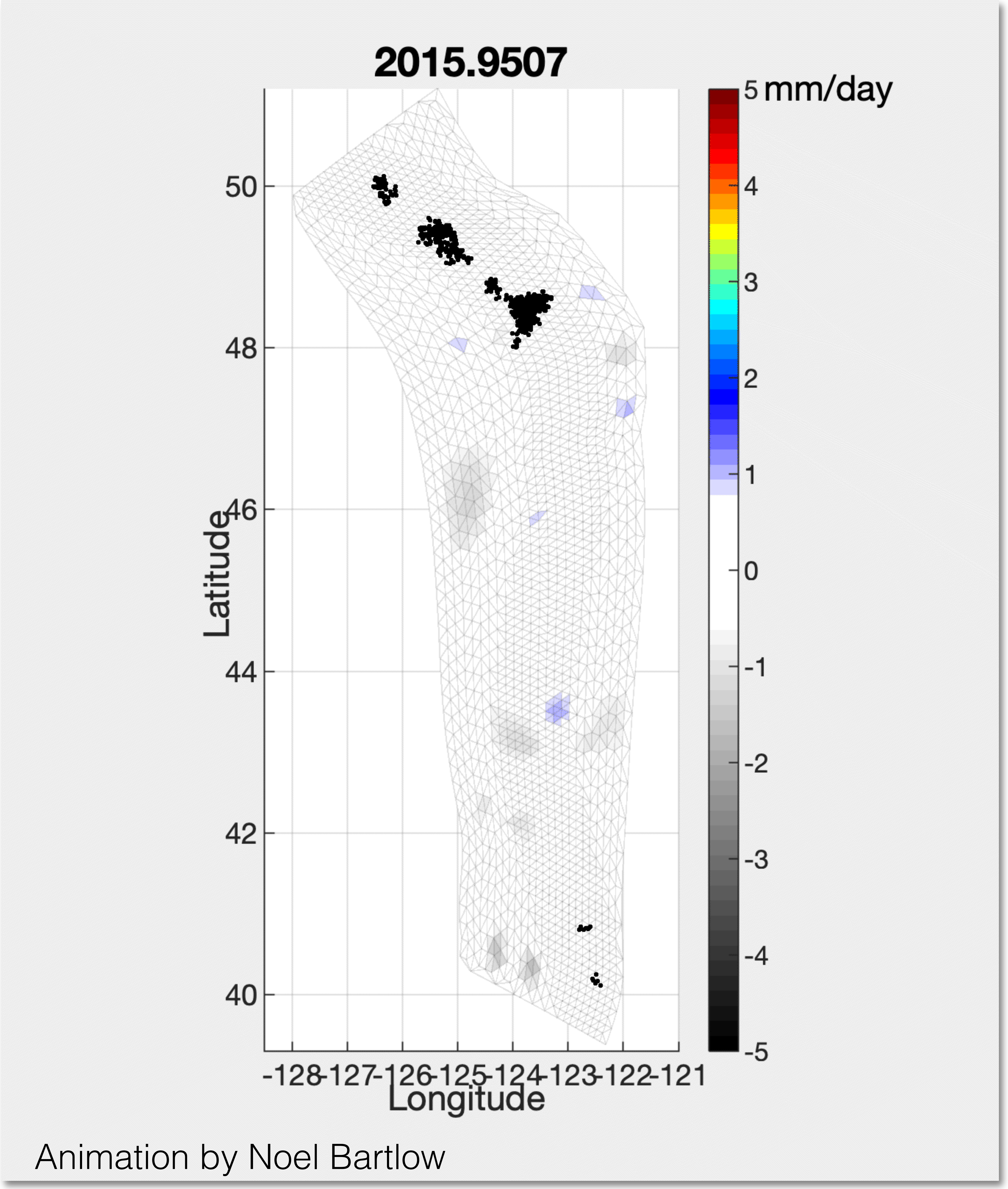


Bodmer et al. 2018

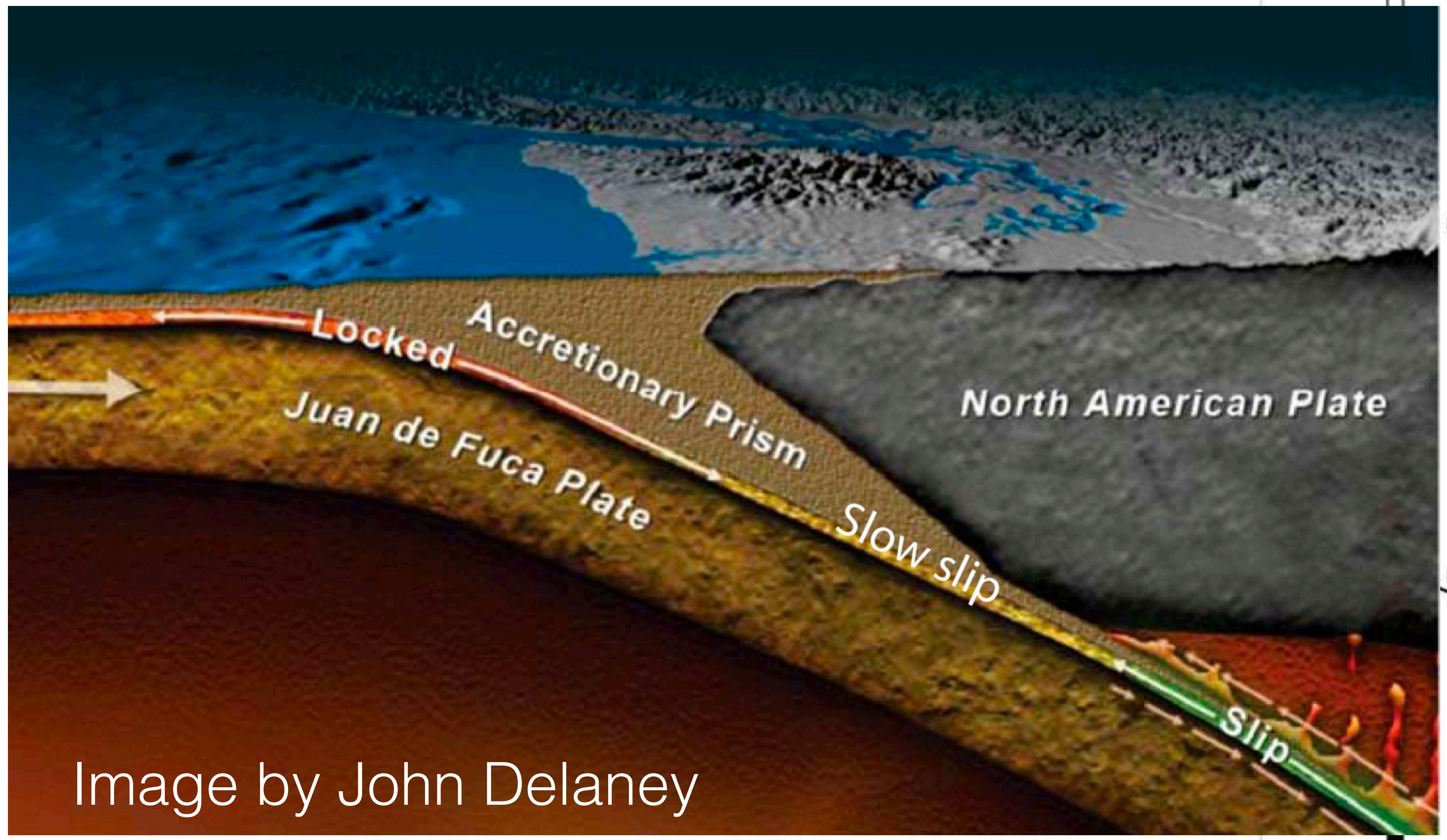
The spectrum of behavior: Slow slip

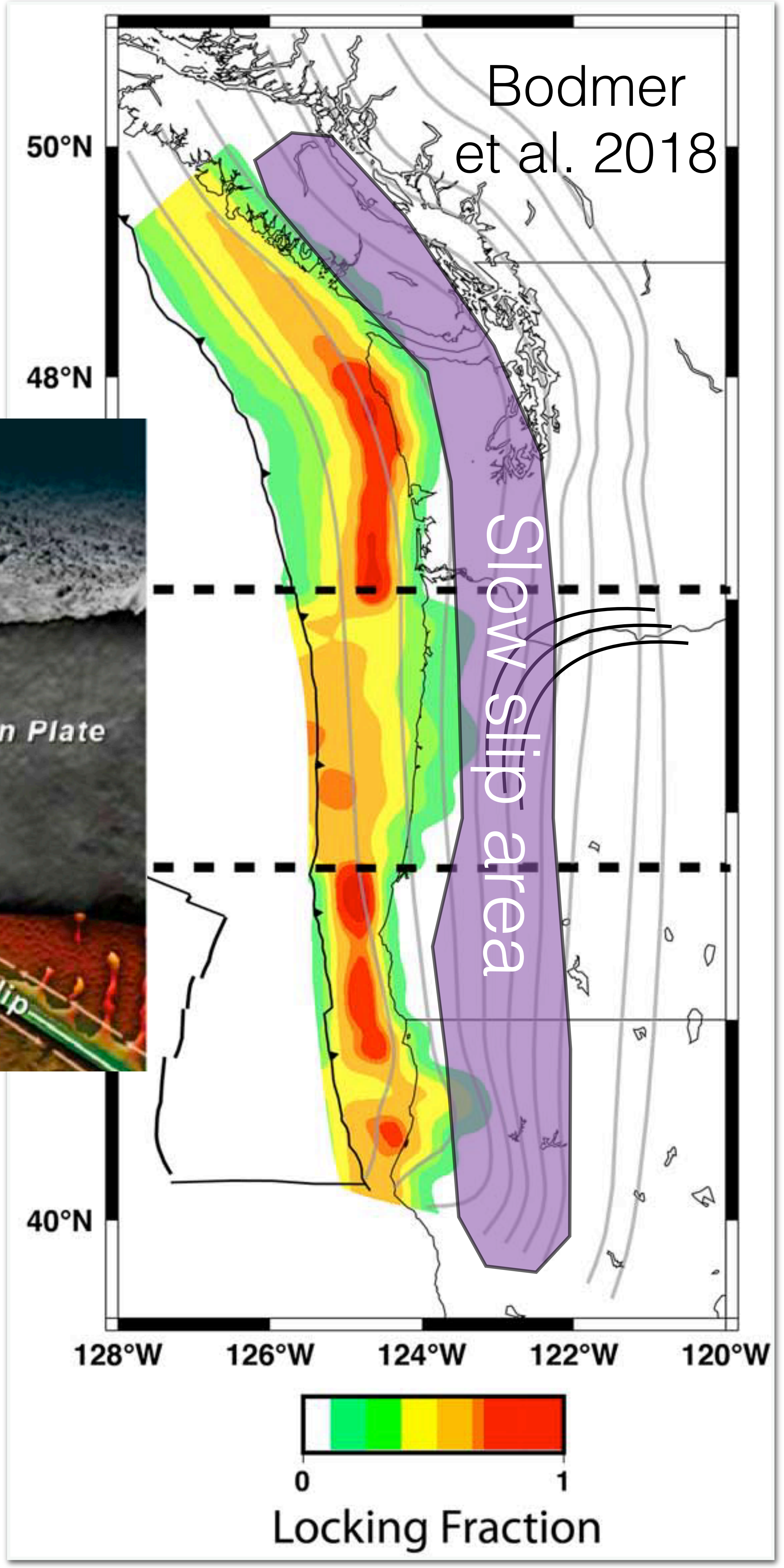






The spectrum of behavior: Slow slip





The slow slip area **cannot** participate in **big earthquakes**

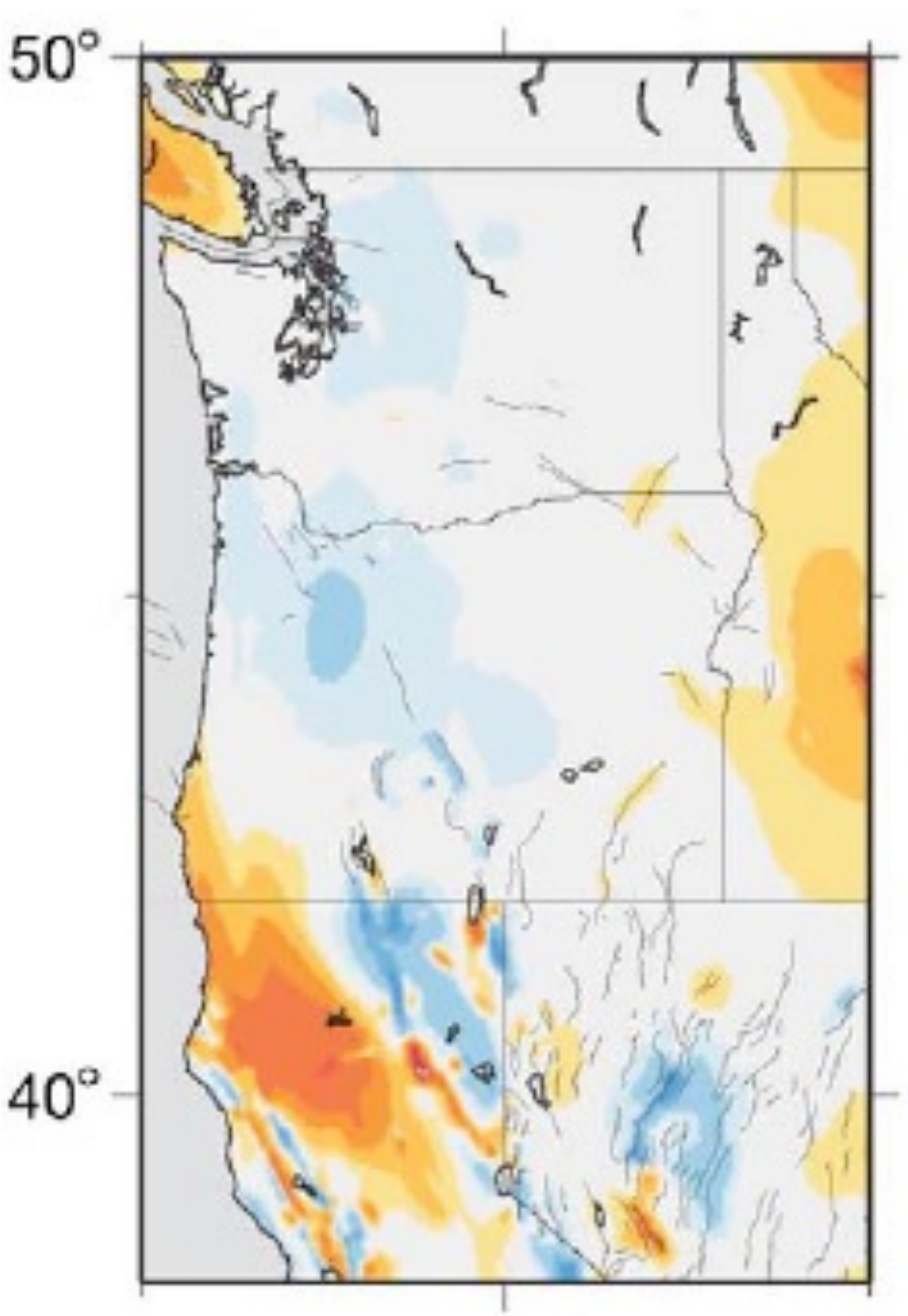
(maybe)

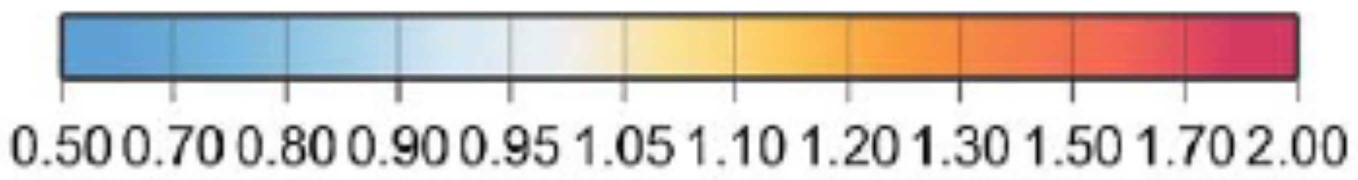
Science to public products

2014 Update of the Pacific Northwest Portion of the U.S. National Seismic Hazard Maps

Arthur Frankel,[a] M.EERI, Rui Chen,[b] Mark Petersen,[c] M.EERI, Morgan Moschetti,[c] and Brian Sherrod[a]

