A New View of Earth

InSAR

PBO

earthscope

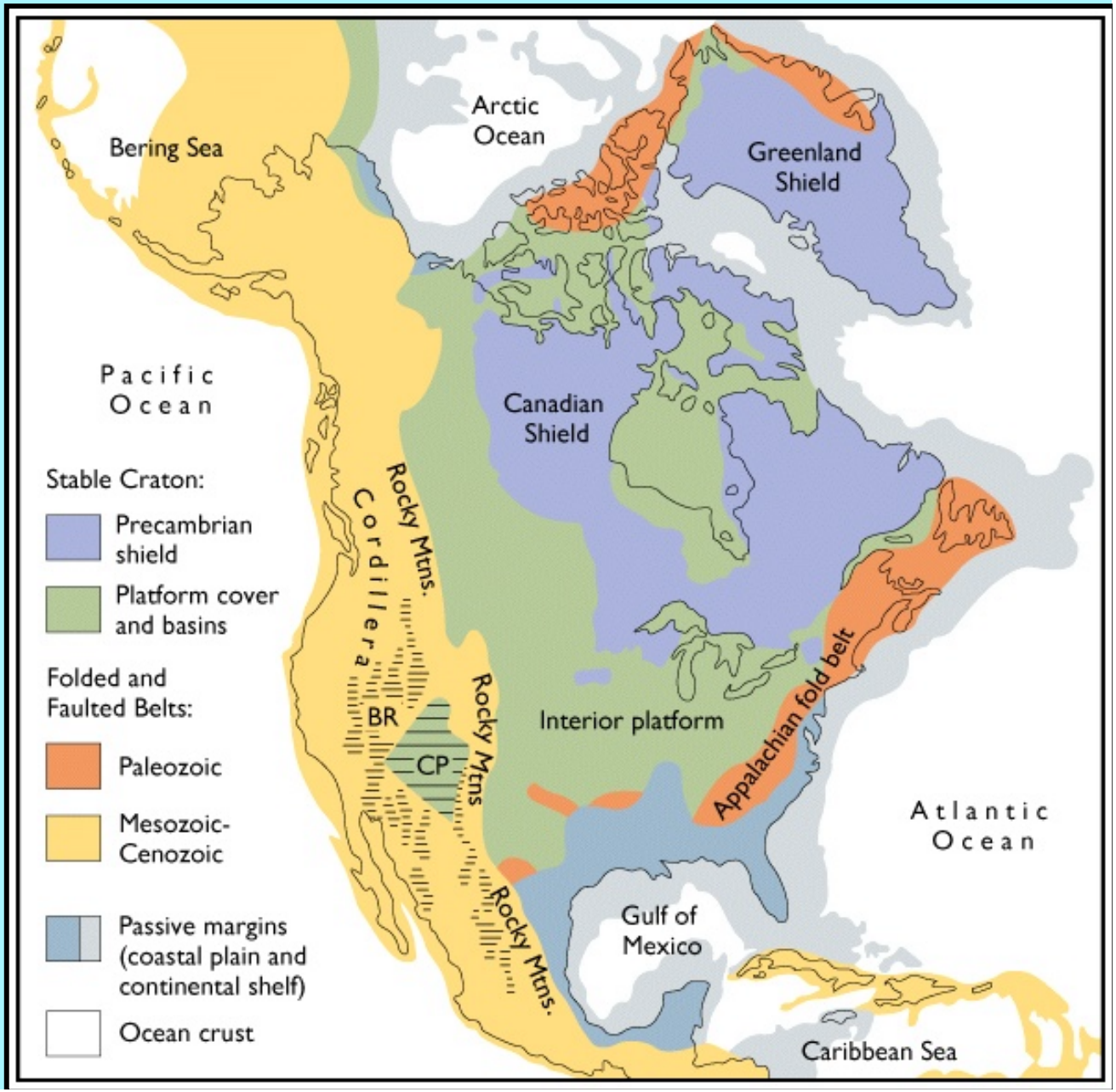
SAFOD

USArray

Integrated Science

The EarthScope Scientific Vision

To understand the structure and deformation of the North American continent in four dimensions x,y,z,t



Four-dimensional imaging of tectonic North America requires all EarthScope component facilities

- **USArray** Images deformational structures at depth.
- **PBO** Observes surface deformation with high temporal and spatial resolution.
- **InSAR** Complementary geodetic tool provides deformation coverage over broad areas.
- **SAFOD** Directly samples the material properties of an actively deforming zone at depth.

EarthScope Science Goals

- Structure and evolution of the continent
- Earthquake processes and seismic hazards
- Magmatic processes and volcanic hazards
- Active deformation and tectonics
- Continental geodynamics
- Fluids in the crust
- Exploration and discovery

Some Key Questions

Some Key Questions

- **What are the underlying geologic processes governing deformation of the North American continent?**

Some Key Questions

- What are the underlying geologic processes governing deformation of the North American continent?
- On what geologic structures do these processes occur?

Some Key Questions

- What are the underlying geologic processes governing deformation of the North American continent?
- On what geologic structures do these processes occur?
- **What are the spatial and temporal scales of deformation across the continent?**

Some Key Questions

- What are the underlying geologic processes governing deformation of the North American continent?
- On what geologic structures do these processes occur?
- What are the spatial and temporal scales of deformation across the continent?
- **How are earthquakes, volcanoes, and mountain building related to pre-existing geologic structures and patterns of ongoing deformation?**

Some Key Questions

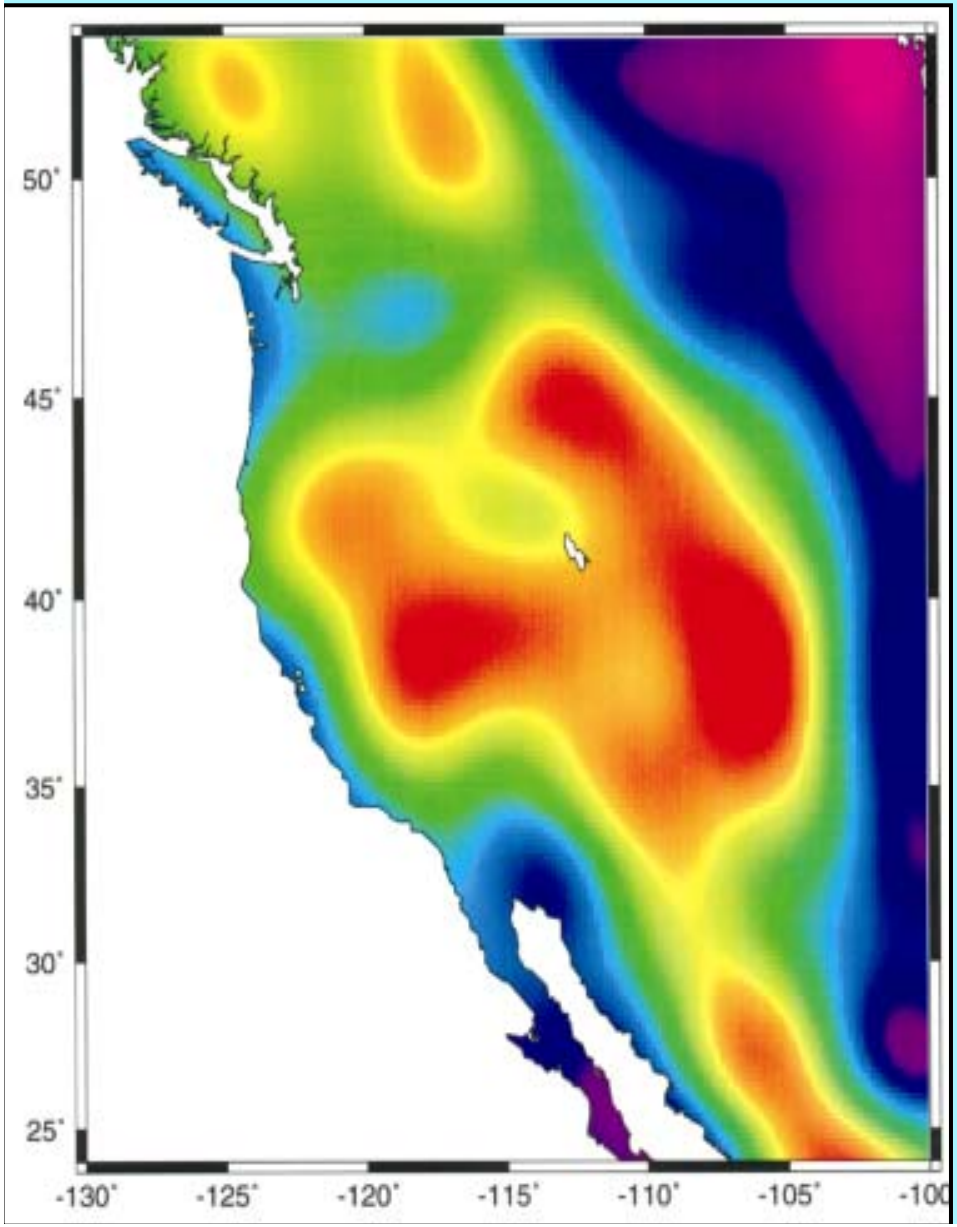
- What are the underlying geologic processes governing deformation of the North American continent?
- On what geologic structures do these processes occur?
- What are the spatial and temporal scales of deformation across the continent?
- How are earthquakes, volcanoes, and mountain building related to pre-existing geologic structures and patterns of ongoing deformation?
- **How are features at Earth's surface related to structures in Earth's interior?**

Some Key Questions

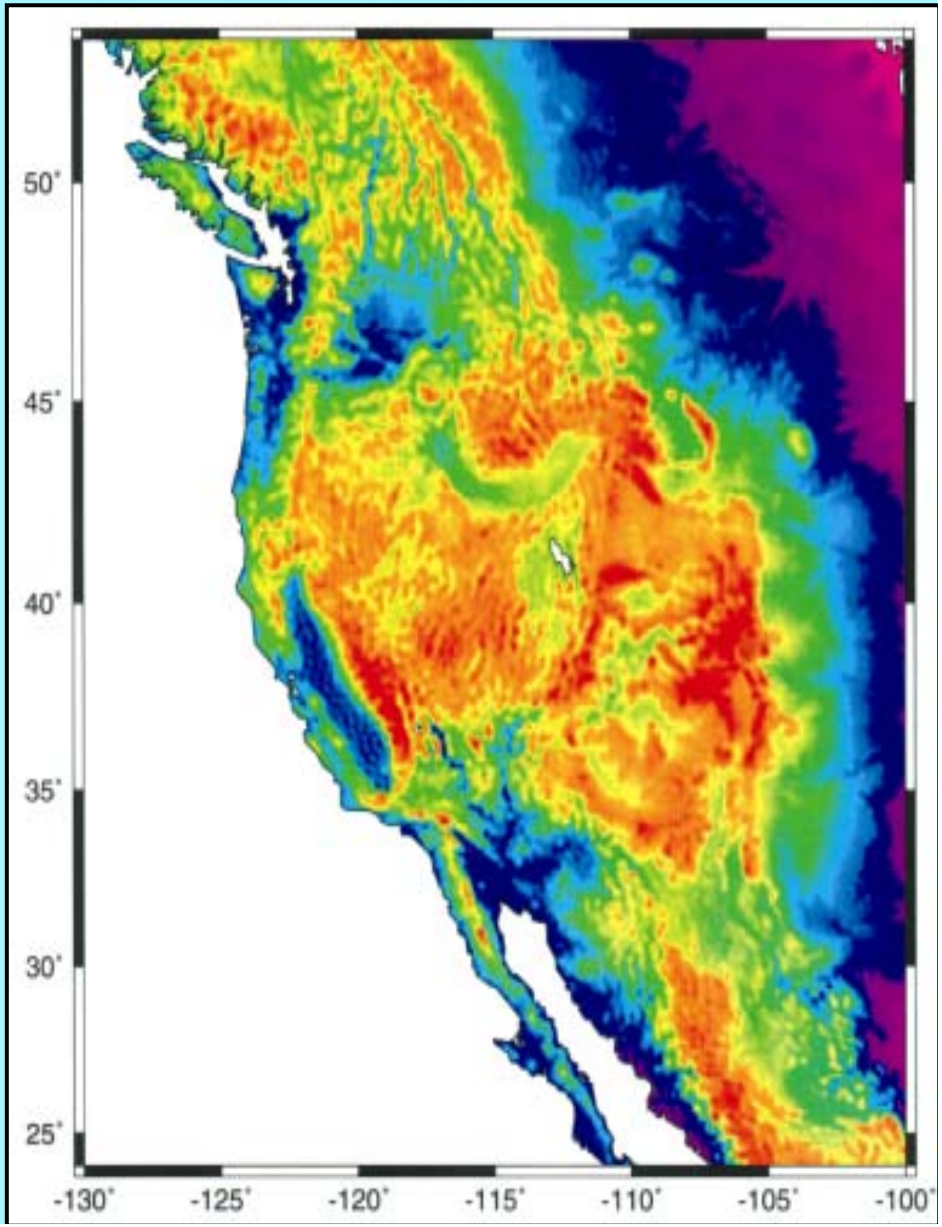
- What are the underlying geologic processes governing deformation of the North American continent?
- On what geologic structures do these processes occur?
- What are the spatial and temporal scales of deformation across the continent?
- How are earthquakes, volcanoes, and mountain building related to pre-existing geologic structures and patterns of ongoing deformation?
- How are features at Earth's surface related to structures in Earth's interior?
- **How can the spatial and temporal patterns of deformation together with knowledge of their associated structures be used in predicting the behaviors of seismic, volcanic, and other geodynamic phenomena?**

EarthScope will increase our resolution of the Subsurface Structure

Topography of western U.S. filtered at 500 km wavelength

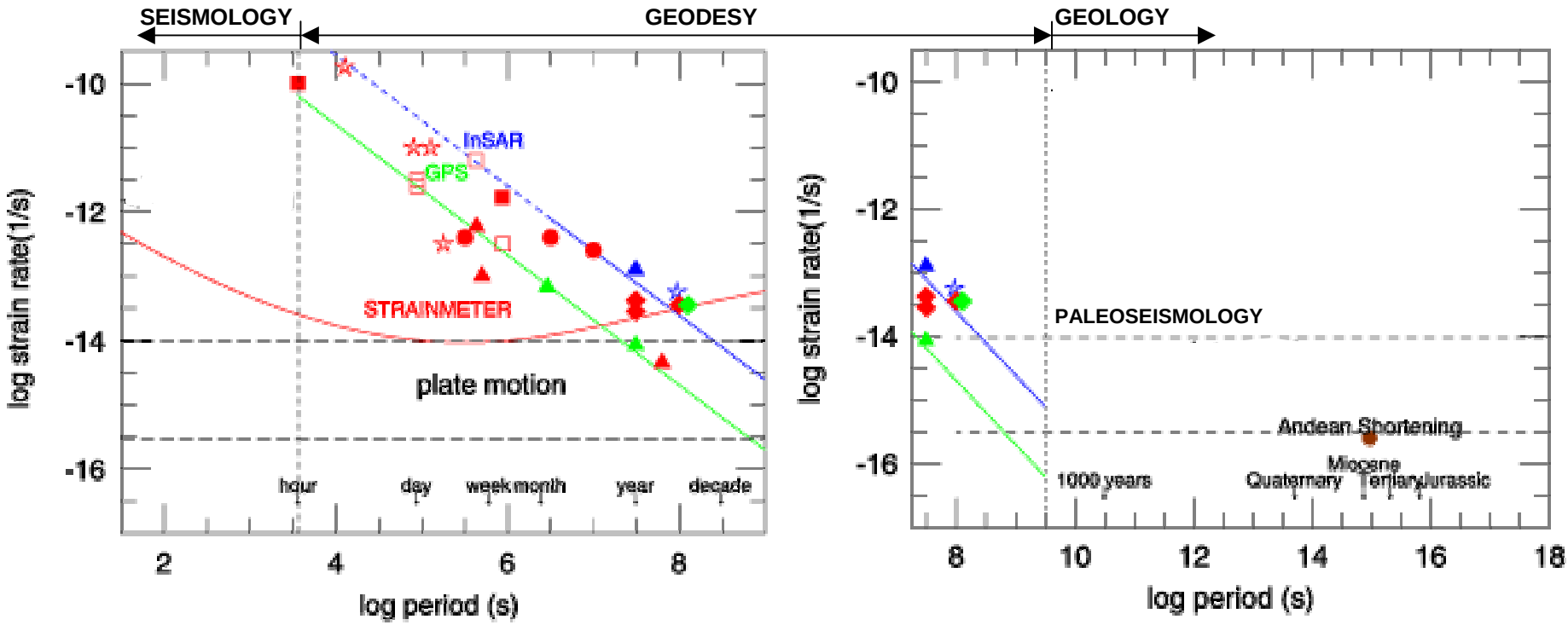


Topography of western U.S. filtered at 30 km wavelength



EarthScope will enhance the spatio-temporal control on regional Rates of Deformation

A Broad Band Approach to Measuring Deformation Through Time



EarthScope will advance our understanding of

Active Tectonics, Earthquake and Magmatic Processes,

and

Seismic and Volcanic Hazard

EarthScope will capitalize on the notion of the Natural Laboratory*

* Where representative behaviors of a complex system can be investigated in appropriate context and detail, and with the appropriate complement of expertise and instrumentation (NRC BROES Report, 2001).

North America as a Natural Laboratory

- **Diverse array of continental processes and structures**
- **Multi-disciplinary investigations**
- **Multi-scale observations**
- **Existing data bases**

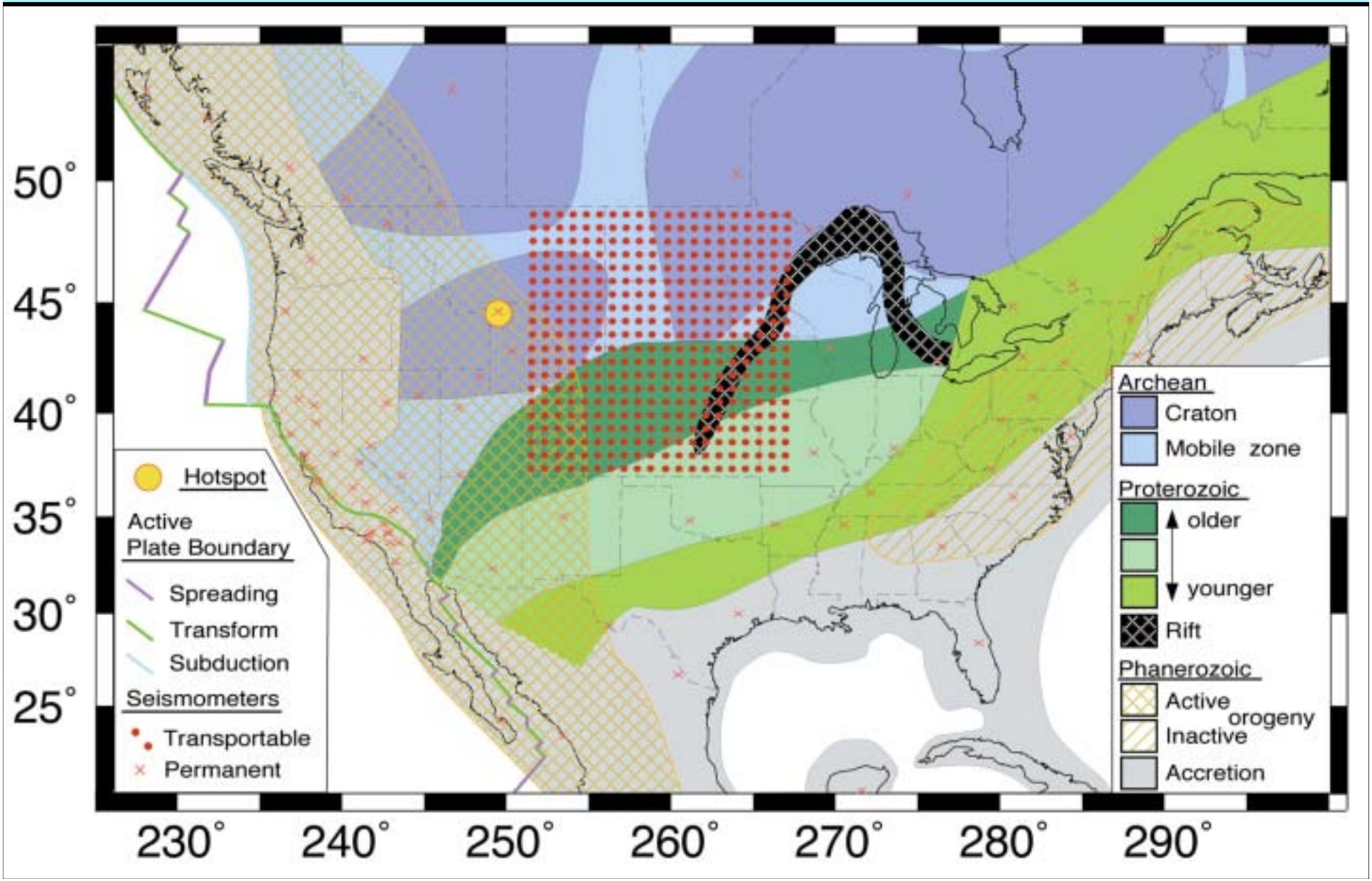
USArray – Components

- **Transportable Array**
  - **fixed design broadband array - “Bigfoot”**
  - **flexible pool: broadband, short period, high frequency instrumentation**
  - **magnetotelluric systems**
- **Permanent Reference Network**
  - **GSN/NSN quality seismometers**
  - **geodetic quality GPS receivers**
- **All data to community in near real time**

USArray – "Bigfoot"

- 400 broadband seismometers
  - 70 km spacing
  - Nominal 1400 x 1400 km grid
- 50 magnetotelluric field systems
- Deployments for ~18 months at each site
- Rolling deployment over ~ 10 years

Tectonic provinces of the U.S. with USArray footprint. 70 km spacing between seismic stations (red dots).