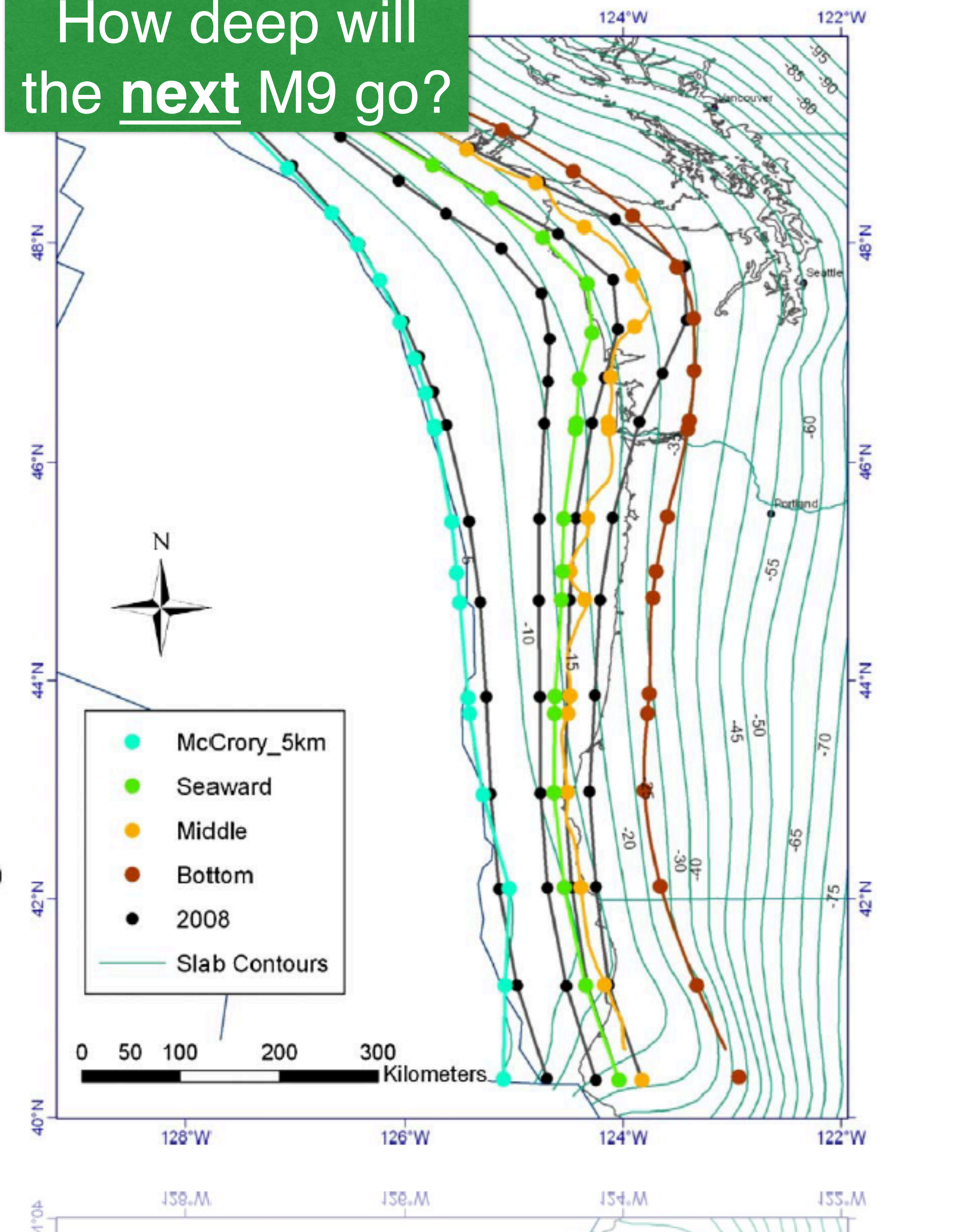
EQ Spectra, 2015





Hazard change (2015/2008)

How deep will the **next** M9 go?

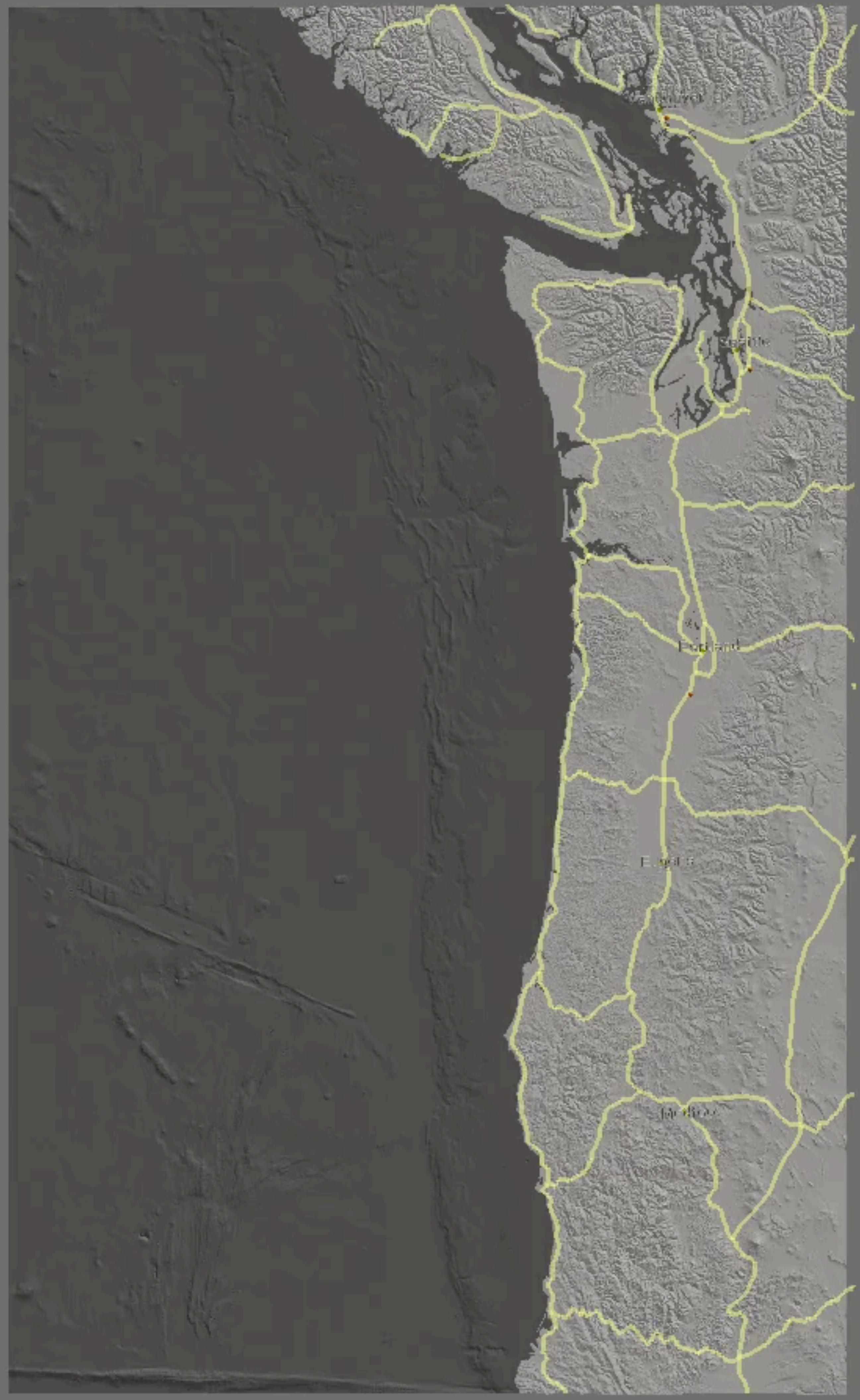


Science to public products

SDSU

Simulations of the next event require deep understanding of the **fault and crustal structure**

Daniel Roten
San Diego State



Plastic Strain (log10)
-4 -3 -2 -1

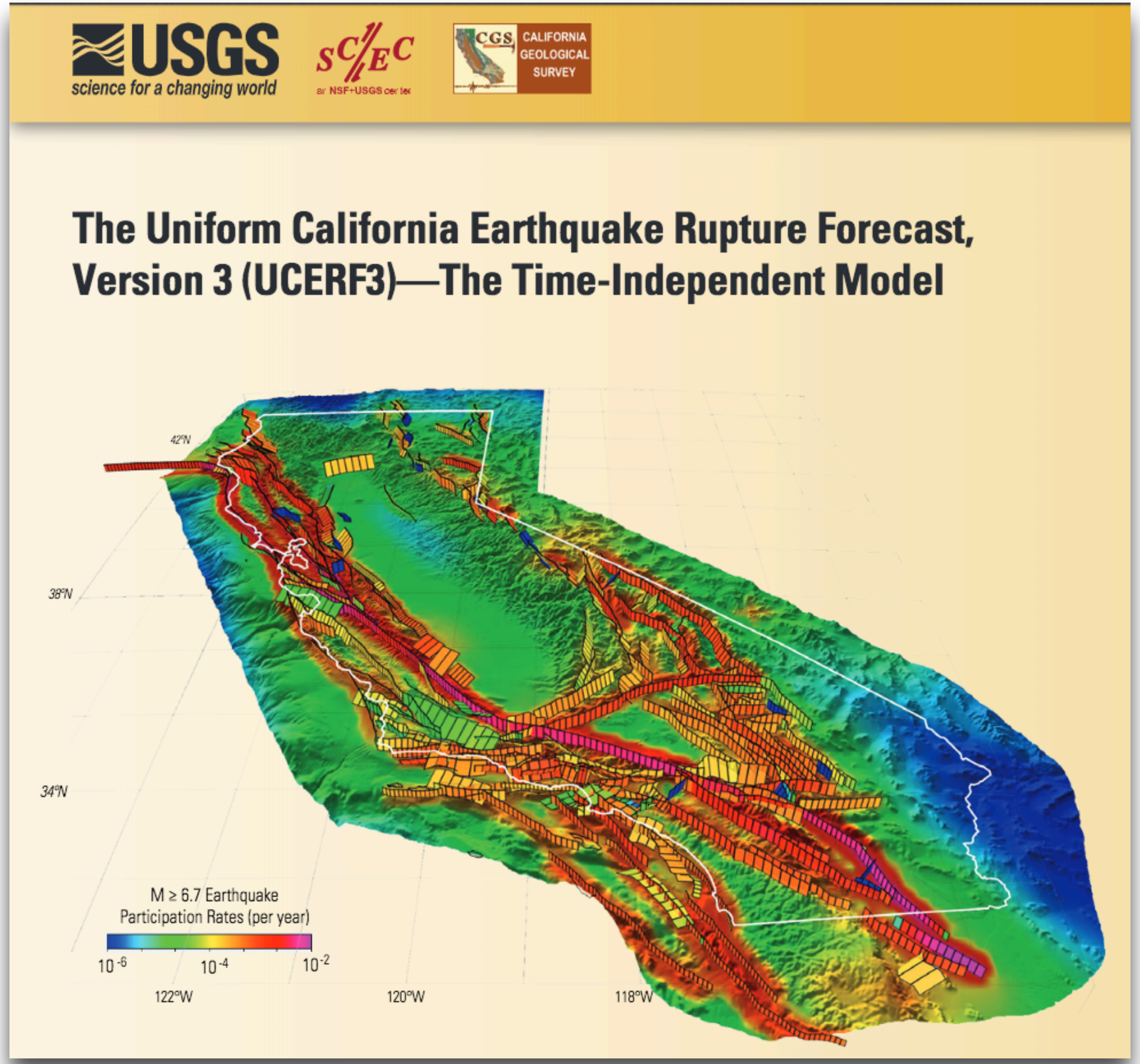
0.3 s

EW-Velocity (m/s)
-0.6 -0.3 0.0 0.3 0.6


The San Andreas
Fault System

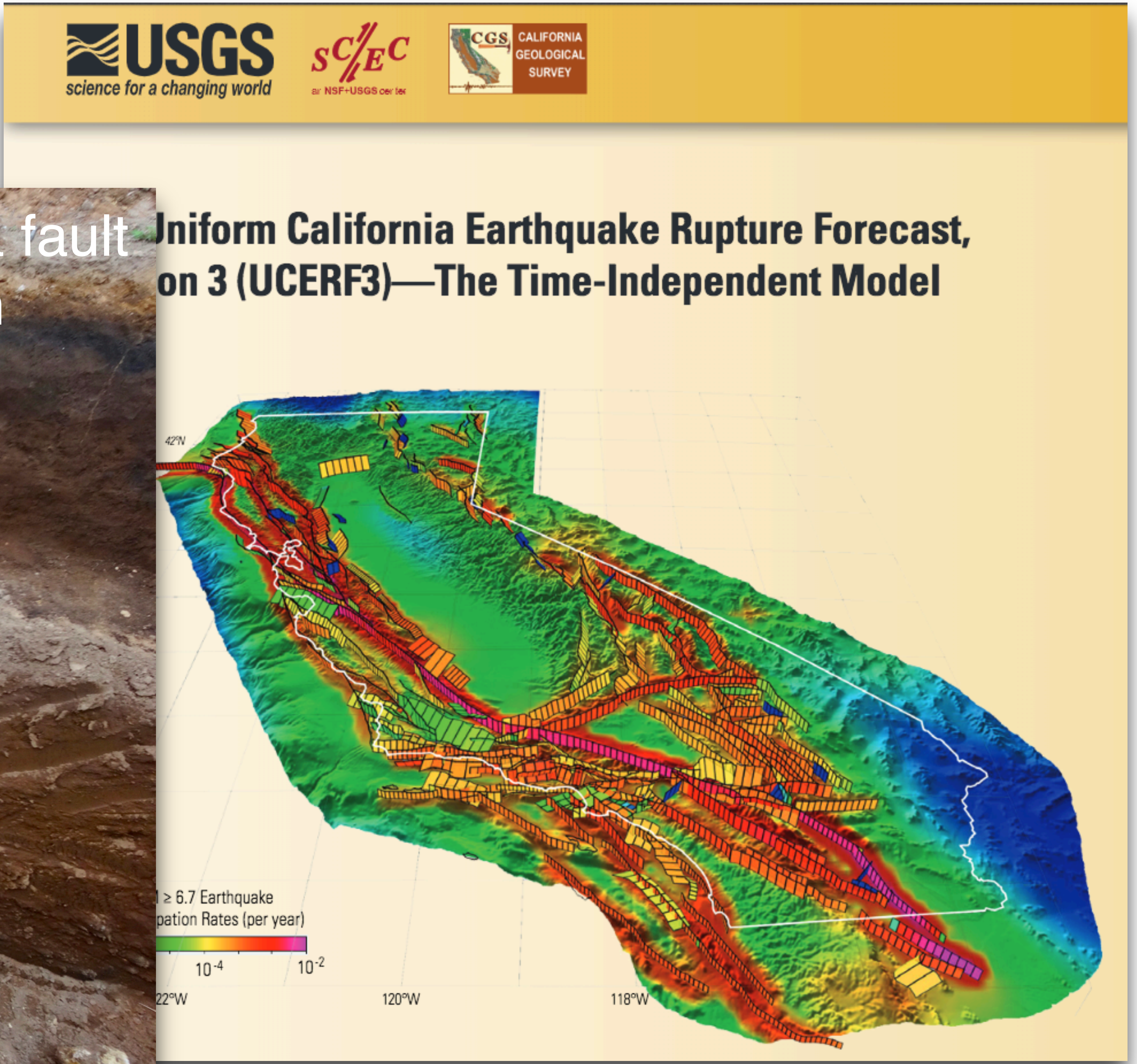
The California Hazard Model (UCERF3)

- The most **comprehensive** earthquake hazard model
- **Combines** seismology, geodesy, and geology
- **New research** incorporated with new iterations