USArray can:

- **Provide increased resolution at depth through comprehensive 3-D coverage of the continental U.S., with possible extensions into Mexico and Canada, and onto the continental margins.**
- **Tie together seemingly disparate tectonic provinces into a coherent model of the origin and evolution of the continental lithosphere.**
- **Tie the lithosphere to structures in the deeper mantle.**
- **Combine local and regional, and short and long term observations of subsurface imaging.**

USArray – Products

- Crust and upper-mantle geologic structure
- Maps of the Moho, transition zones, and core-mantle boundary
- Three-dimensional seismic velocity models of the crust and upper mantle
- Maps of regional seismic attenuation
- Maps of crust and mantle anisotropy
- Earthquake mechanisms

All at high resolution

Plate Boundary Observatory

Imaging the Deformation of Tectonic North America in Four Dimensions

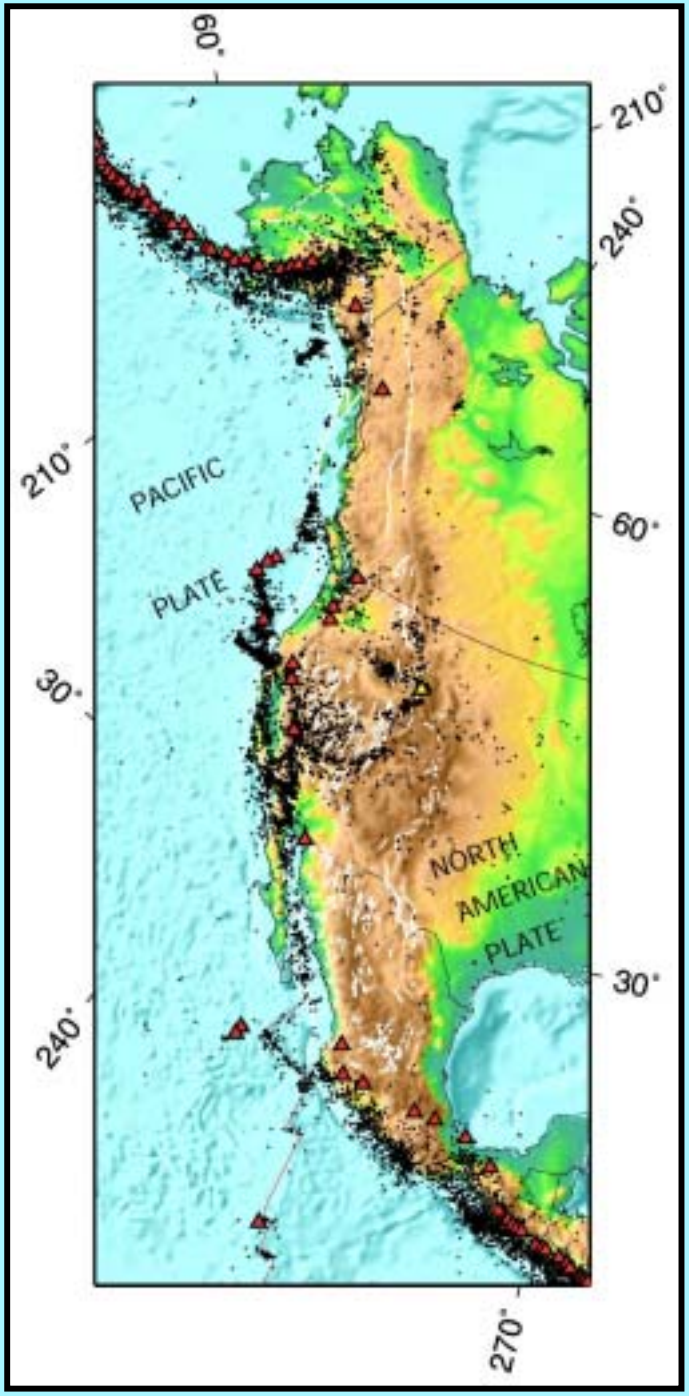


Plate Boundary Observatory

Imaging the Deformation of Tectonic North America in Four Dimensions

- **Physics of earthquakes**

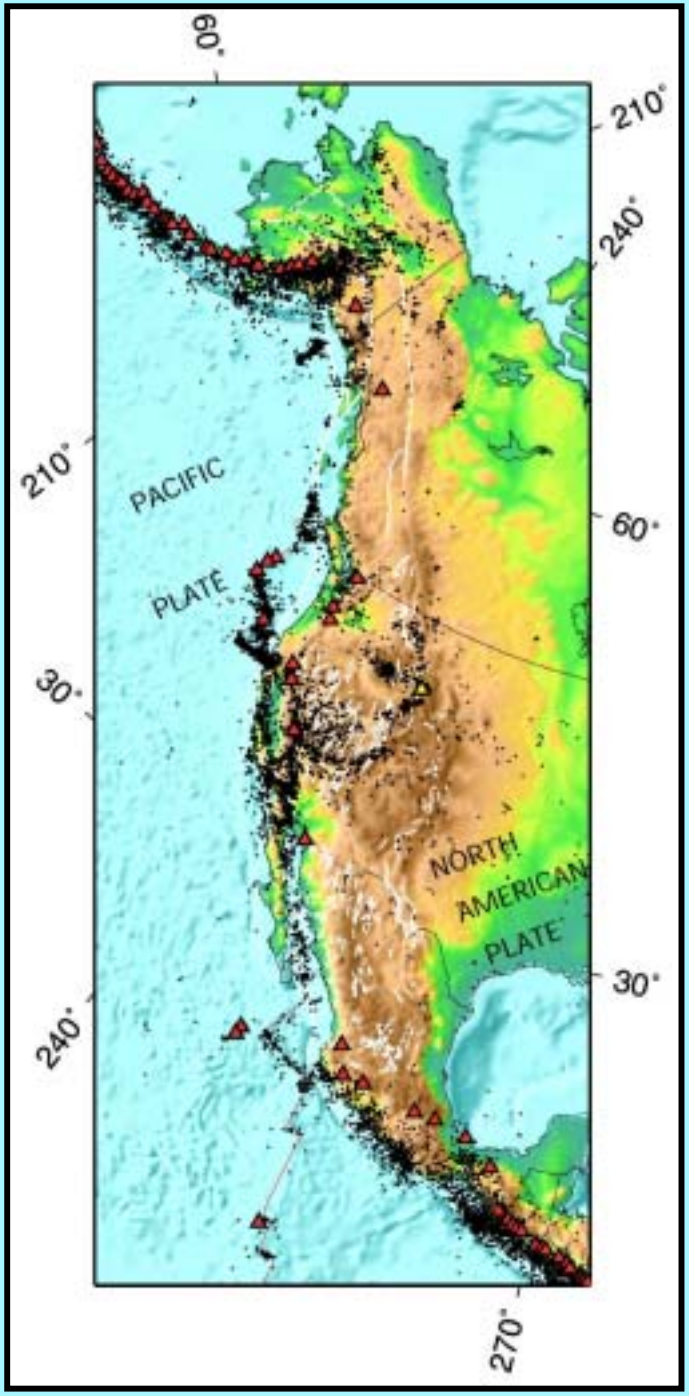


Plate Boundary Observatory

Imaging the Deformation of Tectonic North America in Four Dimensions

- **Physics of earthquakes**
- **Physics of magmatic processes**

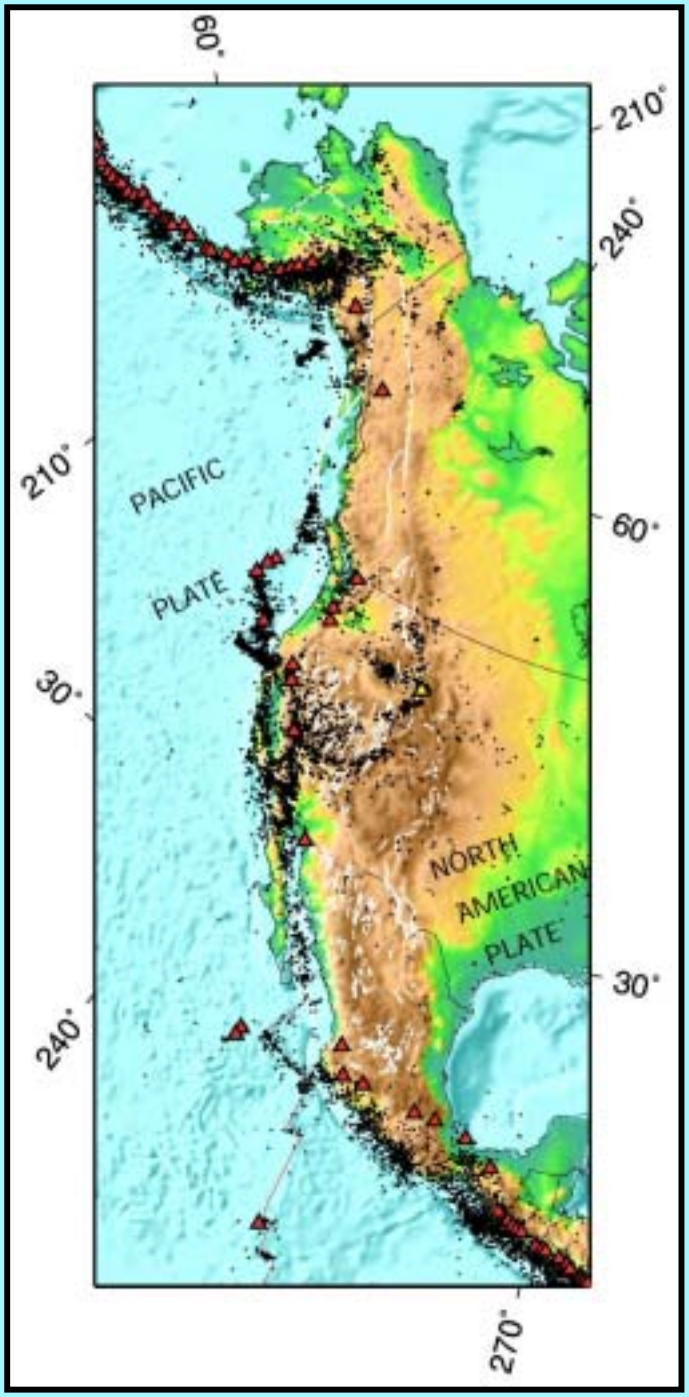
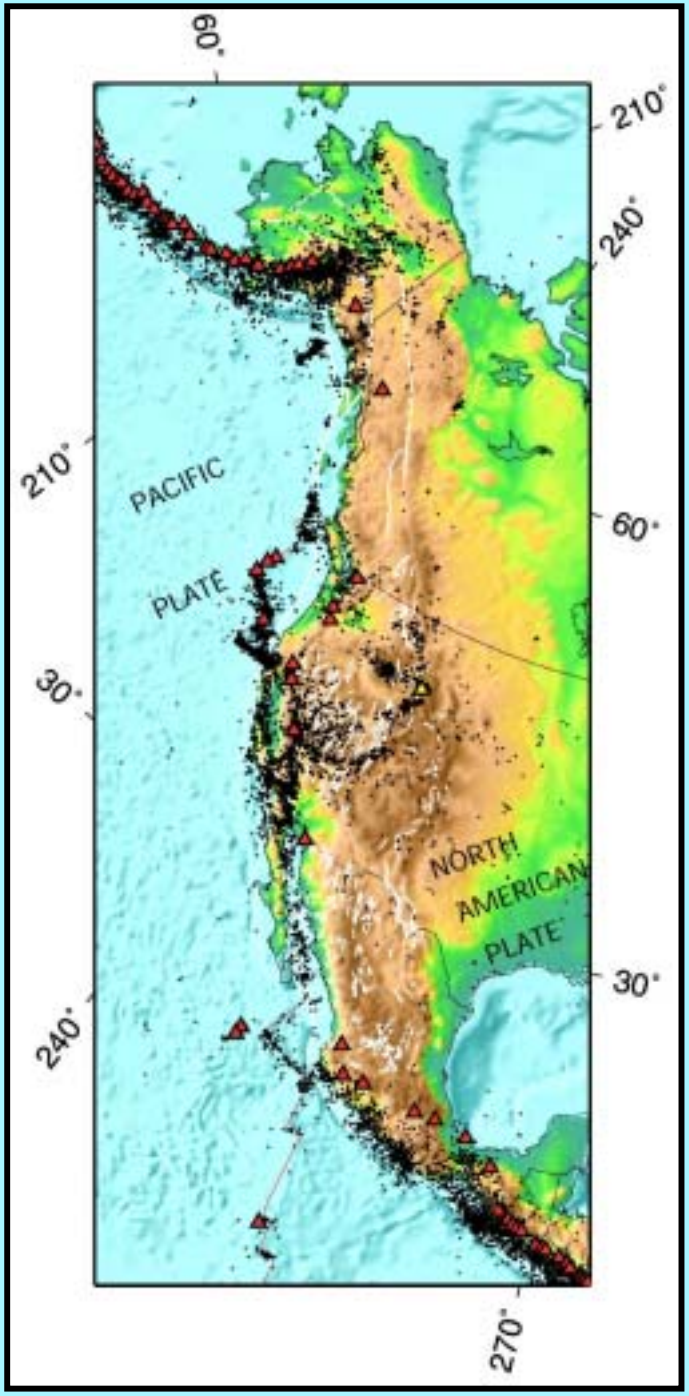