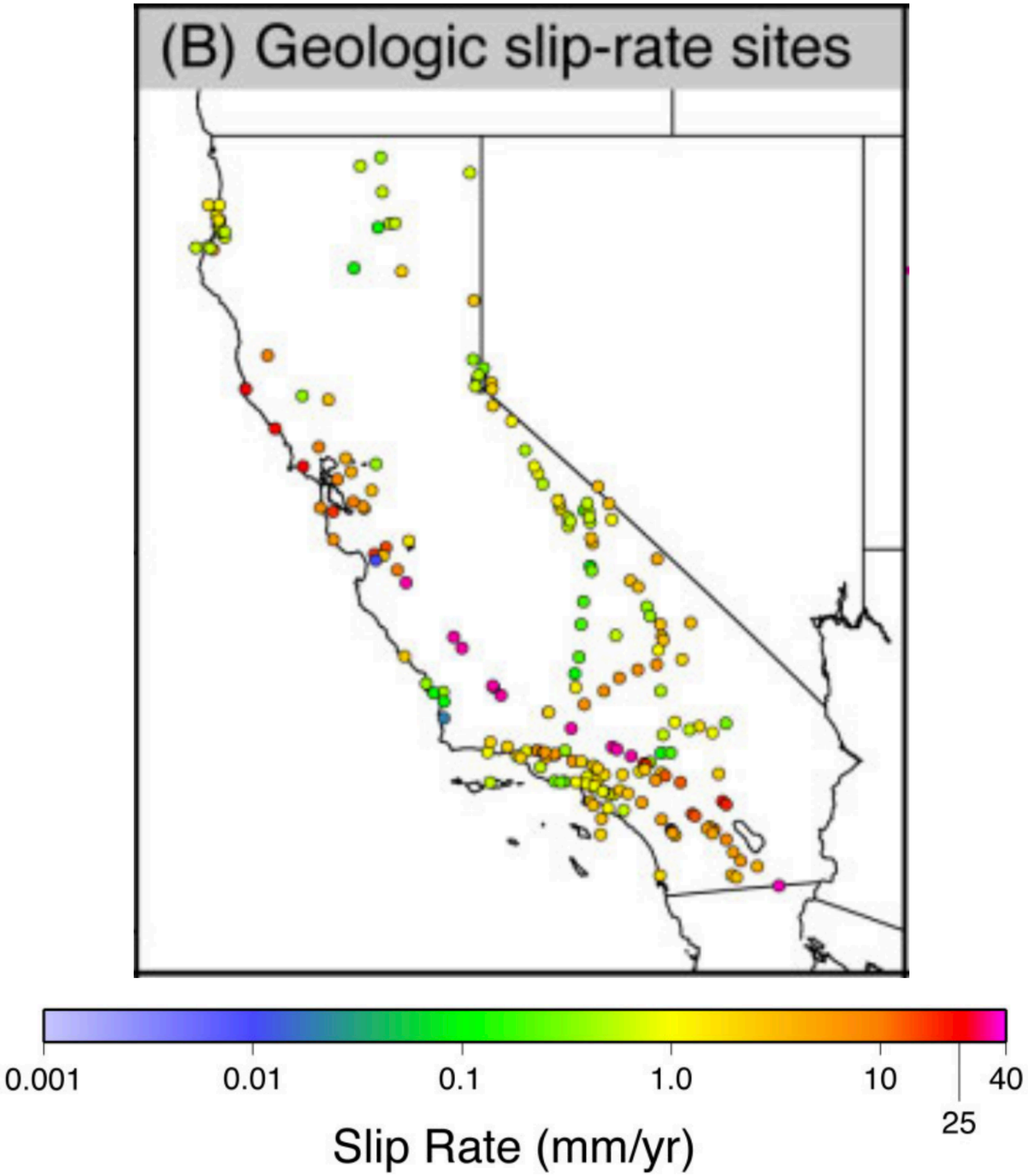
The California Hazard Model (UCERF3)

How **fast** are faults moving?



The California Hazard Model (UCERF3)

How **fast** are faults moving?



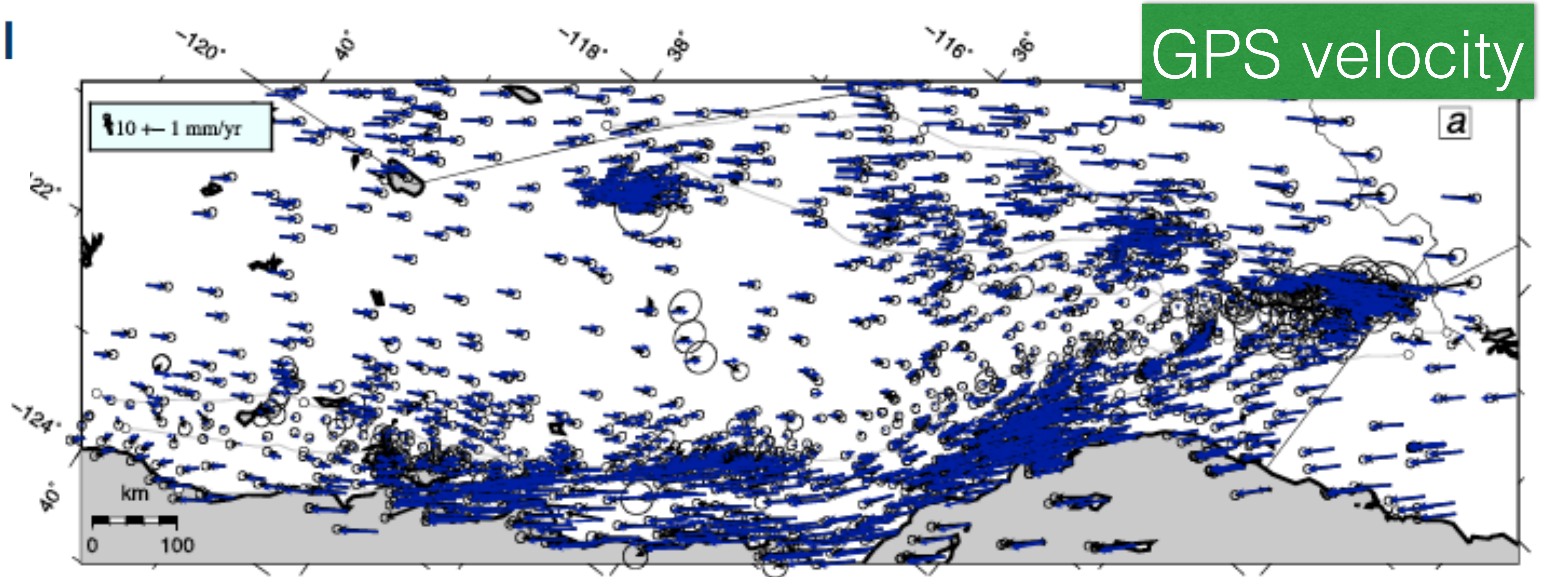
UCERF3, Field et al., 2014

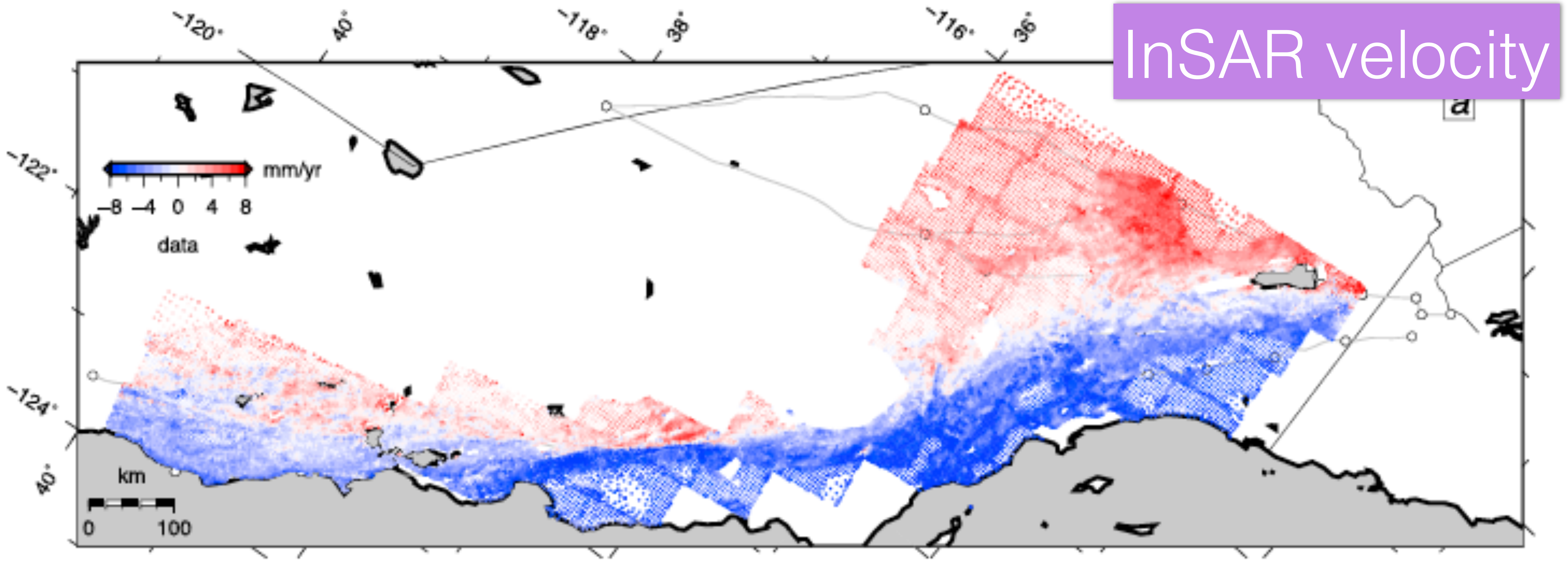
The slip budget on the SAF

Is there a discrepancy between geological and geodetic slip rates along the San Andreas Fault System?

Xiaopeng Tong[1], Bridget Smith-Konter[2], and David T. Sandwell[1]

J. Geophys. Res., 2016





The slip budget on the SAF

The slip budget on the SAF

We know the moment **budget**
of the **entire** fault

Tong et al., 2016

And elsewhere in California

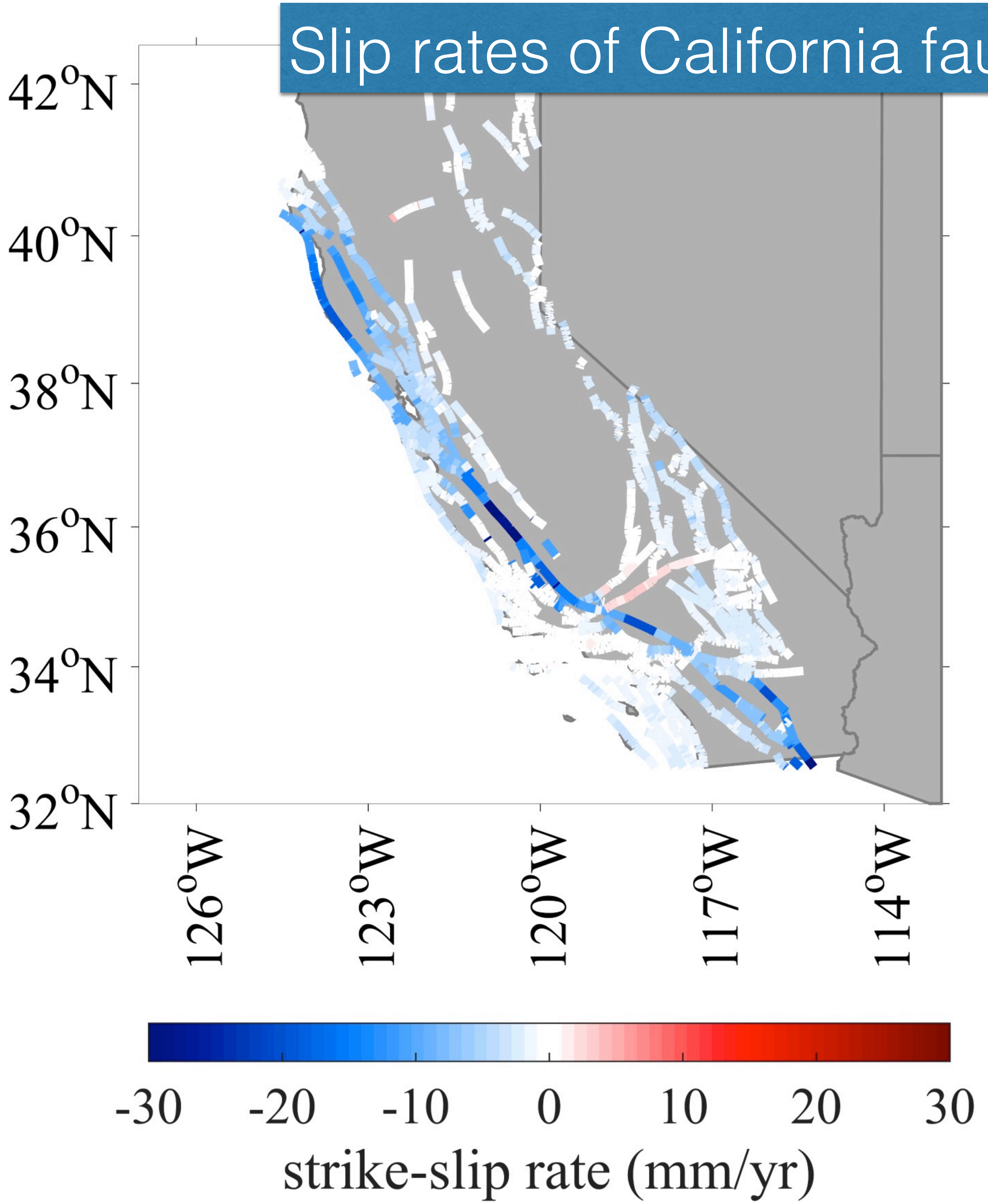
UNIVERSITY OF OREGON

Bulletin of the Seismological Society of America, Vol. 108, No. 1, pp. 1–18, February 2018, doi: 10.1785/0120170159

A Comprehensive Analysis of Geodetic Slip-Rate Estimates and Uncertainties in California

by Eileen L. Evans

And it's **not just** the Andreas Fault



UNIVERSITY OF OREGON

Lithospheric Thinning Beneath Rifted Regions of Southern California

Vedran Lekic,* Scott W. French,† Karen M. Fischer

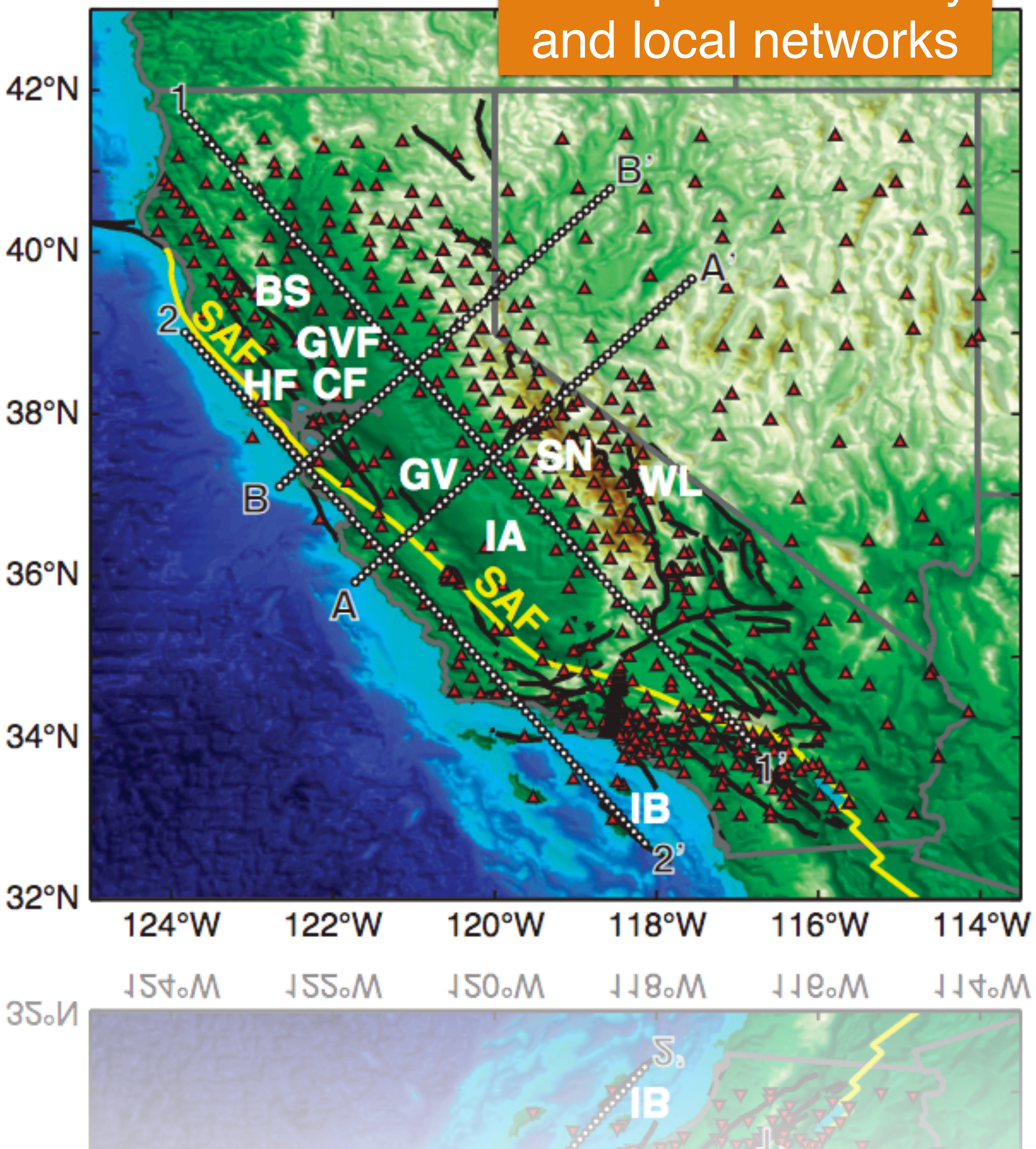
Science 2011

Localized shear in the deep lithosphere beneath the San Andreas fault system

Heather A. Ford[1,*], Karen M. Fischer[1], and Vedran Lekic[2]
[1]Department of Geological Sciences, Brown University, 324 Brook Street, Box 1846, Providence, Rhode Island 02912, USA
[2]Department of Geology, University of Maryland, College Park, Maryland 20742, USA