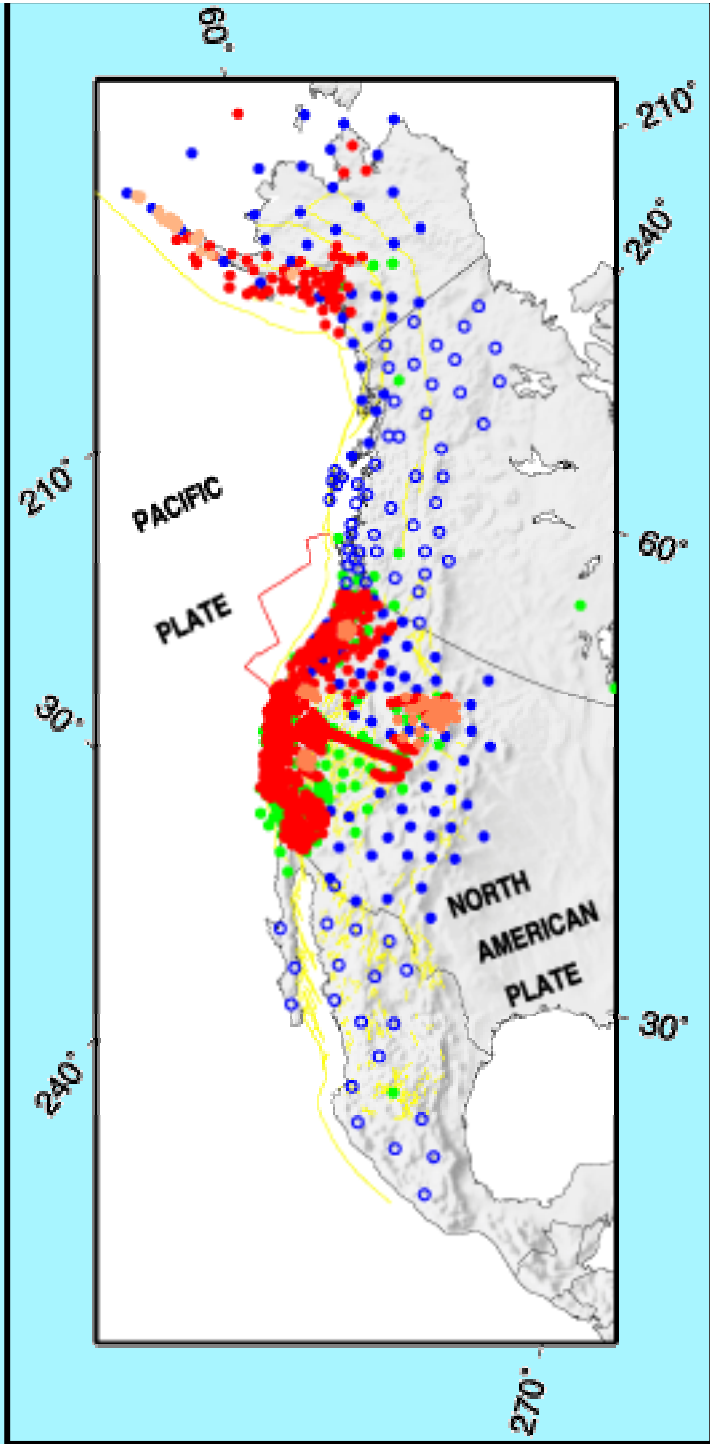
Plate Boundary Observatory

Imaging the Deformation of Tectonic North America in Four Dimensions

- **Physics of earthquakes**
- **Physics of magmatic processes**
- **Plate boundary dynamics and evolution**

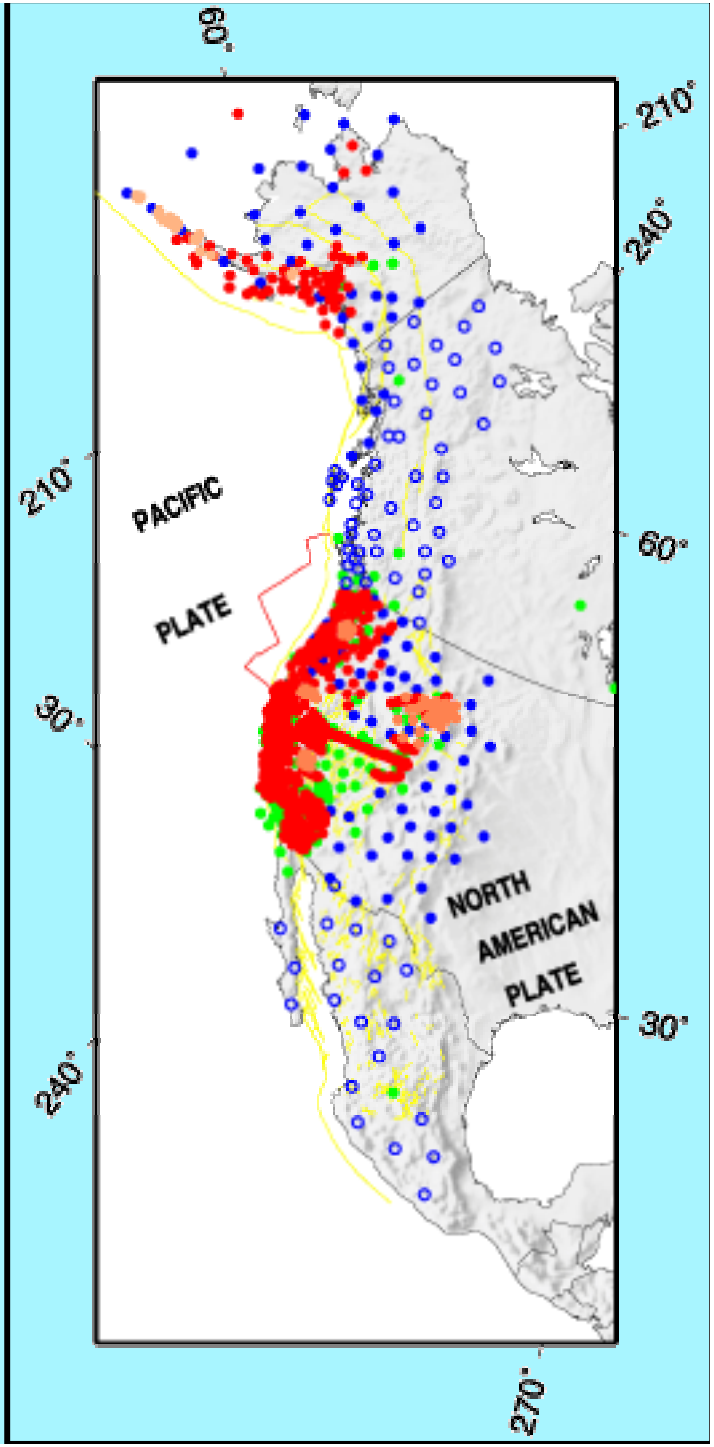


PBO – A Two-Tiered Deployment of Geodetic Instrumentation



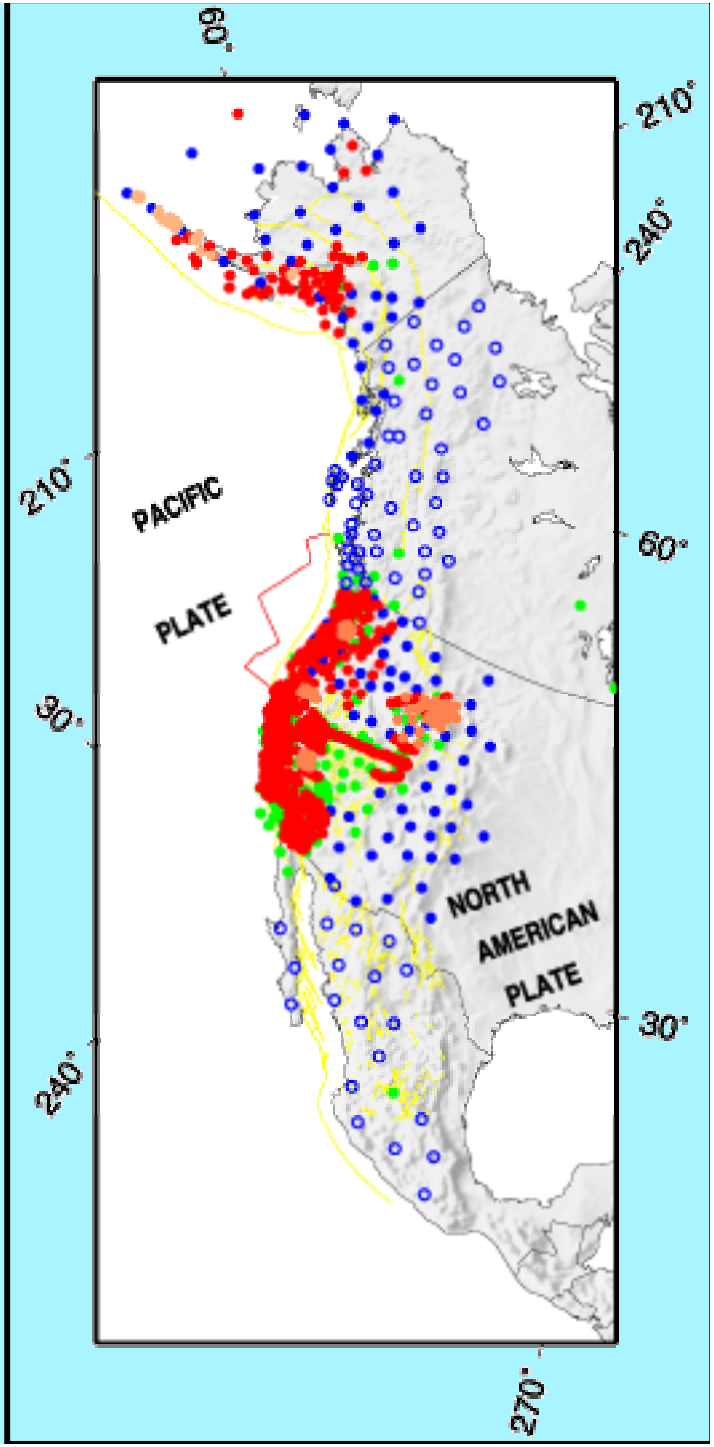
PBO – A Two-Tiered Deployment of Geodetic Instrumentation

- **A backbone of ~100 sparsely distributed continuous GPS receivers to provide a synoptic view of the entire North American plate boundary deformation zone.**