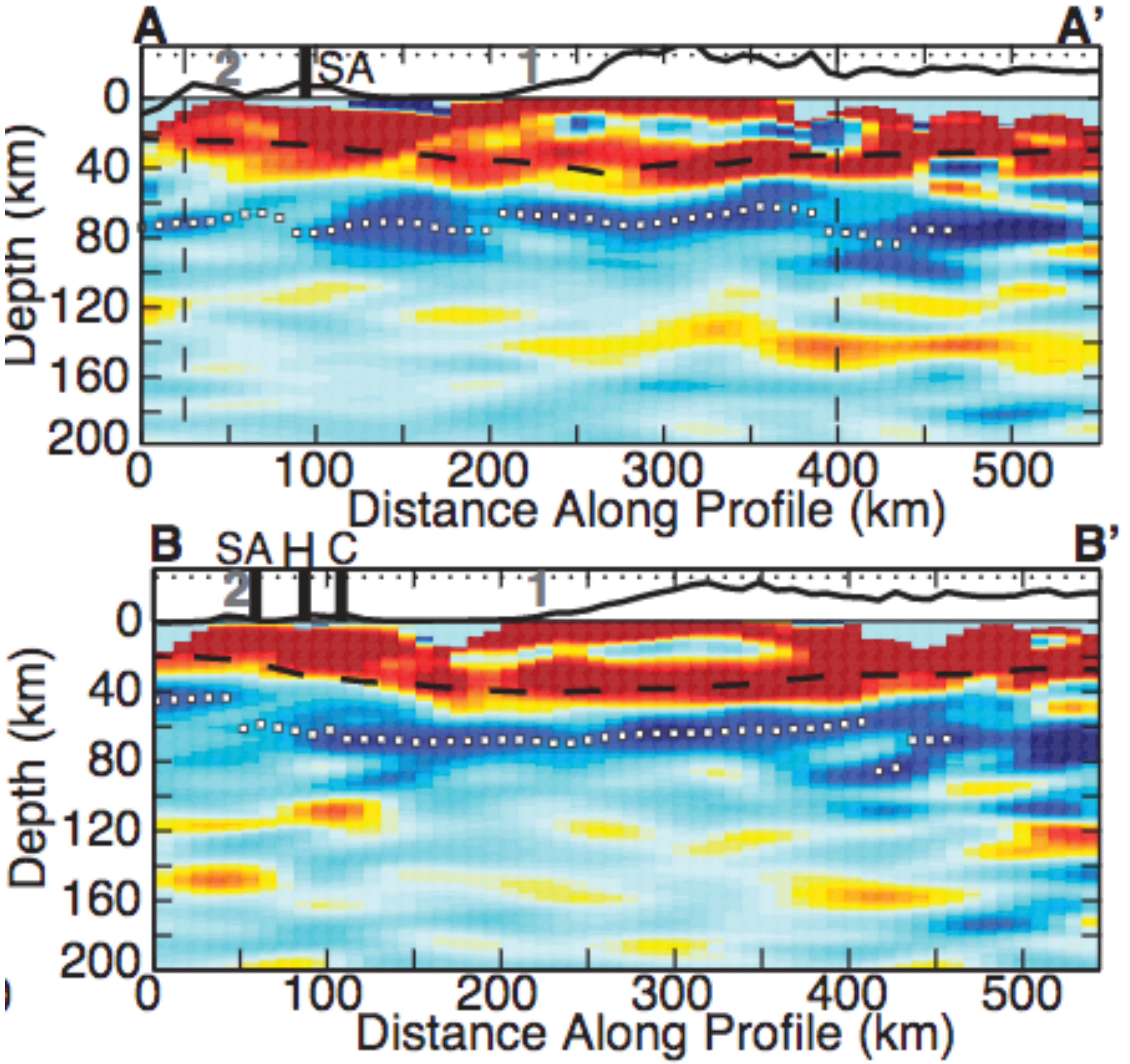
Geology 2014

Transportable array and local networks

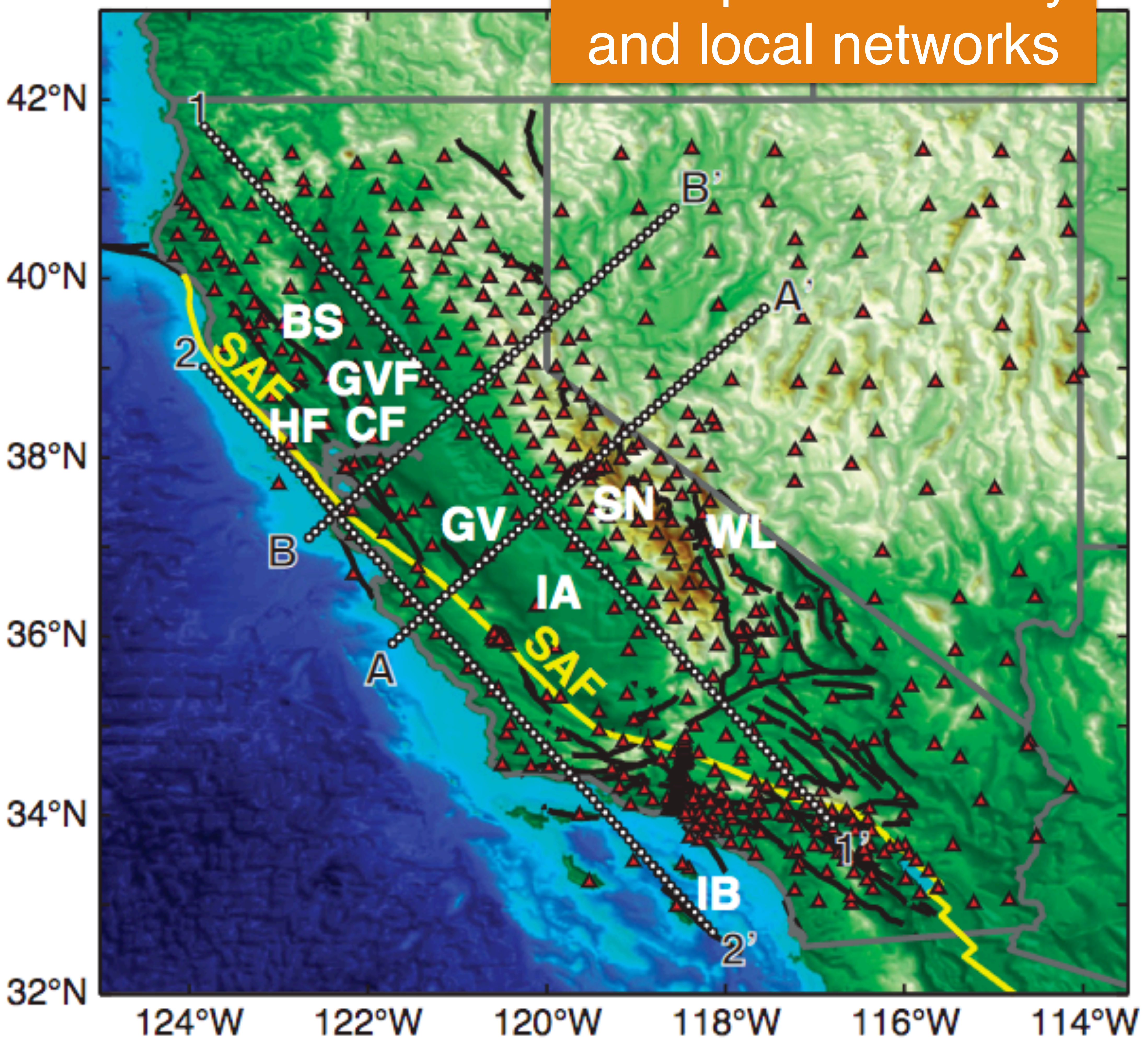


Long-term geodynamics

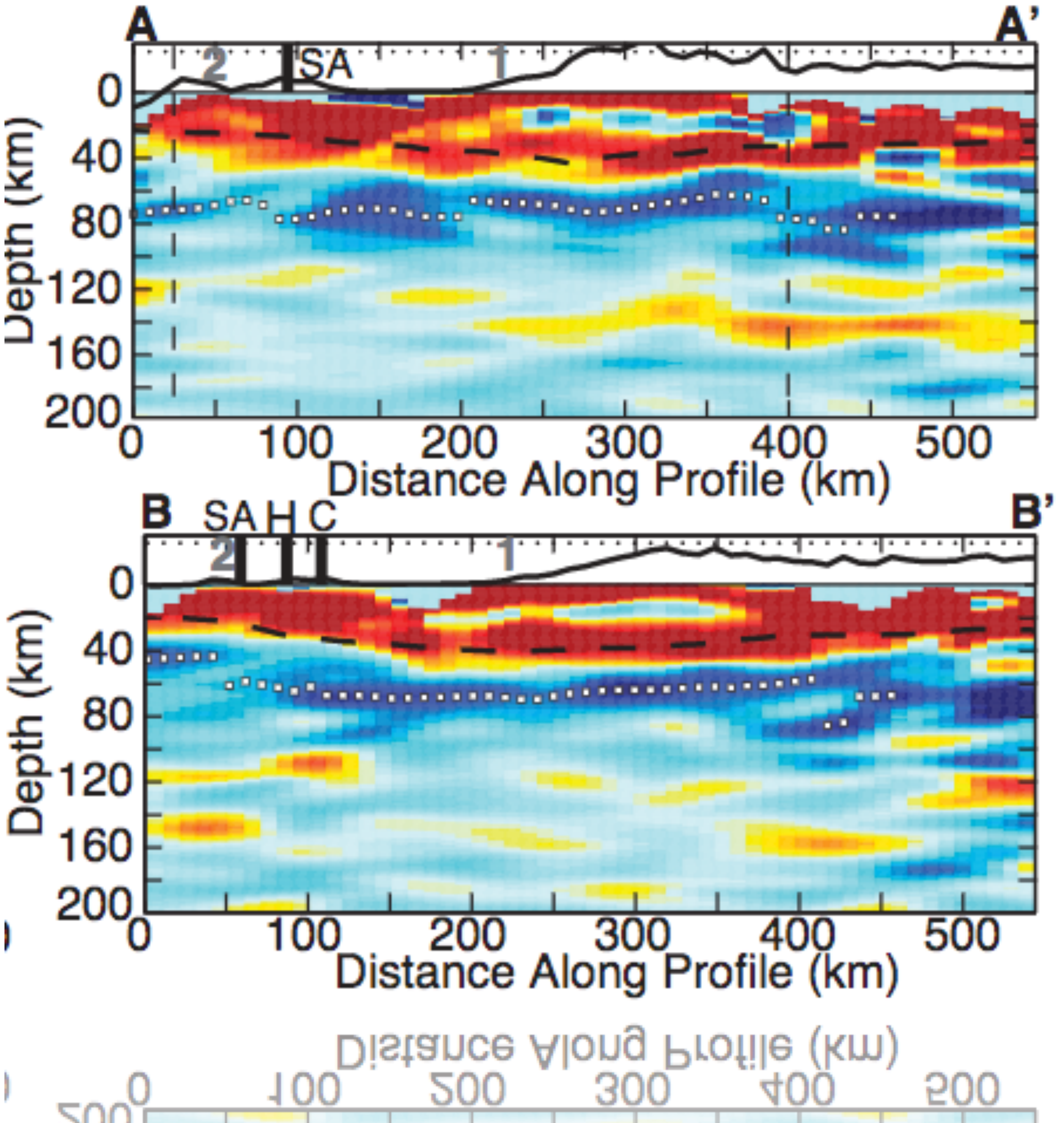
UNIVERSITY OF OREGON



Transportable array and local networks



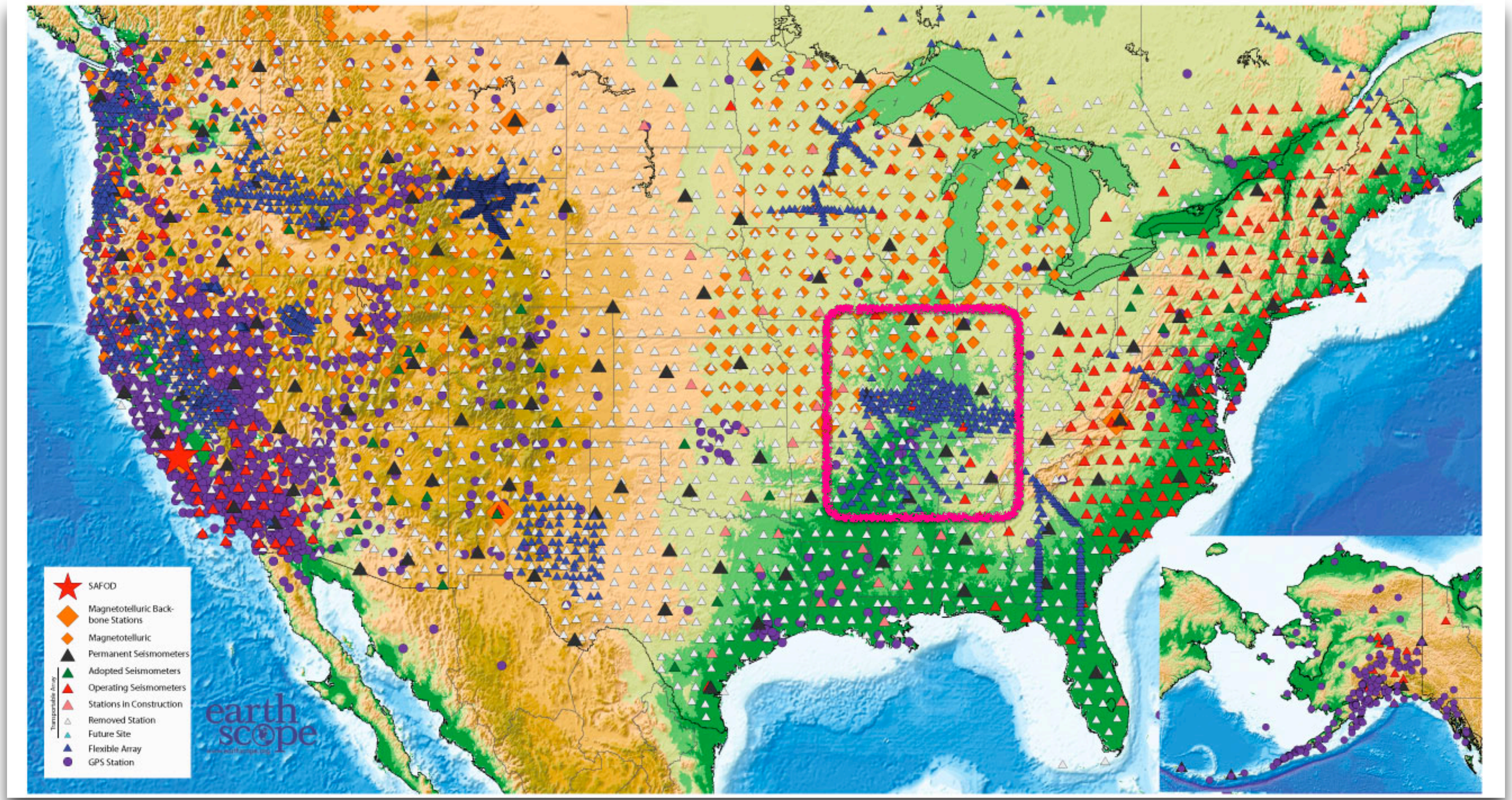
Long-term geodynamics



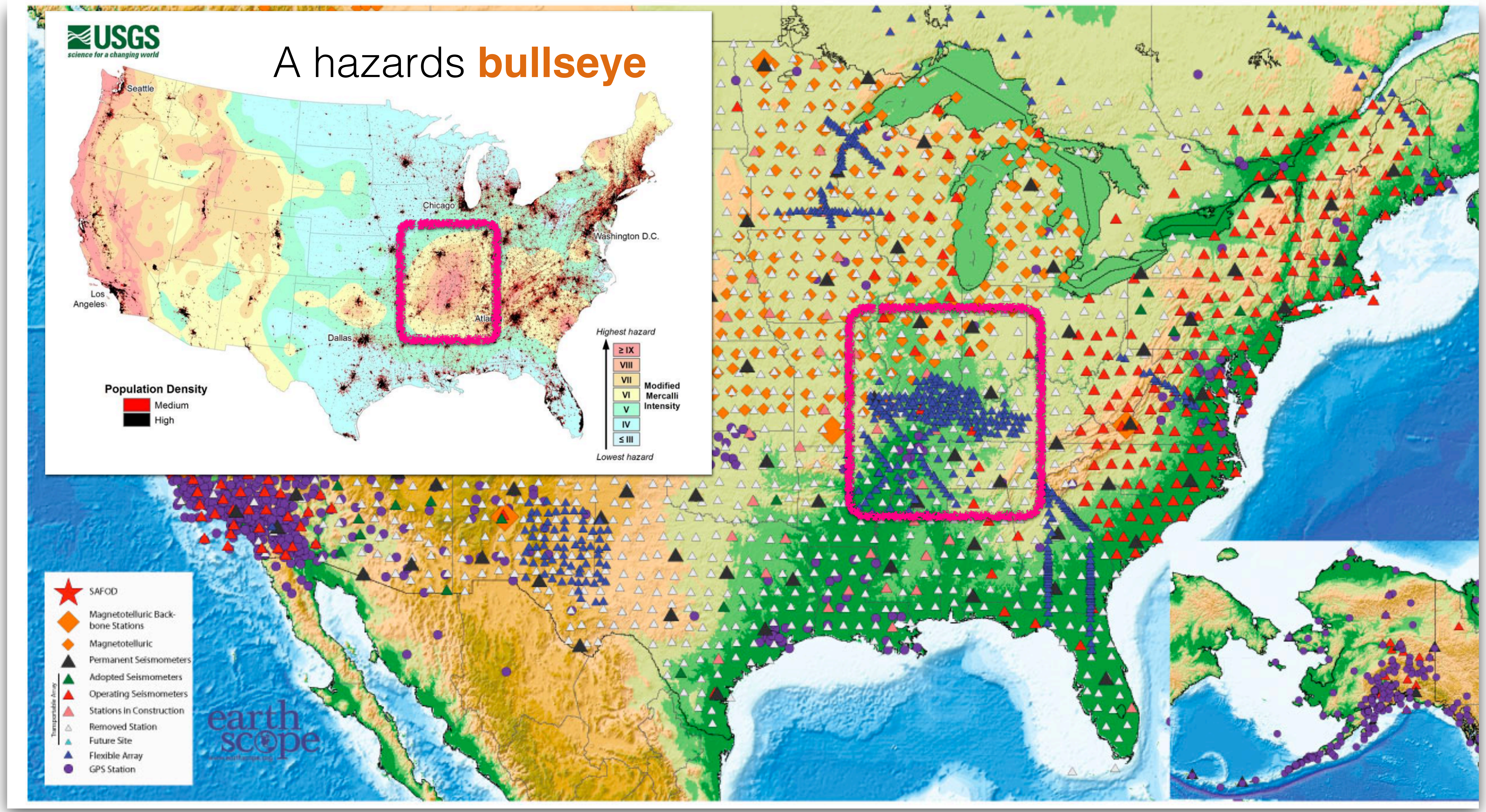
- LAB velocity contrasts **across** faults
- Implications for **long-term** inter-seismic velocities
- It can change the **slip budget** on faults


The New Madrid
Seismic Zone

New Madrid: Far from the plate Boundary



New Madrid: Far from the plate Boundary



It's not moving!

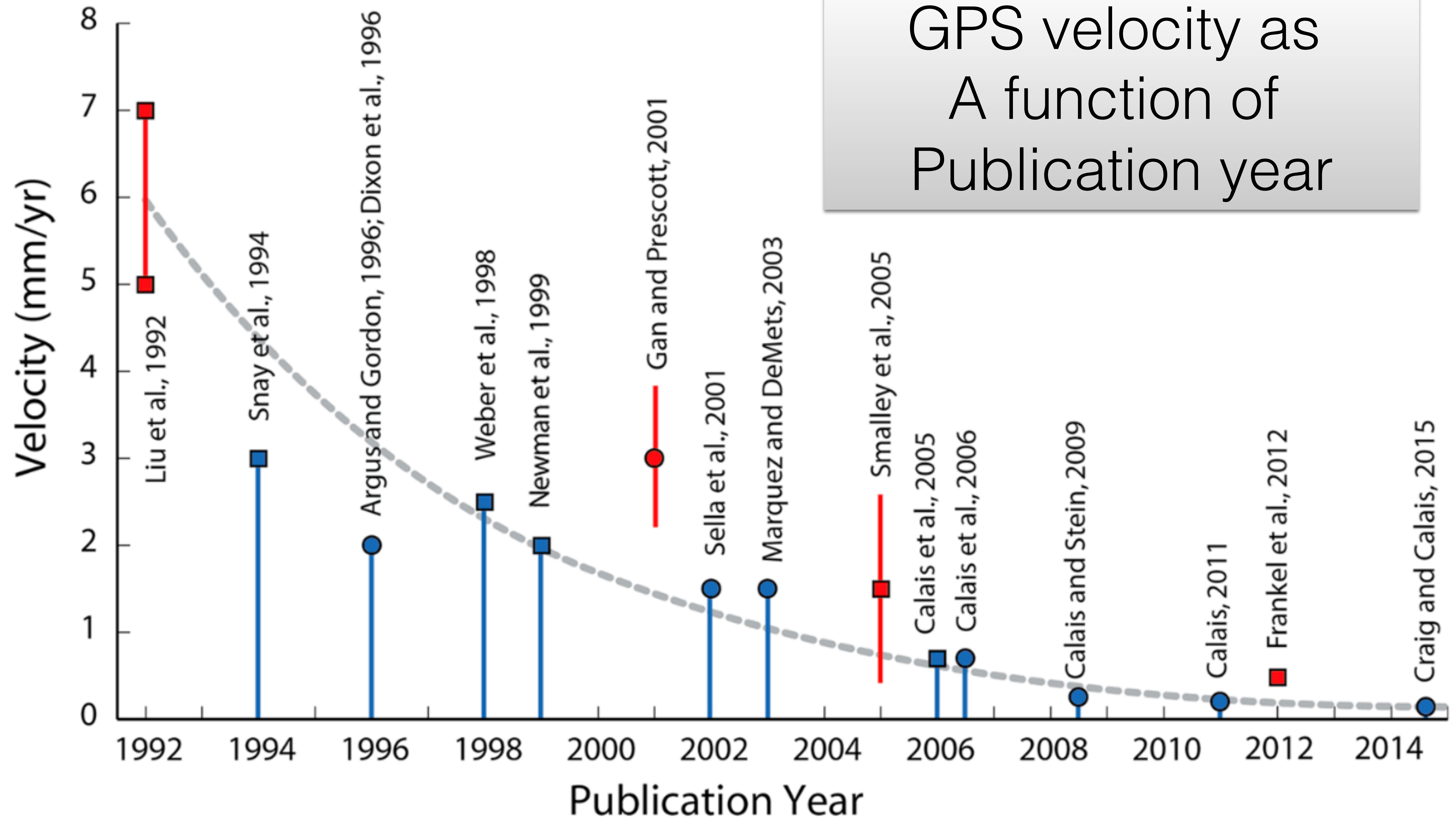
UNIVERSITY OF OREGON