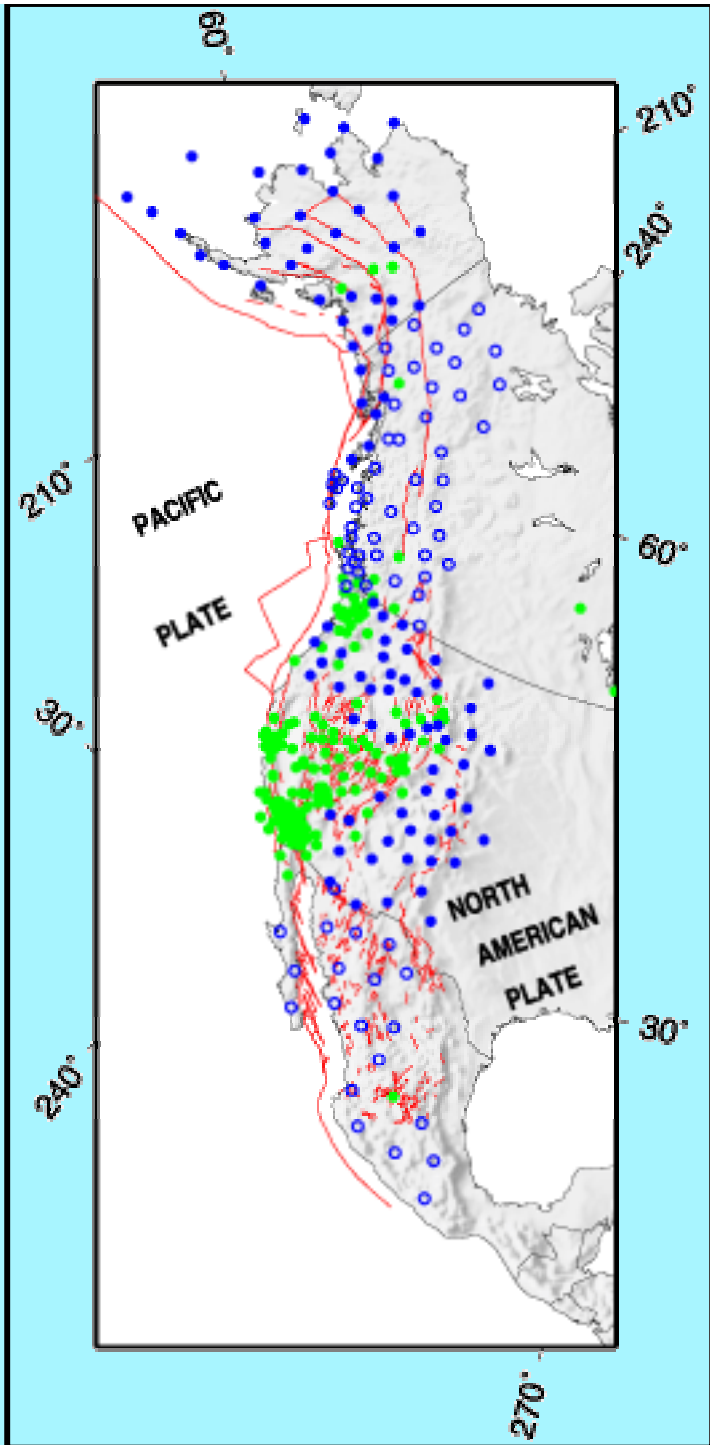
PBO – A Two-Tiered Deployment of Geodetic Instrumentation

- **A backbone of ~100 sparsely distributed continuous GPS receivers to provide a synoptic view of the entire North American plate boundary deformation zone.**
- **Clusters of GPS receivers and strainmeters to be deployed in areas requiring greater spatial and temporal resolution, such as fault systems and magmatic centers (775 GPS units & 200 strainmeters).**



GPS Backbone; The Big Picture

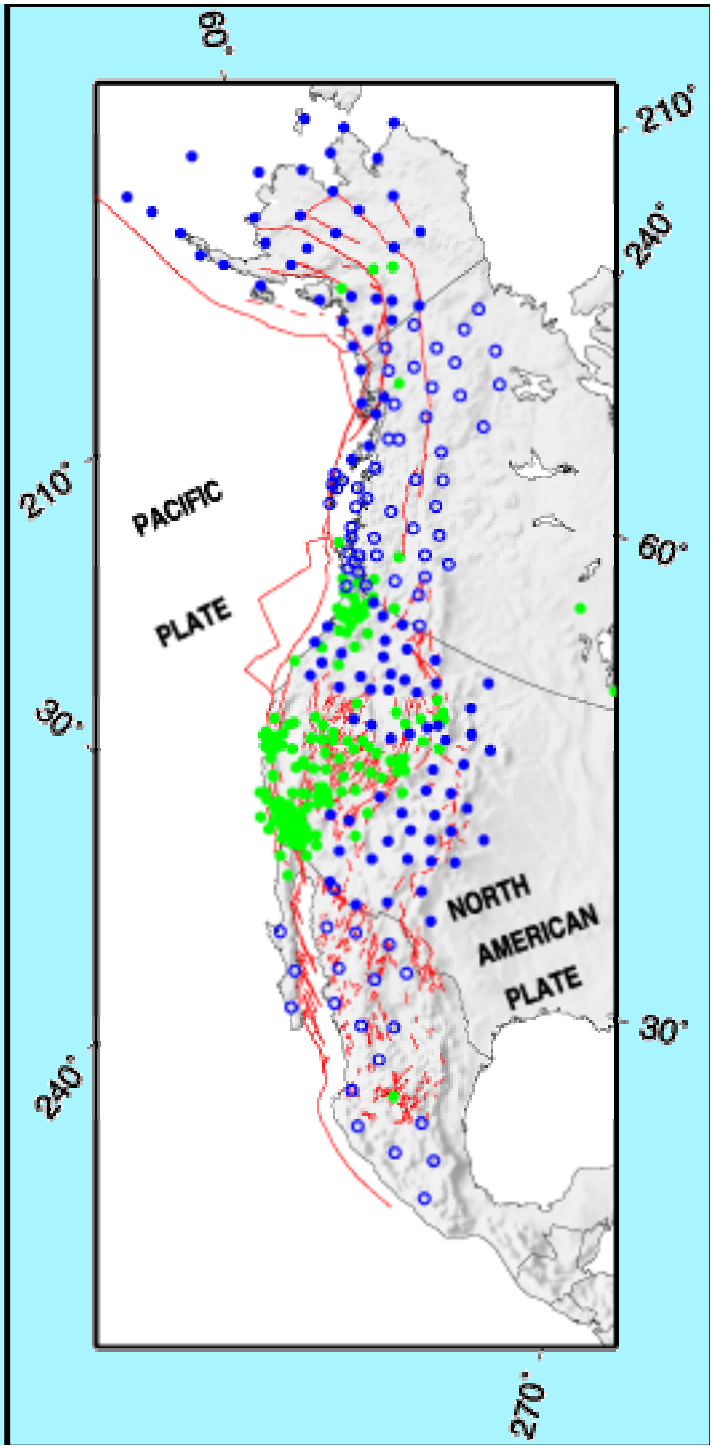
The Backbone will:



GPS Backbone; The Big Picture

The Backbone will:

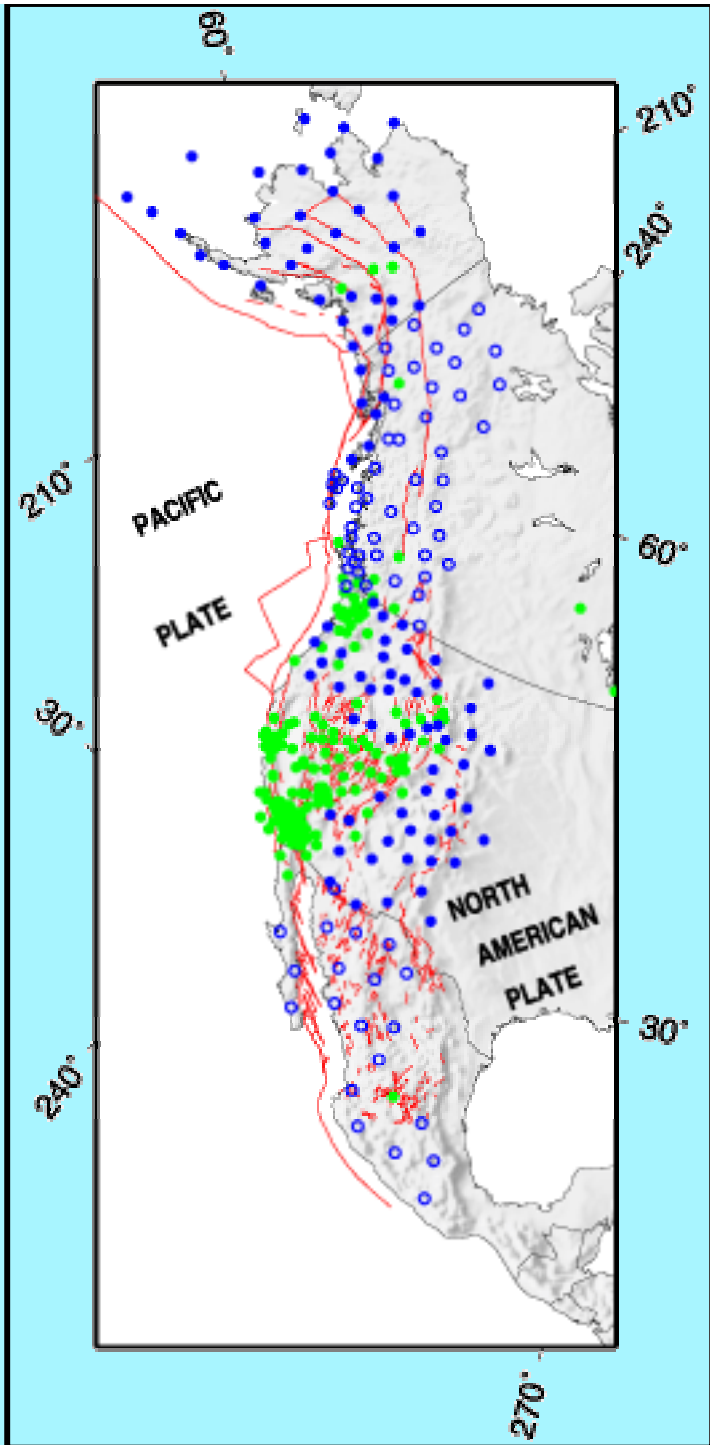
- **Extend from west coast to eastern edge of Rocky Mountains, and from Alaska to Mexico (with international collaboration).**



GPS Backbone; The Big Picture

The Backbone will:

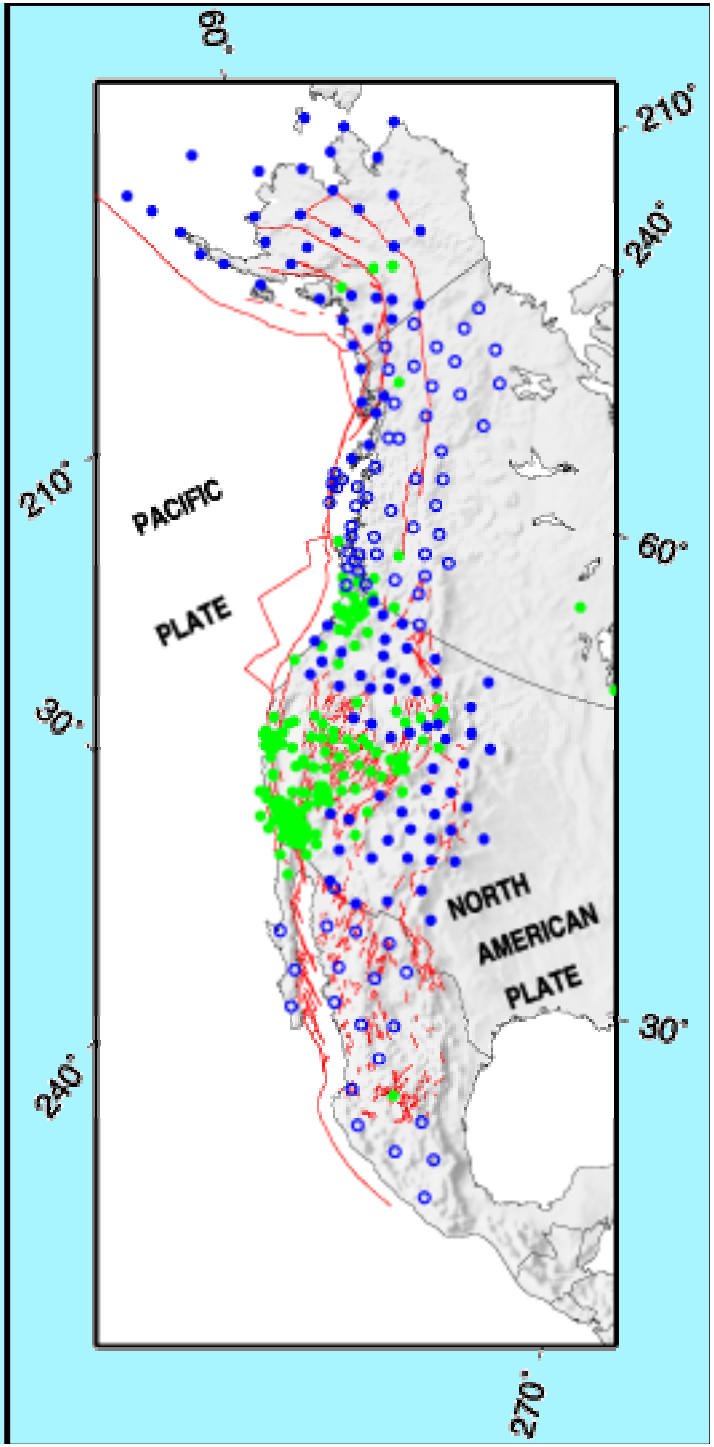
- Extend from west coast to eastern edge of Rocky Mountains, and from Alaska to Mexico (with international collaboration).
- Consist of ~100 continuous GPS receivers at 200 km spacing.