A new paradigm for large earthquakes in stable continental plate interiors

E. Calais[1], T. Camelbeeck[2], S. Stein[3], M. Liu[4], and T. J. Craig[5]

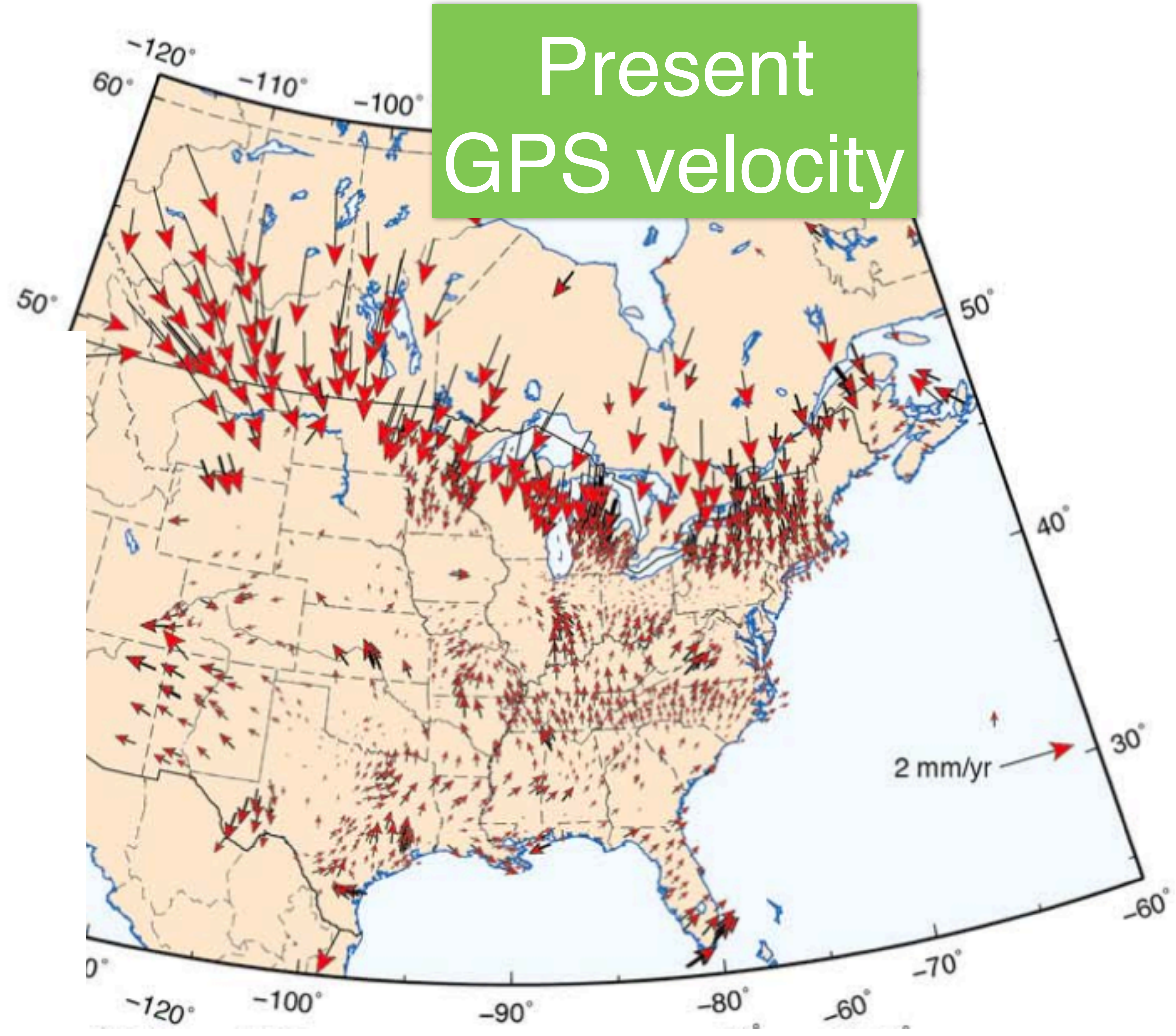
Geophys. Res. Lett. 2016

GPS velocity as A function of Publication year



B

Present GPS velocity



Seismic structure concentrates stress

Seismic structure of the Central US crust and shallow upper mantle: Uniqueness of the Reelfoot Rift

Fred F. Pollitz *, Walter D. Mooney

USGS, 345 Middlefield Road, MS 977, Menlo Park, CA 94025, USA

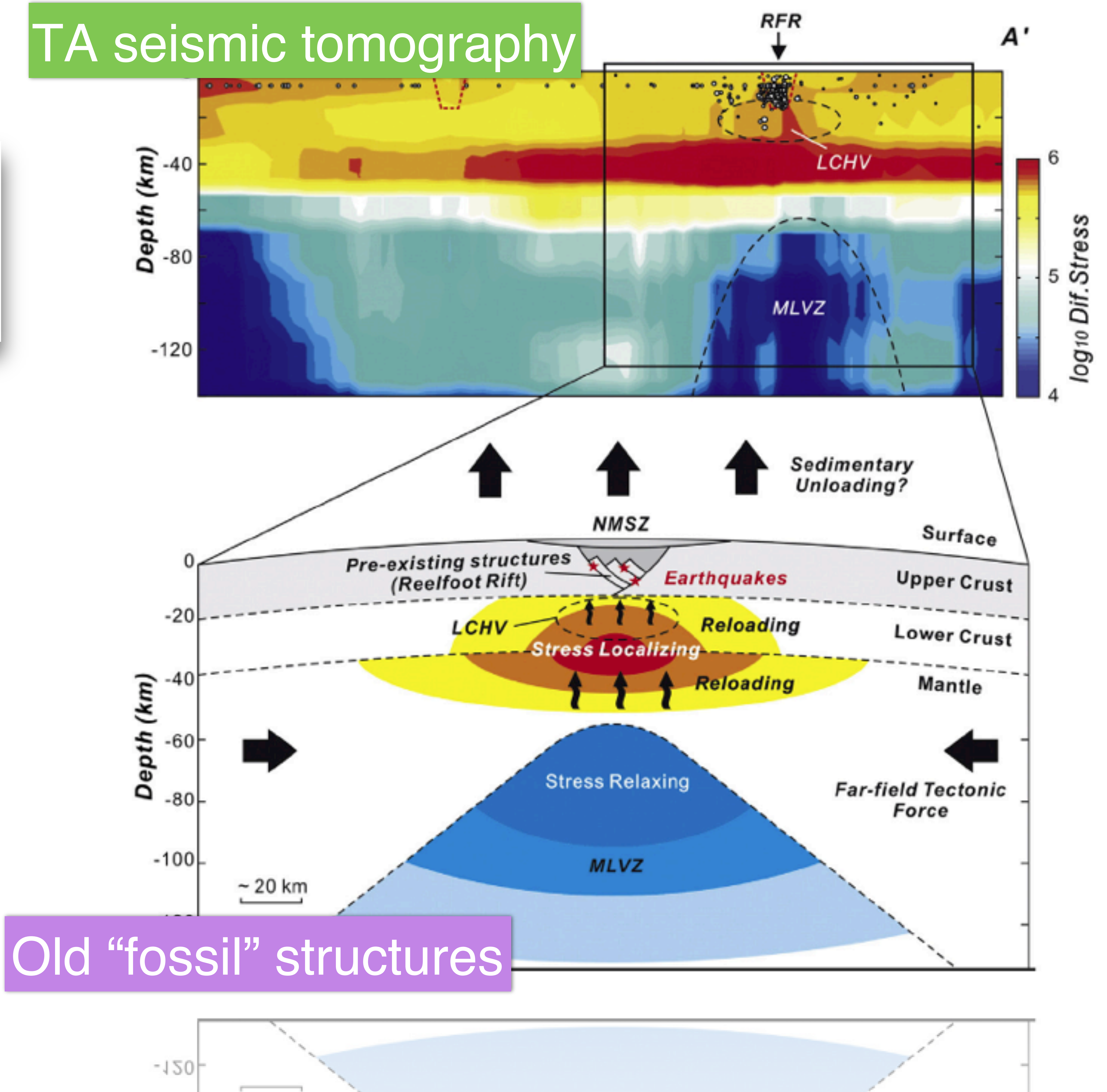
Earth. Planet. Sci. Lett. 2014

Stress development in heterogenetic lithosphere: Insights into earthquake processes in the New Madrid Seismic Zone