GPS Backbone; The Big Picture

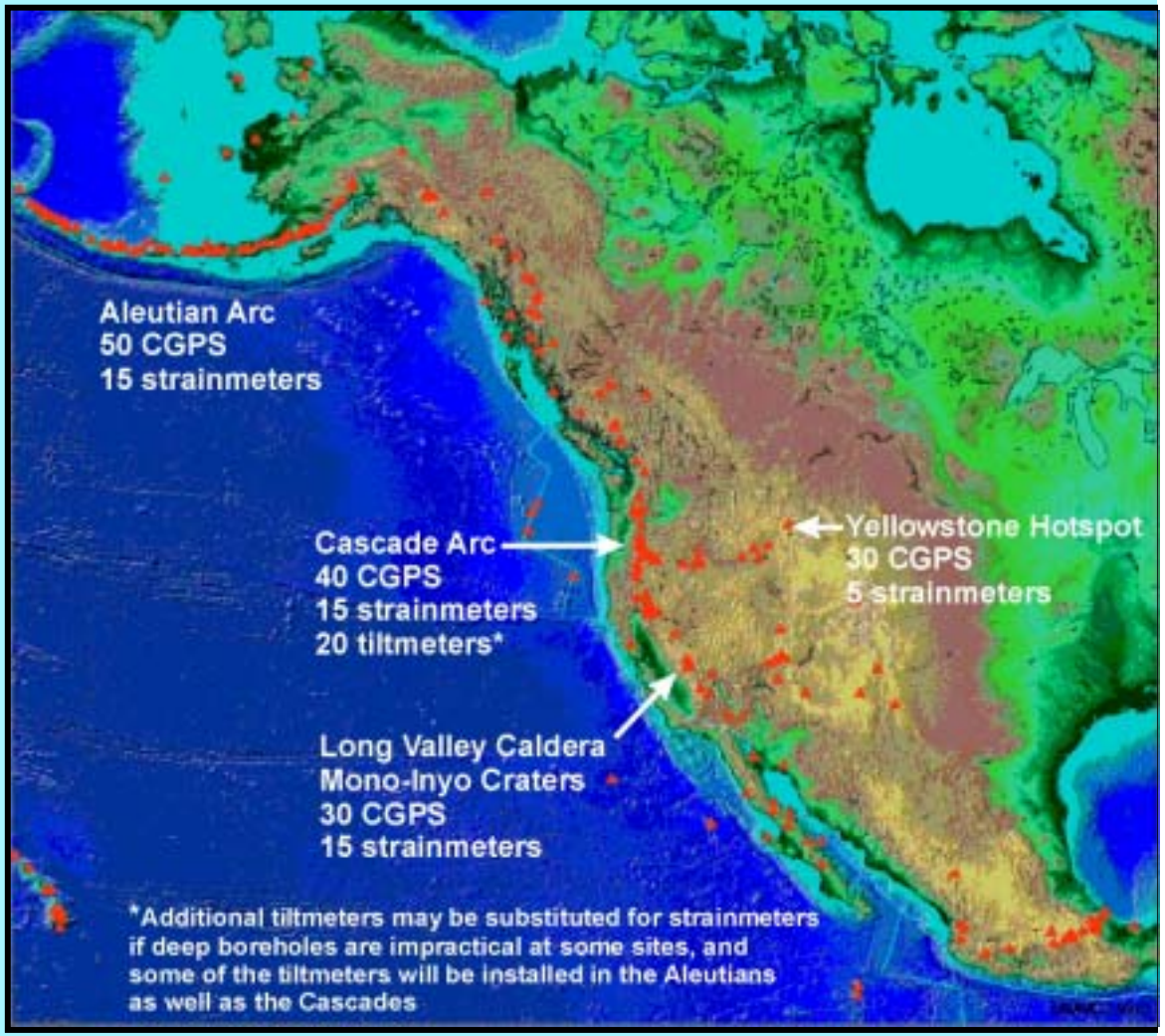
The Backbone will:

- Extend from west coast to eastern edge of Rocky Mountains, and from Alaska to Mexico (with international collaboration).
- Consist of ~100 continuous GPS receivers at 200 km spacing.
- Provide a synoptic view of North American plate boundary deformation.



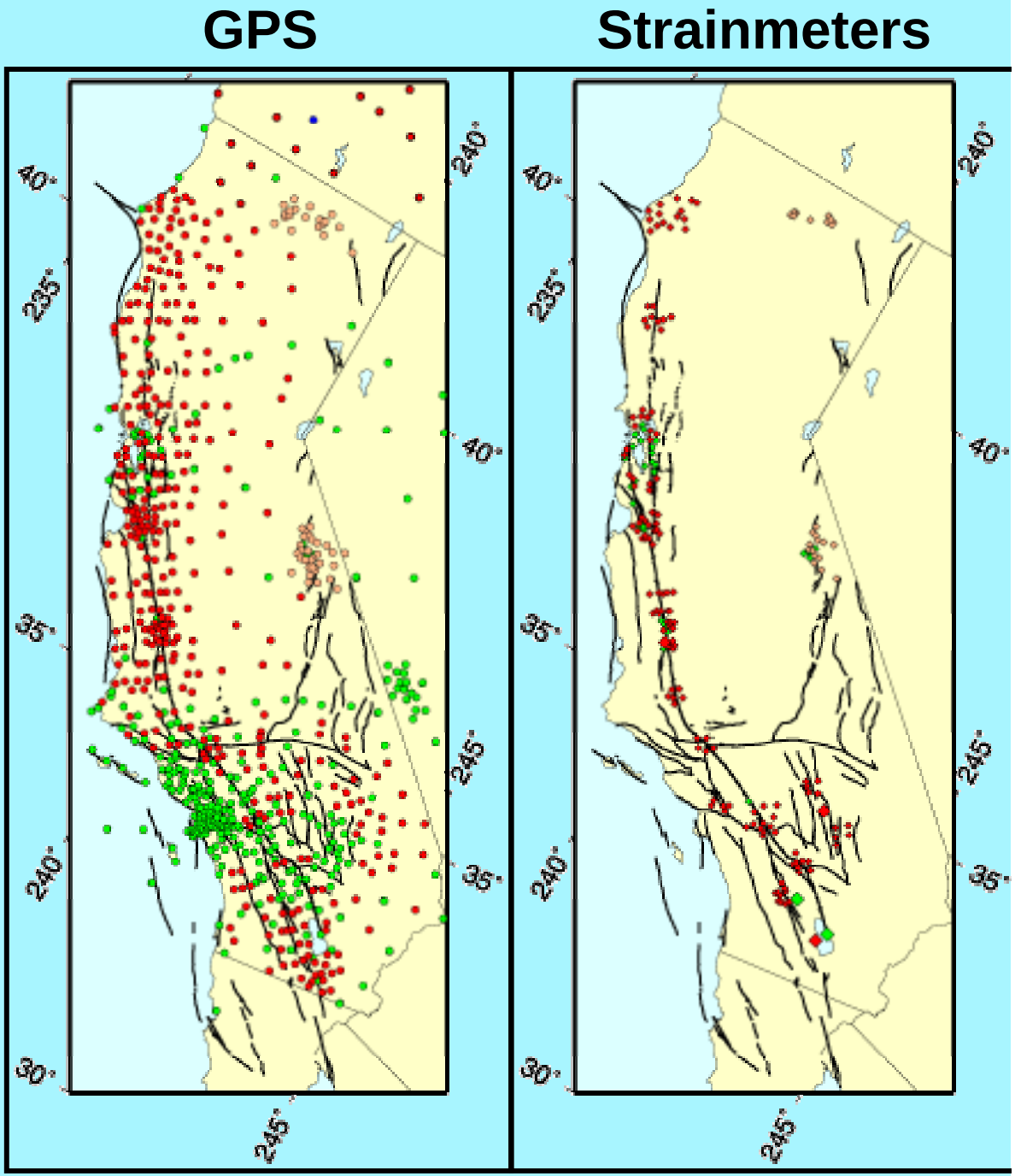
PBO Deployment Plan for Magmatic Systems

- **What are the dynamics and kinematics of magma rise, inrusion, and eruption?**
- **How do the temporal and spatial scales of deformation vary with eruptive style and magma type?**
- **Can the deformation that leads to an eruption be characterized?**



The San Andreas Fault System – A Natural Laboratory for Studying Earthquake Physics

- What determines the sequencing of seismic events?
- How do earthquakes nucleate?



SAFOD

San Andreas Fault Observatory at Depth

A comprehensive series of experiments aimed at:

SAFOD
San Andreas Fault Observatory at Depth

A comprehensive series of experiments aimed at:

- **Sampling fault zone materials and fluids**

SAFOD
San Andreas Fault Observatory at Depth

A comprehensive series of experiments aimed at:

- **Sampling fault zone materials and fluids**
- **Measuring a wide variety of physical properties**

SAFOD
San Andreas Fault Observatory at Depth

A comprehensive series of experiments aimed at:

- **Sampling fault zone materials and fluids**
- **Measuring a wide variety of physical properties**
- **Monitoring a creeping and seismically active fault zone at depth**