Yan Zhan [a], Guiting Hou [a,*], Timothy Kusky [b], Patricia M. Gregg [c]

[a] *The Key Laboratory of Orogenic Belts and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China*
[b] *Center for Global Tectonics, State Key Laboratory for Geologic Processes and Mineral Resources, China University of Geosciences Wuhan, Wuhan 430074, China*
[c] *Department of Geology, University of Illinois at Urbana–Champaign, 152 Computer Applications Building, 605 E. Springfield Ave., Champaign, IL 61820, USA*

Tectonophysics 2016

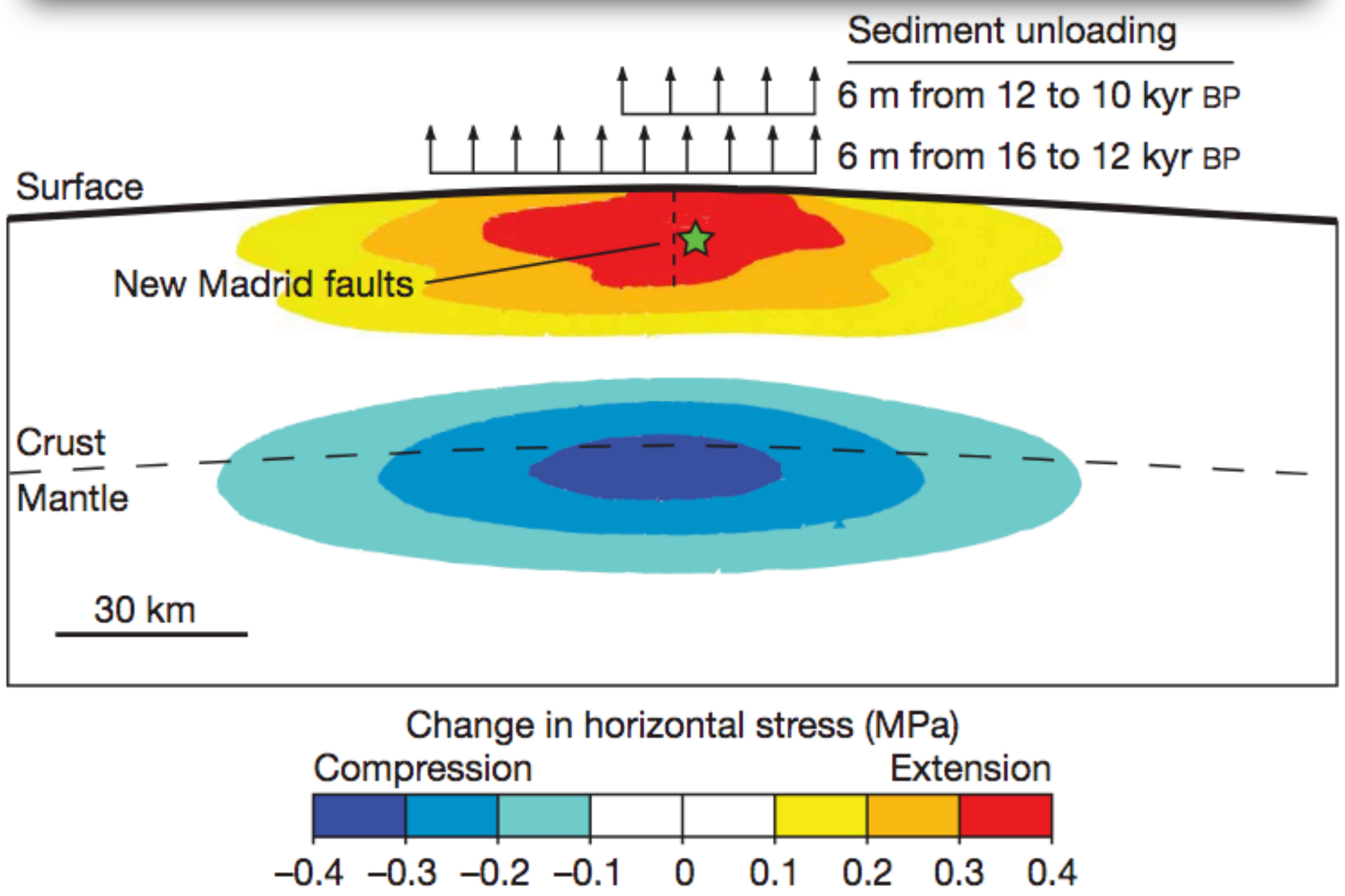


Transient unloading leads to failure

Triggering of New Madrid seismicity by late-Pleistocene erosion

E. Calais[1], A. M. Freed[1], R. Van Arsdale[2] & S. Stein[3]

Nature, 2010



Incision of the Mississippi river removes sediment and **unclamps** the faults

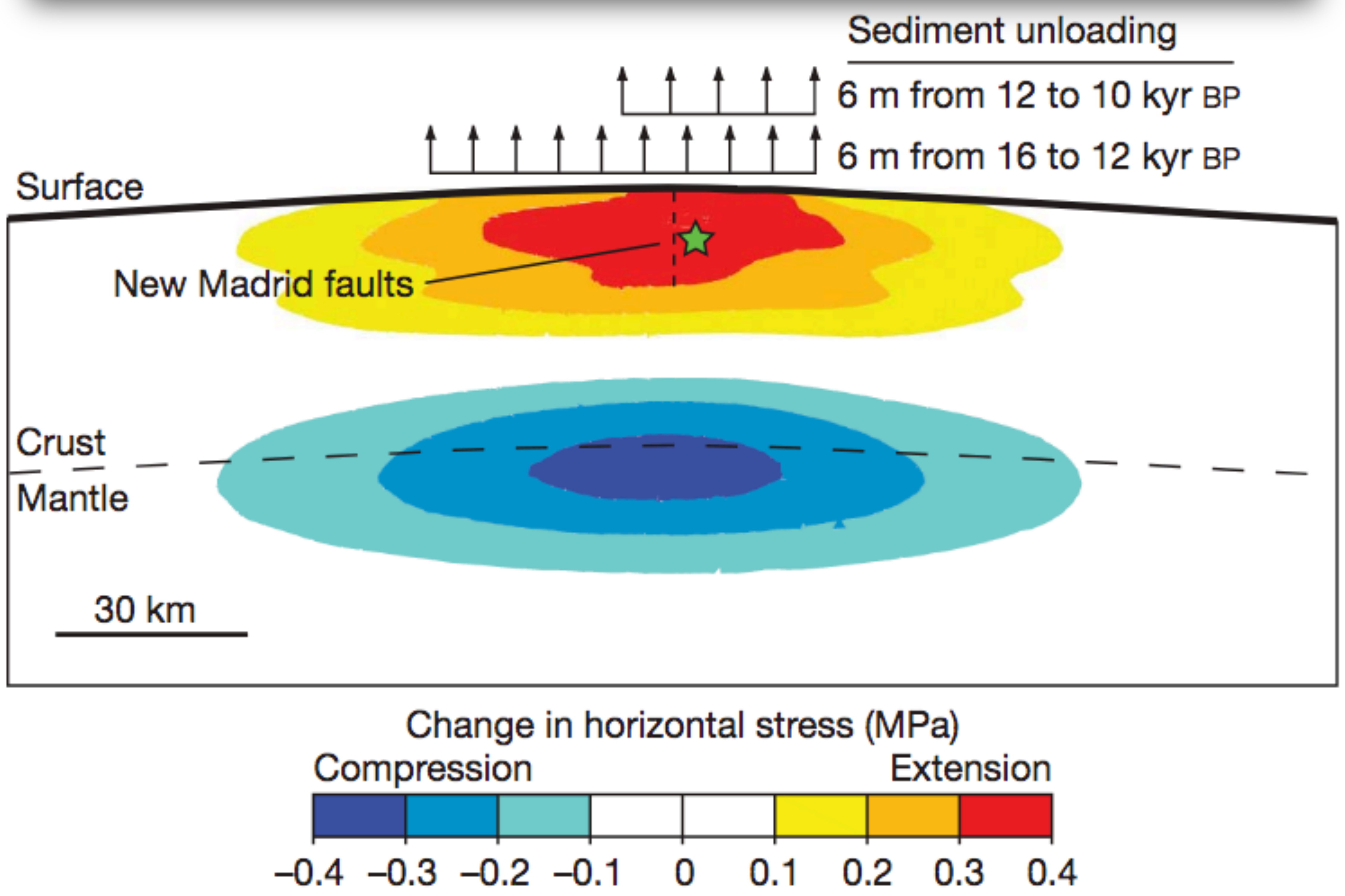
Transient unloading leads to failure

UNIVERSITY OF OREGON

Triggering of New Madrid seismicity by late-Pleistocene erosion

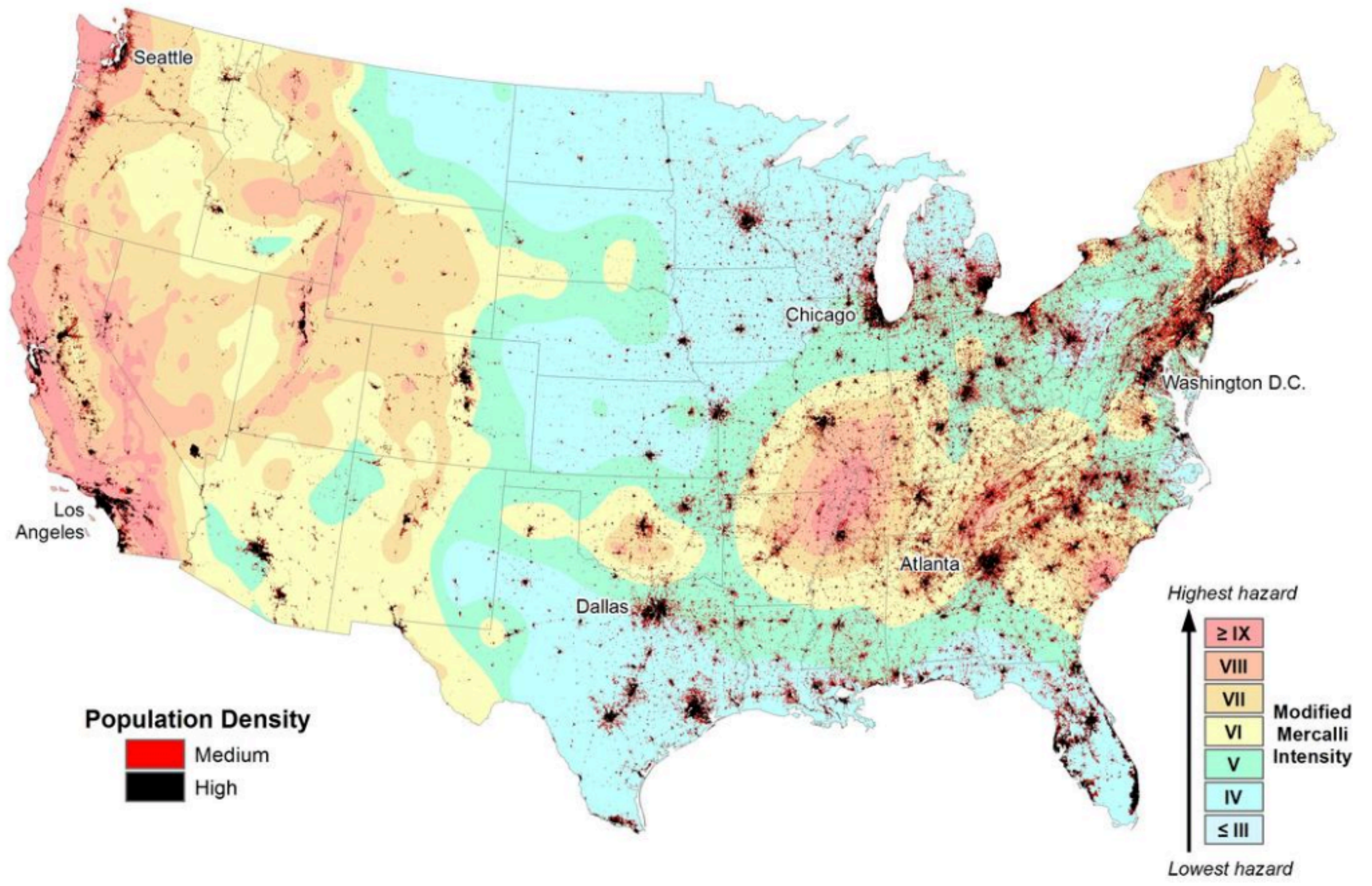
E. Calais[1], A. M. Freed[1], R. Van Arsdale[2] & S. Stein[3]

Nature, 2010



- Far-field loading has **nothing** to do with it.
- Strain is accumulated over **far longer** time scales related to when the structures formed
- It is transient changes in **strength** lead to failure
- This view argues that once broken re-loading of the fault will **not happen**

Will it happen again?



- Is the bullseye **warranted**?
- Can we find other similar regions in the **“stable”** US?

Technology breakthroughs: Earthscope and Early Warning

Geodesy for the largest earthquakes

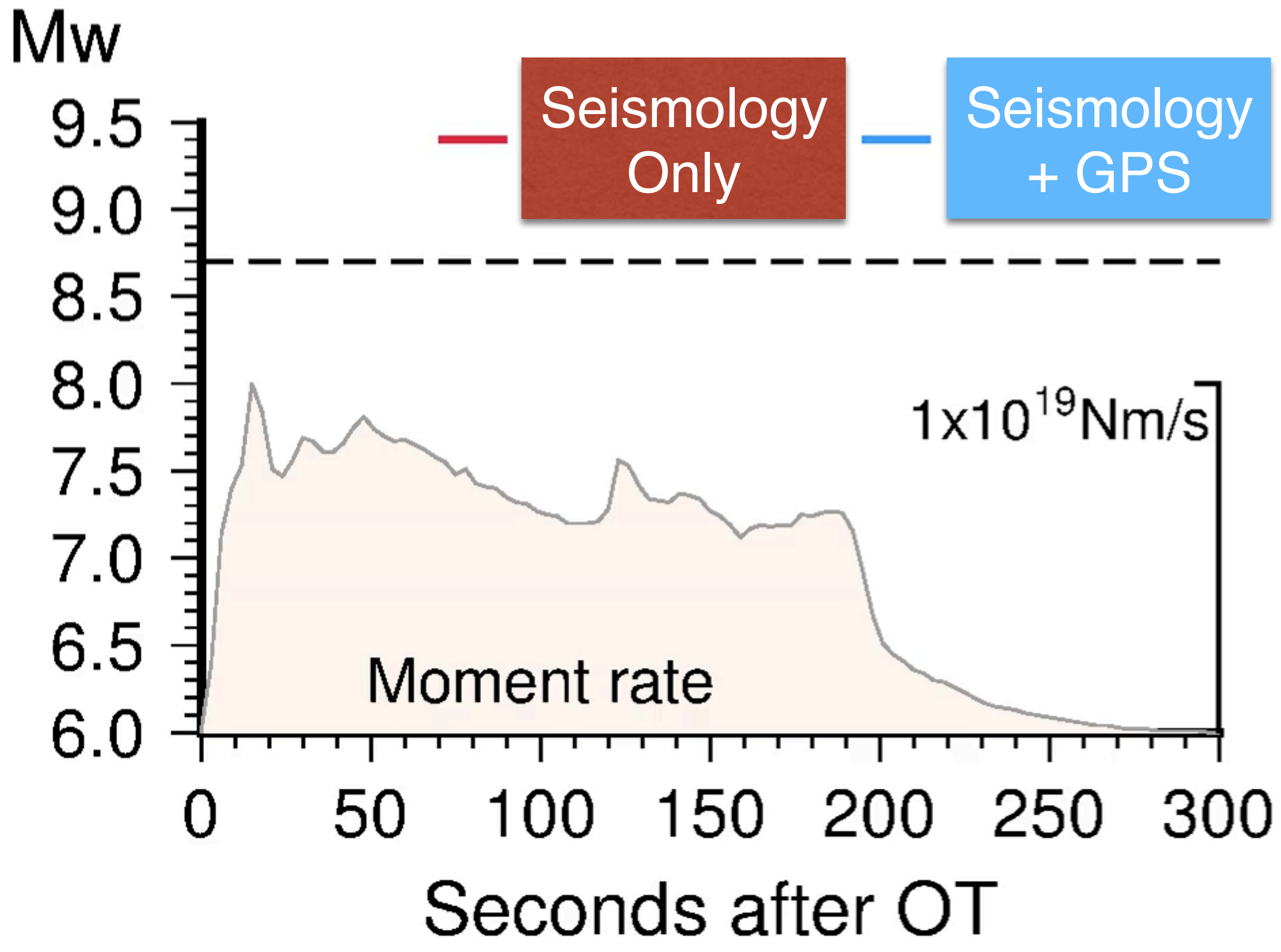
The value of real-time GNSS to earthquake early warning

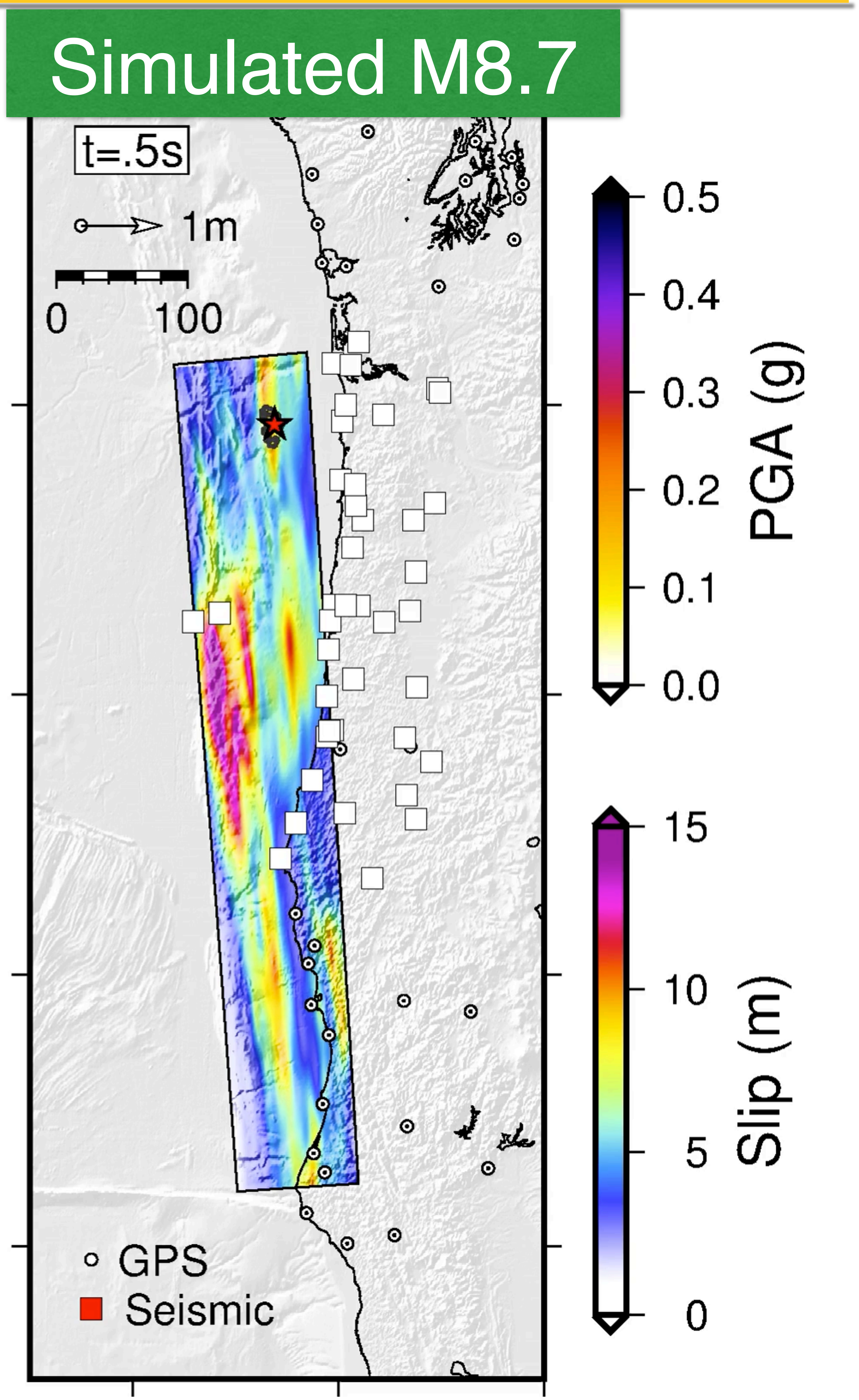
C. J. Ruhl[1], D. Melgar[1], R. Grapenthin[2], and R. M. Allen[1]

[1]UC Berkeley Seismological Laboratory, University of California, Berkeley, Berkeley, California, USA, [2]New Mexico Institute of Mining and Technology, Socorro, New Mexico, USA

Geophys. Res. Lett., 2017

- Through Earthscope we learned to use GPS to in **real-time**
- **Caught** some significant events M7.2 El Mayor, M6.1 Napa, etc.





Geodesy for the largest earthquakes

Operational real-time GPS-enhanced earthquake early warning

R. Grapenthin[1,2], I. A. Johanson[1], and R. M. Allen[1]

J. Geophys. Res., 2014

Real-time inversions for finite fault slip models and rupture geometry based on high-rate GPS data

S. E. Minson[1,2], Jessica R. Murray[3], John O. Langbein[3], and Joan S. Gomberg[1]

J. Geophys. Res., 2014

Demonstration of the Cascadia G-FAST Geodetic Earthquake Early Warning System for the Nisqually, Washington, Earthquake

by Brendan W. Crowell, David A. Schmidt, Paul Bodin, John E. Vidale, Joan Gomberg, J. Renate Hartog, Victor C. Kress, Timothy I. Melbourne, Marcelo Santillan, Sarah E. Minson, and Dylan G. Jamison

Seism. Res. Lett., 2016

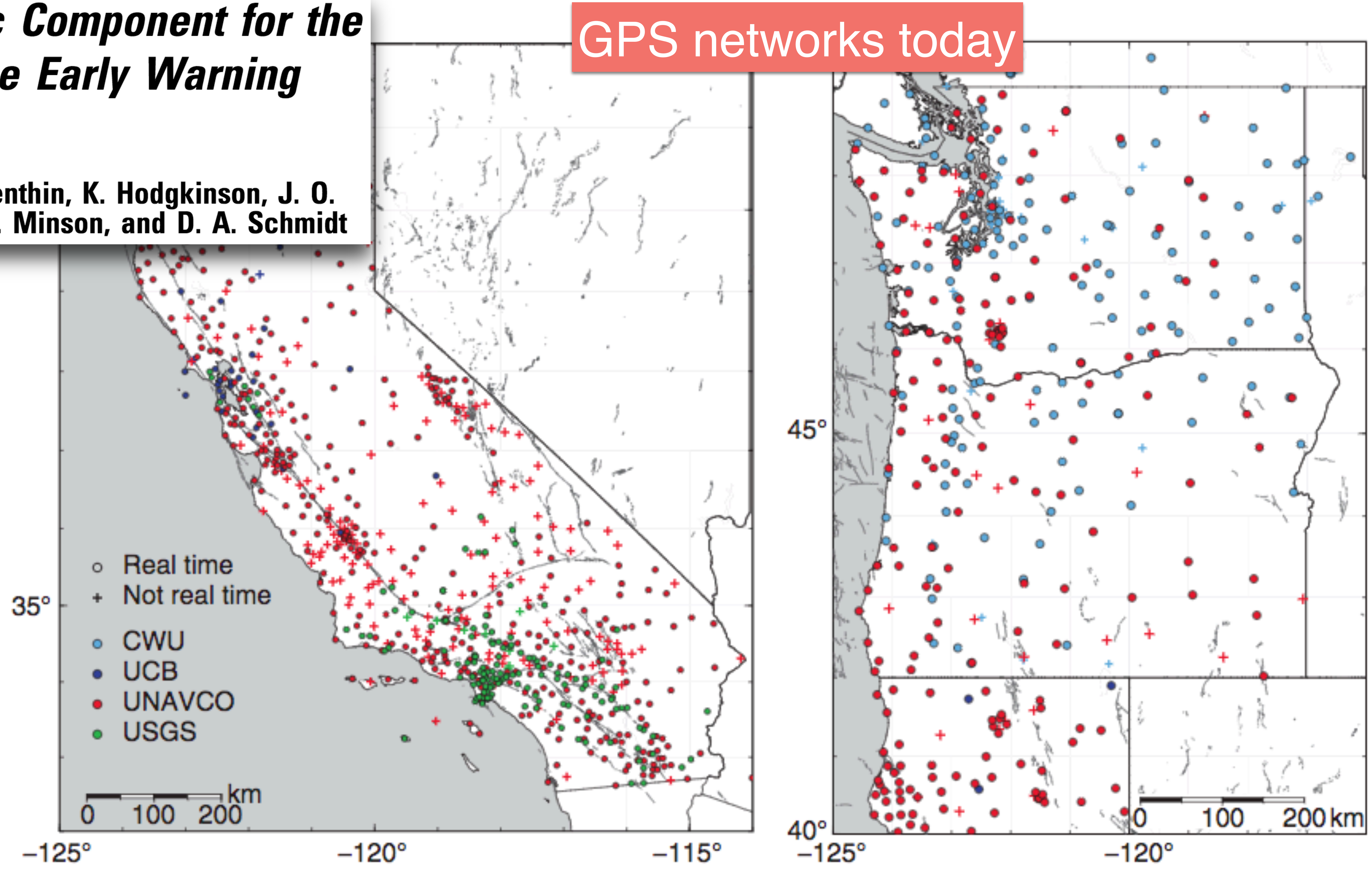
Geodesy for the largest earthquakes

UNIVERSITY OF OREGON

Development of a Geodetic Component for the U.S. West Coast Earthquake Early Warning System

by J. R. Murray, B. W. Crowell, R. Grapenthin, K. Hodgkinson, J. O. Langbein, T. Melbourne, D. Melgar, S. E. Minson, and D. A. Schmidt

Seism. Res. Lett., 2018



Geodesy for the largest earthquakes

UNIVERSITY OF OREGON

Local tsunami warnings: Perspectives from recent large events

Diego Melgar[1], Richard M. Allen[1], Sebastian Riquelme[2], Jianghui Geng[3,4], Francisco Bravo[5], Juan Carlos Baez[2], Hector Parra[6], Sergio Barrientos[2], Peng Fang[3], Yehuda Bock[3], Michael Bevis[7], Dana J. Caccamise II[7,8], Christophe Vigny[9], Marcos Moreno[10], and Robert Smalley Jr.[11]

Geophys. Res. Lett., 2016

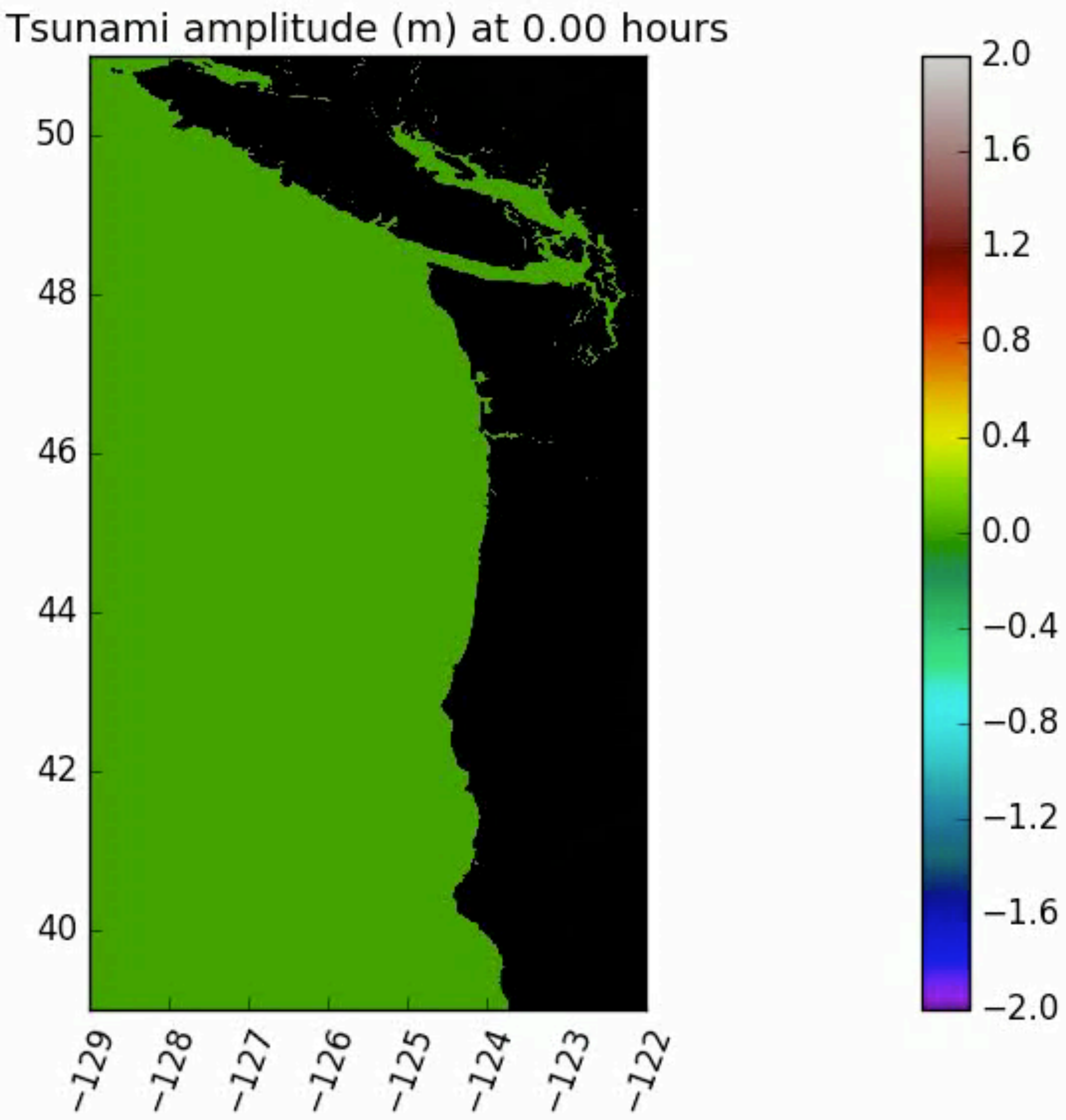
frontiers
2019

Ocean Observations Required to Minimize Uncertainty in Global Tsunami Forecasts, Warnings, and Emergency Response

Michael Angove[1*], Diego Arcas[2], Rick Bailey[3], Patricio Carrasco[4], David Coetzee[5], Bill Fry[6], Ken Gledhill[6], Satoshi Harada[7], Christa von Hillebrandt-Andrade[8], Laura Kong[9], Charles McCreery[10], Sarah-Jayne McCurrach[5], Yuelong Miao[11], Andi Eka Sakya[12], François Schindelé[13]

[1]National Weather Service, National Oceanic and Atmospheric Administration, Silver Spring, MD, USA

The ultimate goal is to **use GPS** to issue **forecasts** in **2-3 mins** following a **large** earthquakes