SAFOD

San Andreas Fault Observatory at Depth

SAFOD

San Andreas Fault Observatory at Depth

- **A 4-km-deep hole into the San Andreas fault zone**

SAFOD

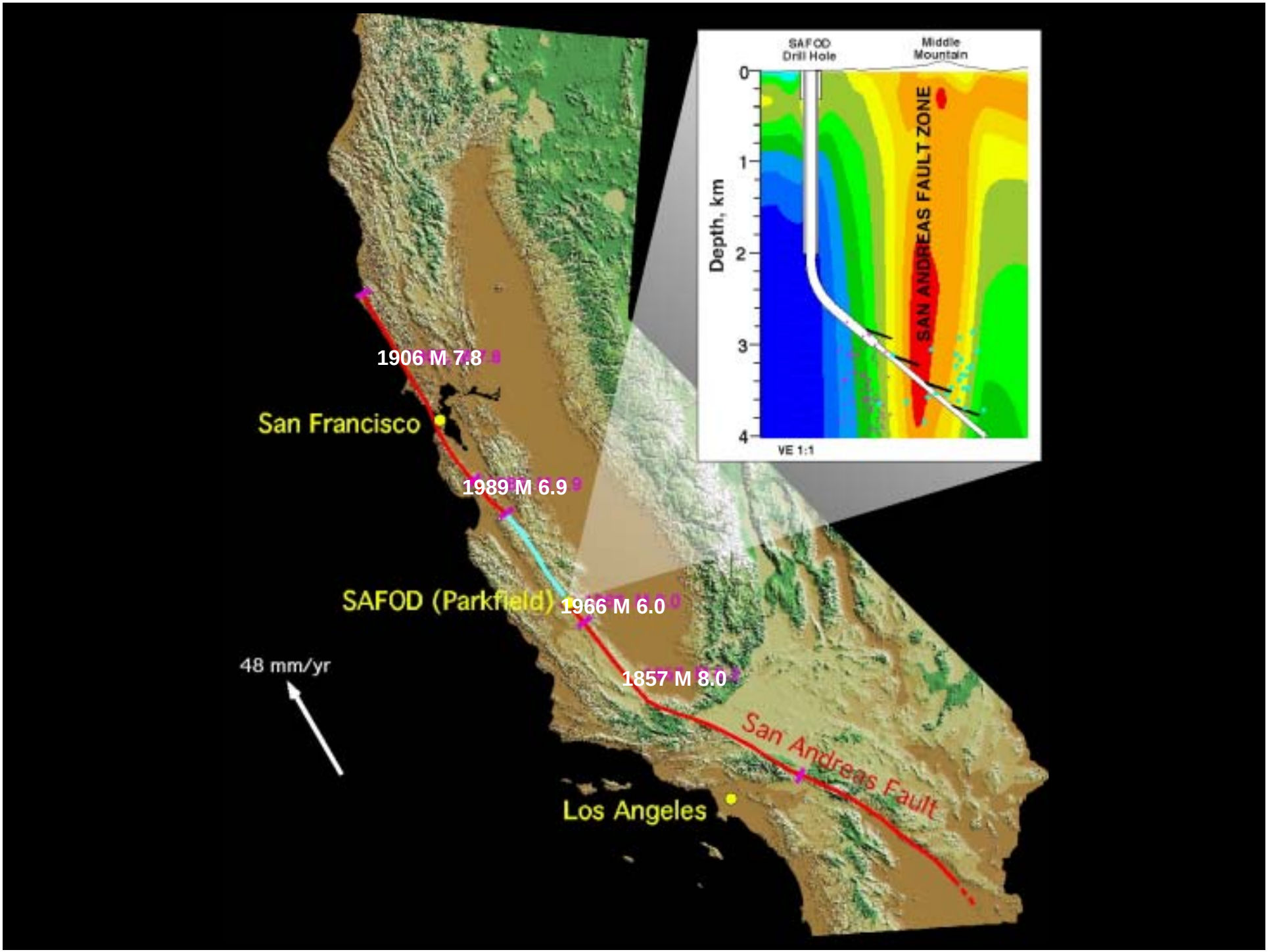
San Andreas Fault Observatory at Depth

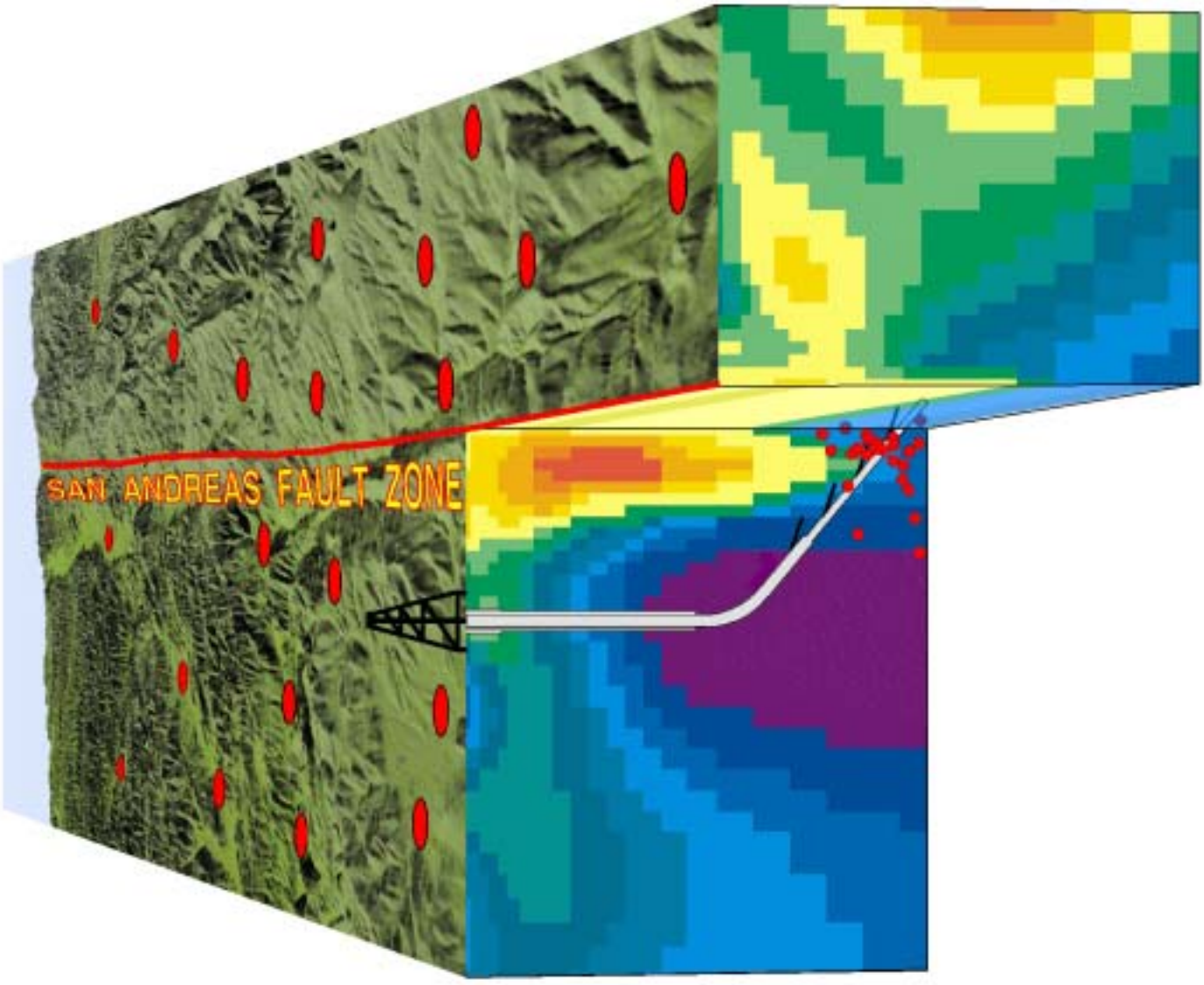
- A 4-km-deep hole into the San Andreas fault zone
- **Close to the hypocenter of the 1966 M~6 Parkfield earthquake**

SAFOD

San Andreas Fault Observatory at Depth

- A 4-km-deep hole into the San Andreas fault zone
- Close to the hypocenter of the 1966 M~6 Parkfield earthquake
- **Where the San Andreas slips through a combination of creep & small-to-moderate magnitude earthquakes**


SAFOD
Drill Hole
Middle
Mountain
0
1
2
3
4
Depth, km
SAN ANDREAS FAULT ZONE
VE 1:1
1906 M 7.8
San Francisco
1989 M 6.9
SAFOD (Parkfield)
1966 M 6.0
48 mm/yr
1857 M 8.0
San Andreas Fault
Los Angeles


SAN ANDREAS FAULT ZONE

InSAR will enable:

InSAR will enable:

- **Synoptic mapping of surface movements before, during and after earthquakes and volcanic eruptions**

InSAR will enable:

- Synoptic mapping of surface movements before, during and after earthquakes and volcanic eruptions
- **Imaging the time-evolution of active fault systems, providing unique insights into the mechanics of fault loading and earthquake rupture**

InSAR will enable:

- Synoptic mapping of surface movements before, during and after earthquakes and volcanic eruptions
- Imaging the time-evolution of active fault systems, providing unique insights into the mechanics of fault loading and earthquake rupture
- **Mapping strain accumulation across broad tectonic regions to identify zones of strain concentration, and to improve our understanding of crust and upper mantle rheology**

InSAR will enable:

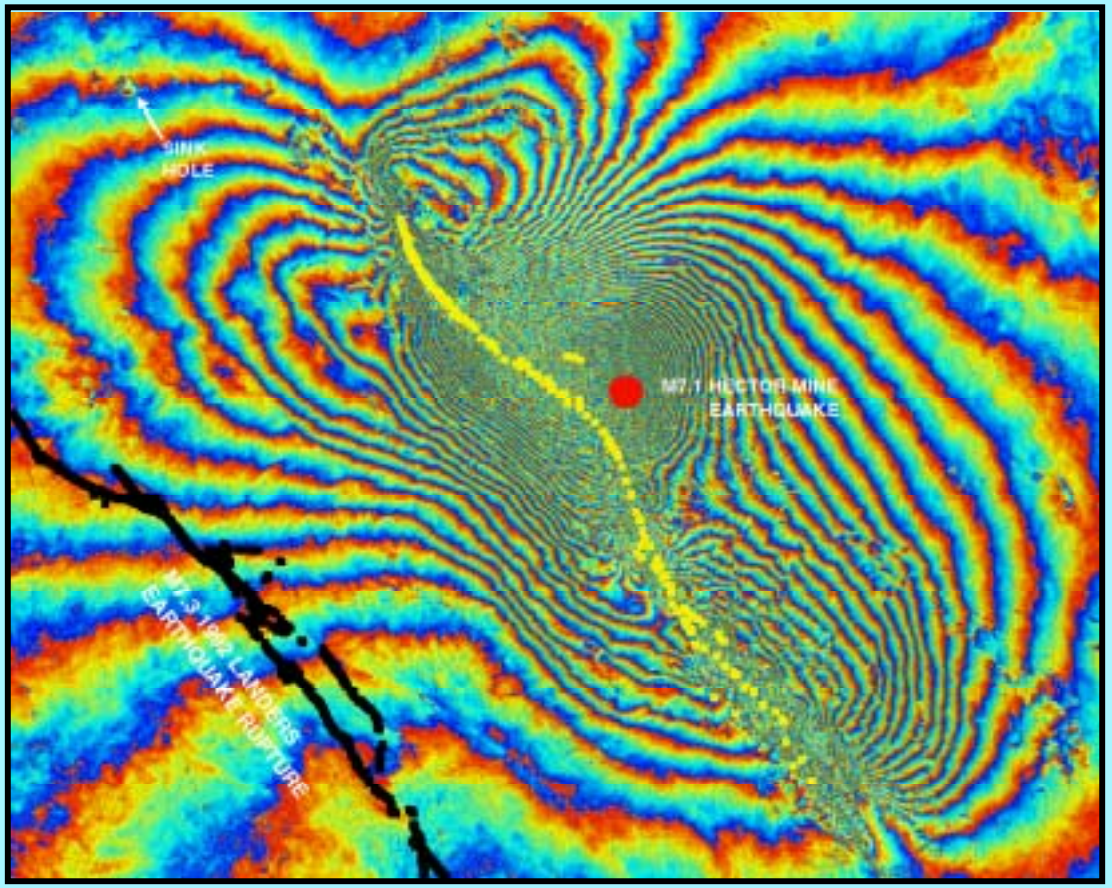
- Synoptic mapping of surface movements before, during and after earthquakes and volcanic eruptions
- Imaging the time-evolution of active fault systems, providing unique insights into the mechanics of fault loading and earthquake rupture
- Mapping strain accumulation across broad tectonic regions to identify zones of strain concentration, and to improve our understanding of crust and upper mantle rheology
- **Imaging the deformation of volcanic edifices to infer the nature of source zones and the dynamics of magma migration**