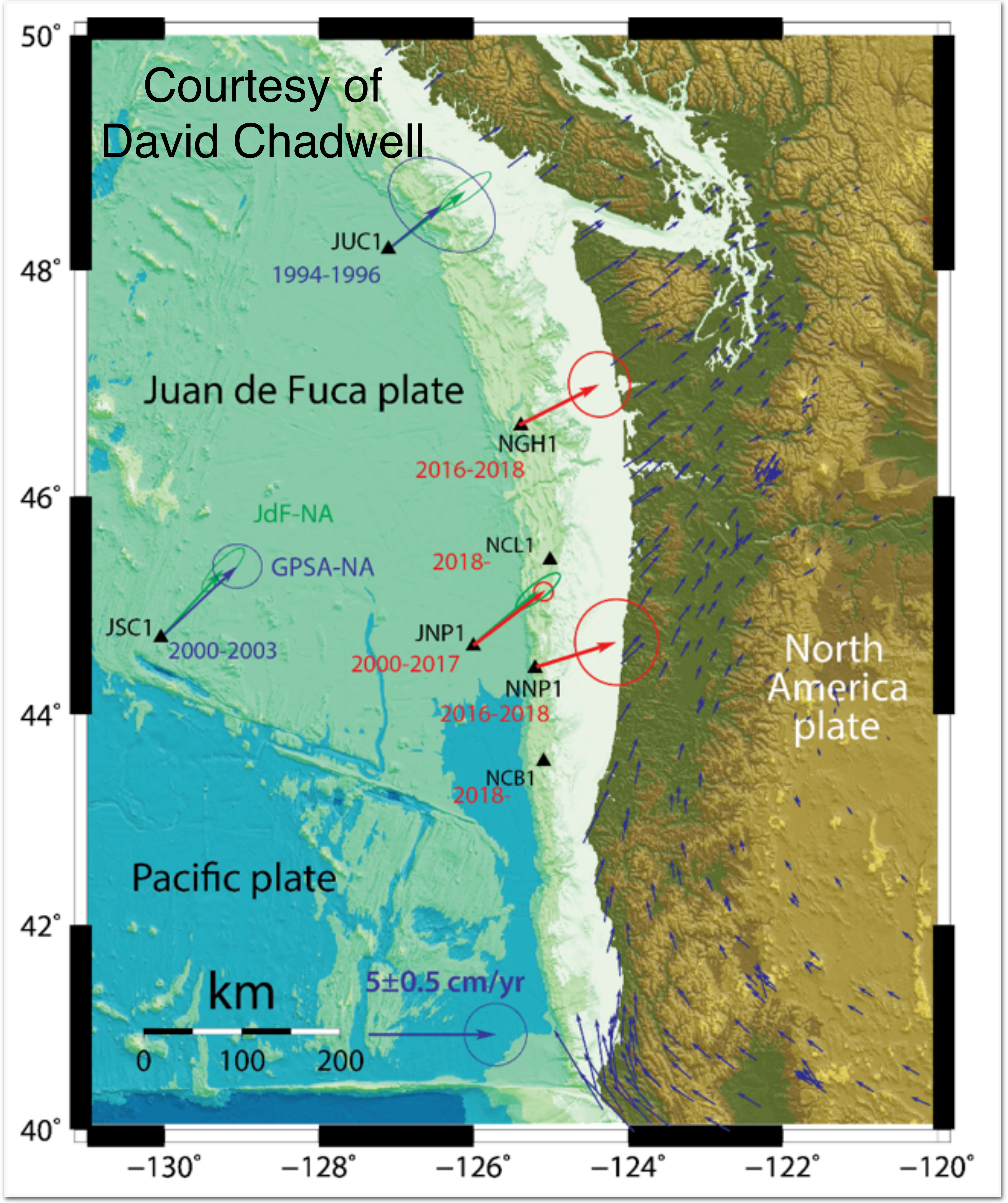



The Future

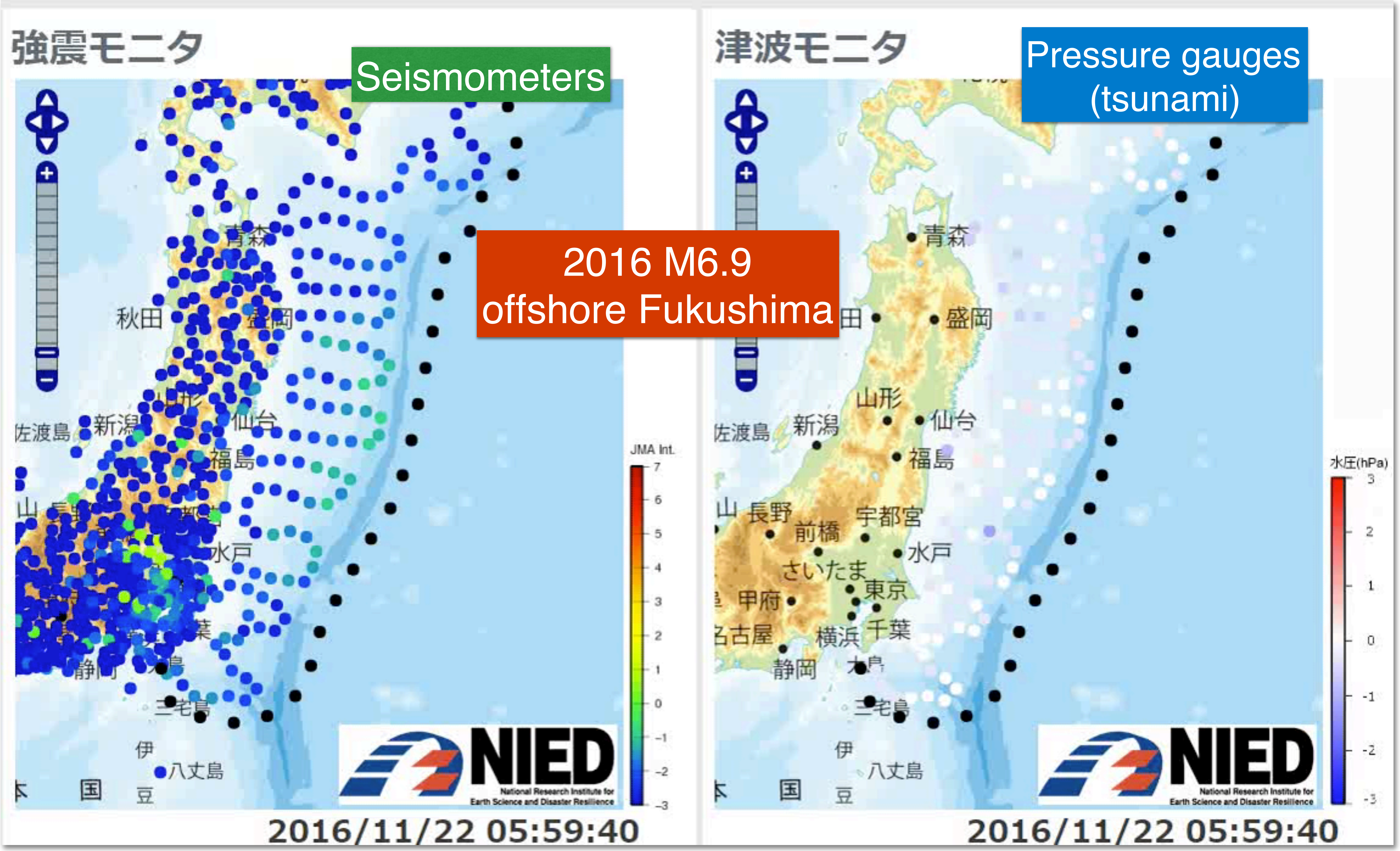
The next frontier is offshore

- Go offshore in a concerted way
  - Shallow coupling
  - Structure of the wedge
  - Tsunamigenesis
  - Role and budget of fluids

- Catch a large rupture in action
  - What happens at nucleation?
  - Are all earthquakes created equal?
  - How do foreshocks behave?



The next frontier is offshore



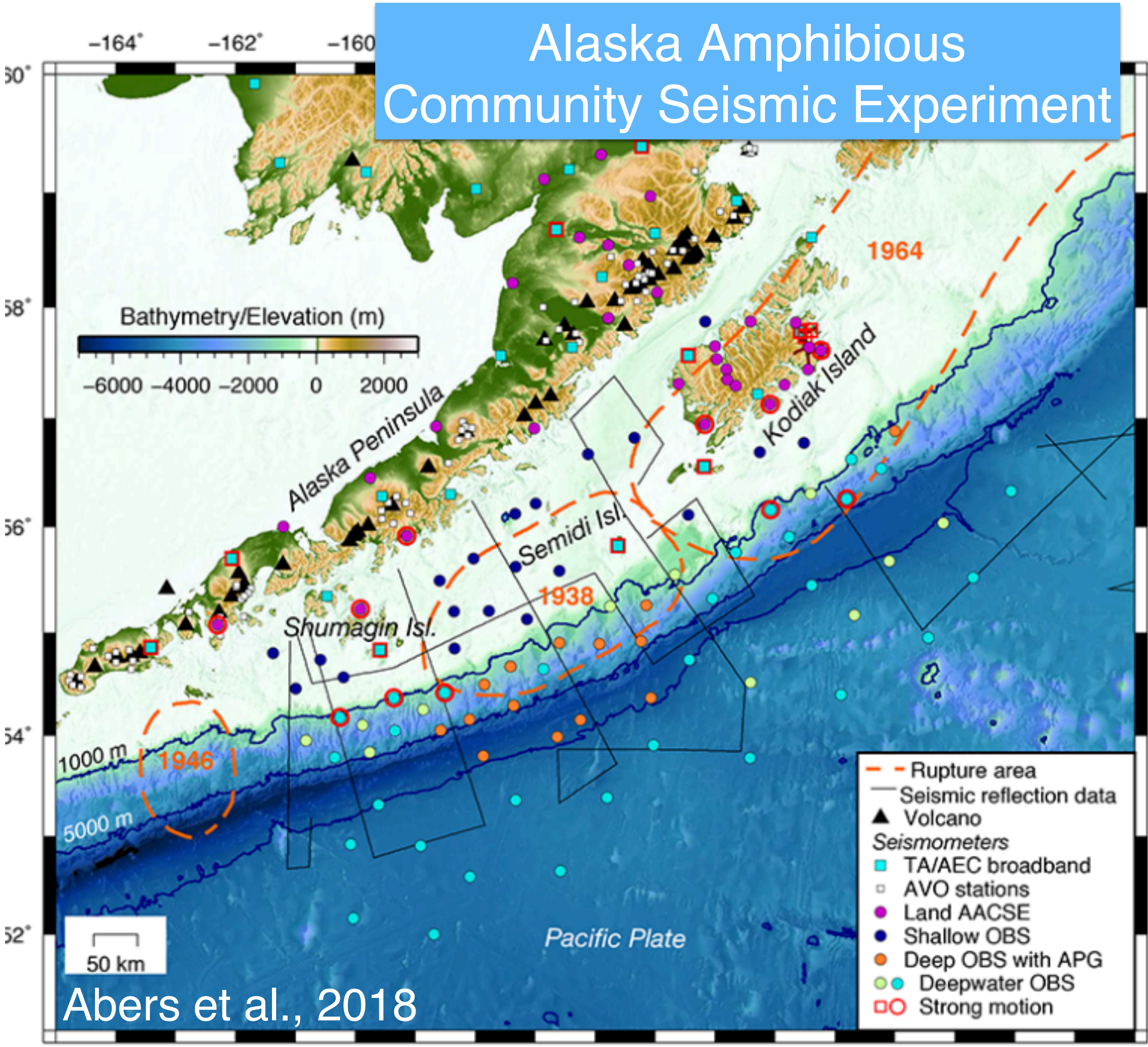
The next frontier is offshore

UNIVERSITY OF OREGON

- Go offshore in a concerted way
  - Shallow coupling
  - Structure of the wedge
  - Tsunamigenesis
  - Role and budget of fluids

- Catch a large rupture in action
  - What happens at nucleation?
  - Are all earthquakes created equal?
  - How do foreshocks behave?

Alaska Amphibious Community Seismic Experiment

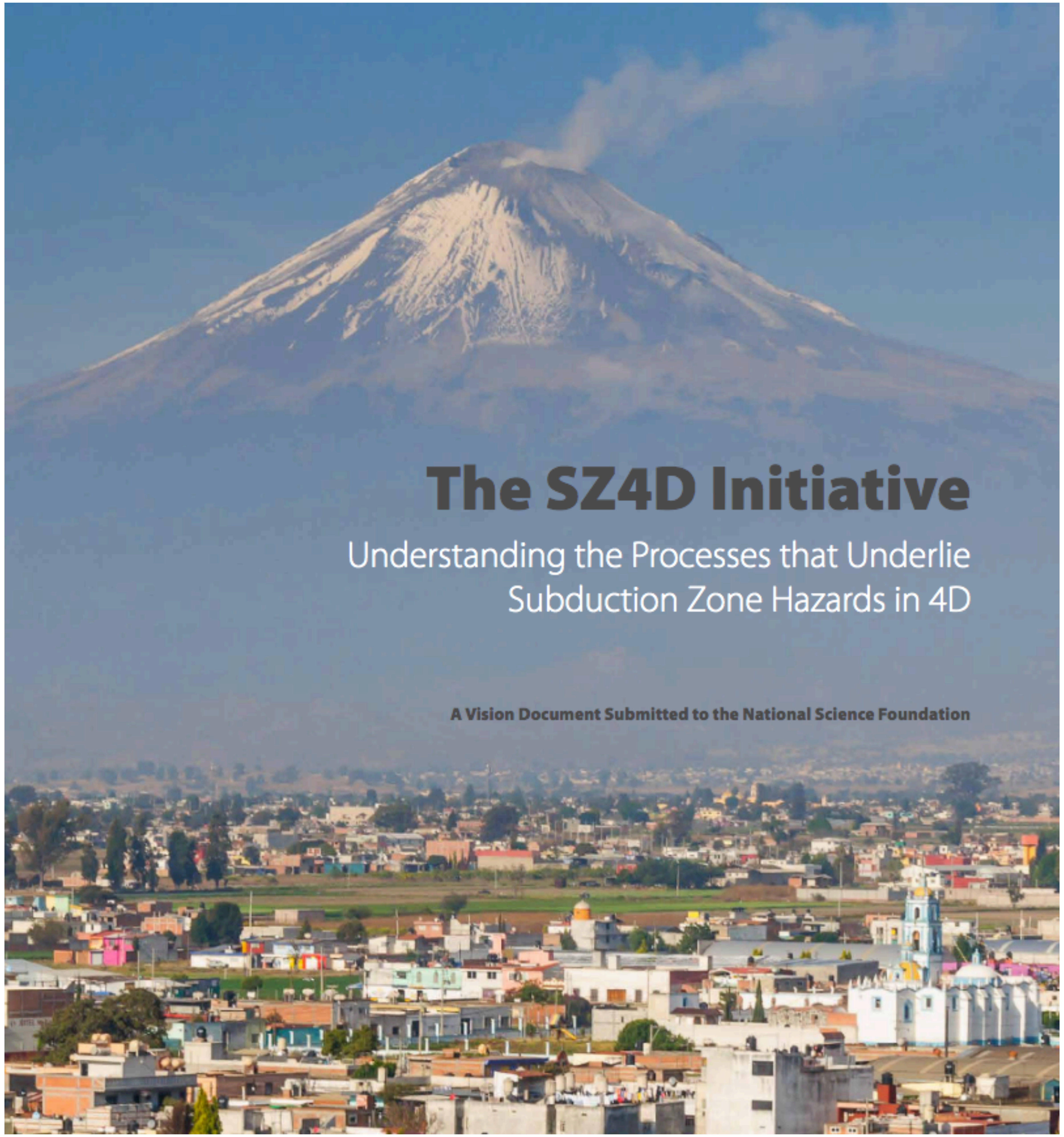


Abers et al., 2018

The next frontier is offshore

- Go offshore in a concerted way
  - Shallow coupling
  - Structure of the wedge
  - Tsunamigenesis
  - Role and budget of fluids

- Catch a large rupture in action
  - What happens at nucleation?
  - Are all earthquakes created equal?
  - How do foreshocks behave?



Conclusions

Impactful science serves society


earth
scope
www.earthscope.org