InSAR will enable:

- Synoptic mapping of surface movements before, during and after earthquakes and volcanic eruptions
- Imaging the time-evolution of active fault systems, providing unique insights into the mechanics of fault loading and earthquake rupture
- Mapping strain accumulation across broad tectonic regions to identify zones of strain concentration, and to improve our understanding of crust and upper mantle rheology
- Imaging the deformation of volcanic edifices to infer the nature of source zones and the dynamics of magma migration
- **All-weather mapping of surface change associated with a wide range of natural hazards**

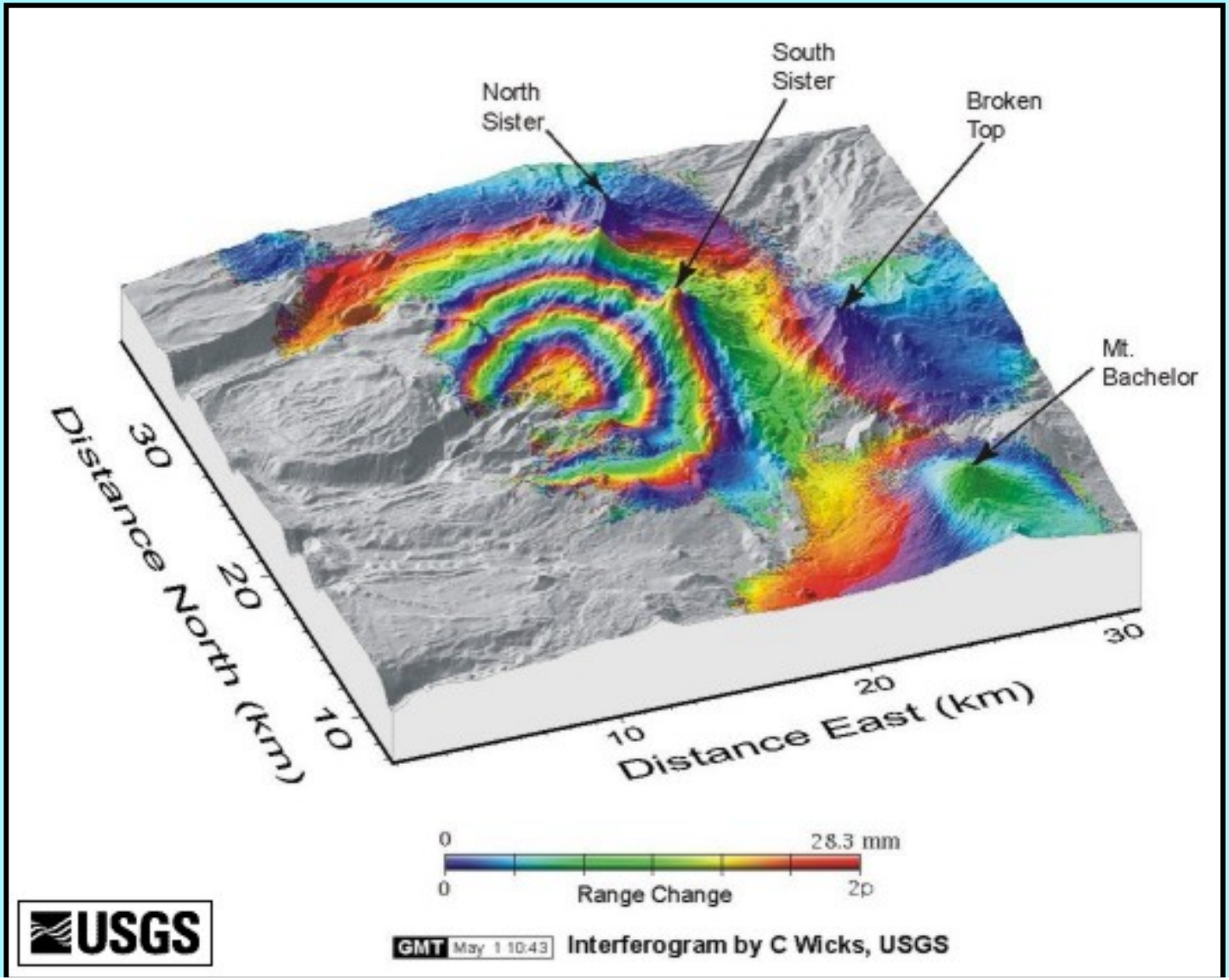
InSAR Image of the Hector Mine Earthquake

- A satellite-generated Interferometric Synthetic Aperture Radar (InSAR) image of the 1999 Hector Mine earthquake.
- Shows the displacement field in the direction of radar imaging.
- Each fringe (e.g., from red to red) corresponds to a few centimeters of displacement.



Uplift of the ground surface near the Three Sisters volcanoes, central Oregon Cascade Range

Occurred between 1996 and 2000; covers an area of 15 to 20 km in diameter with a maximum uplift at its center of about 10 cm



EarthScope Integration

EarthScope Integration

- **Structural Representation**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**
  - **Gravity and Electromagnetic Surveying**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**
  - **Gravity and Electromagnetic Surveying**
- **Kinematic (Deformational) Representation**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**
  - **Gravity and Electromagnetic Surveying**
- **Kinematic (Deformational) Representation**
  - **Geologic Structures**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**
  - **Gravity and Electromagnetic Surveying**
- **Kinematic (Deformational) Representation**
  - **Geologic Structures**
  - **Geochronology**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**
  - **Gravity and Electromagnetic Surveying**
- **Kinematic (Deformational) Representation**
  - **Geologic Structures**
  - **Geochronology**
  - **Geodesy (PBO and InSAR)**

EarthScope Integration

- **Structural Representation**
  - **Structural Geology Field Investigations**
  - **Seismic Imaging (USArray)**
  - **Gravity and Electromagnetic Surveying**
- **Kinematic (Deformational) Representation**
  - **Geologic Structures**
  - **Geochronology**
  - **Geodesy (PBO and InSAR)**
  - **Earthquake Seismology (ANSS)**

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)
  - Seismic Wave Propagation

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)
  - Seismic Wave Propagation
- **Structures Deformation Material properties Process (community models) Prediction**

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)
  - Seismic Wave Propagation
- **Structures⊗Deformation Material properties**
  Process (community models) Prediction

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)
  - Seismic Wave Propagation
- **Structures⊗Deformation⊗Material properties**
  Process (community models) Prediction

EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)
  - Seismic Wave Propagation
- **Structures⊗Deformation⊗Material properties = Process (community models) Prediction**

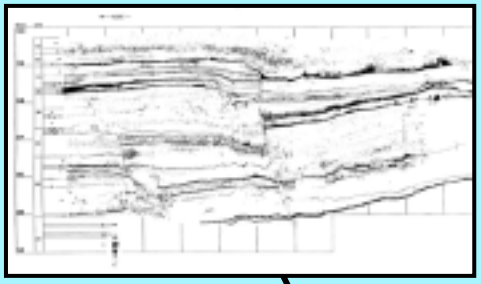
EarthScope Integration

- **Structural Representation**
  - Structural Geology Field Investigations
  - Seismic Imaging (USArray)
  - Gravity and Electromagnetic Surveying
- **Kinematic (Deformational) Representation**
  - Geologic Structures
  - Geochronology
  - Geodesy (PBO and InSAR)
  - Earthquake Seismology (ANSS)
- **Behavioral (Material Properties) Representation**
  - Subsurface Sampling (SAFOD)
  - Seismic Wave Propagation
- **Structures ⊗ Deformation ⊗ Material properties = Process (community models) → Prediction**

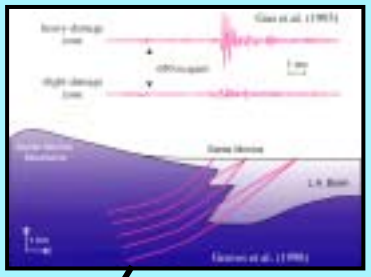
Seismic Hazard Model Ingredients

Seismicity

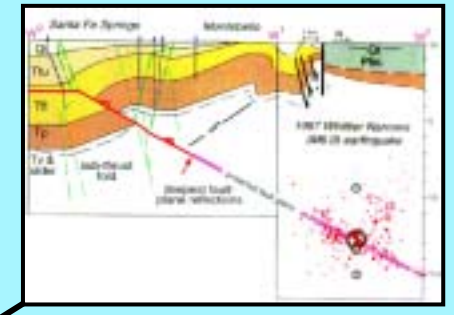
Paleoseismology



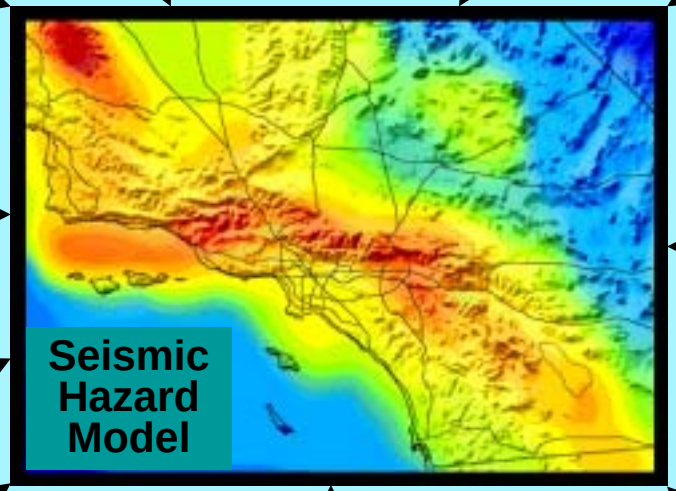
Local site effects

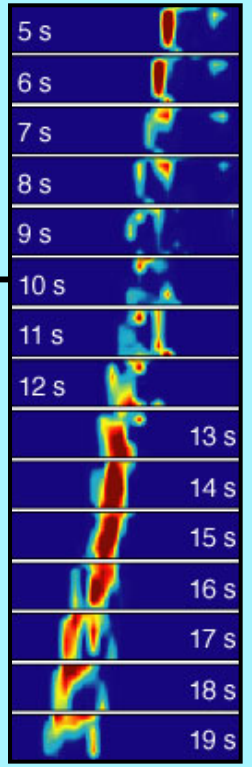


Geologic structure

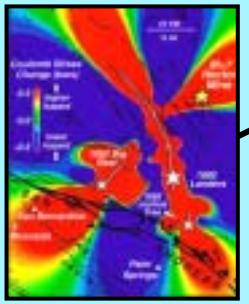


Faults

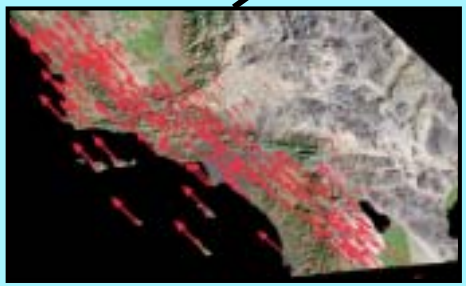




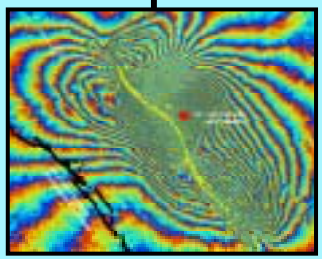
Rupture dynamics



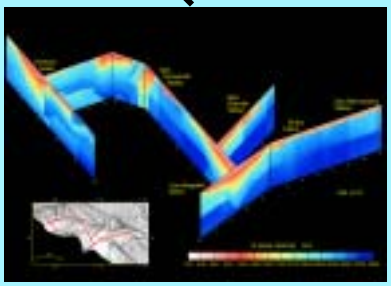
Stress transfer



Crustal motion



Crustal deformation



Velocity structure

EarthScope as an NSF/EAR Facility

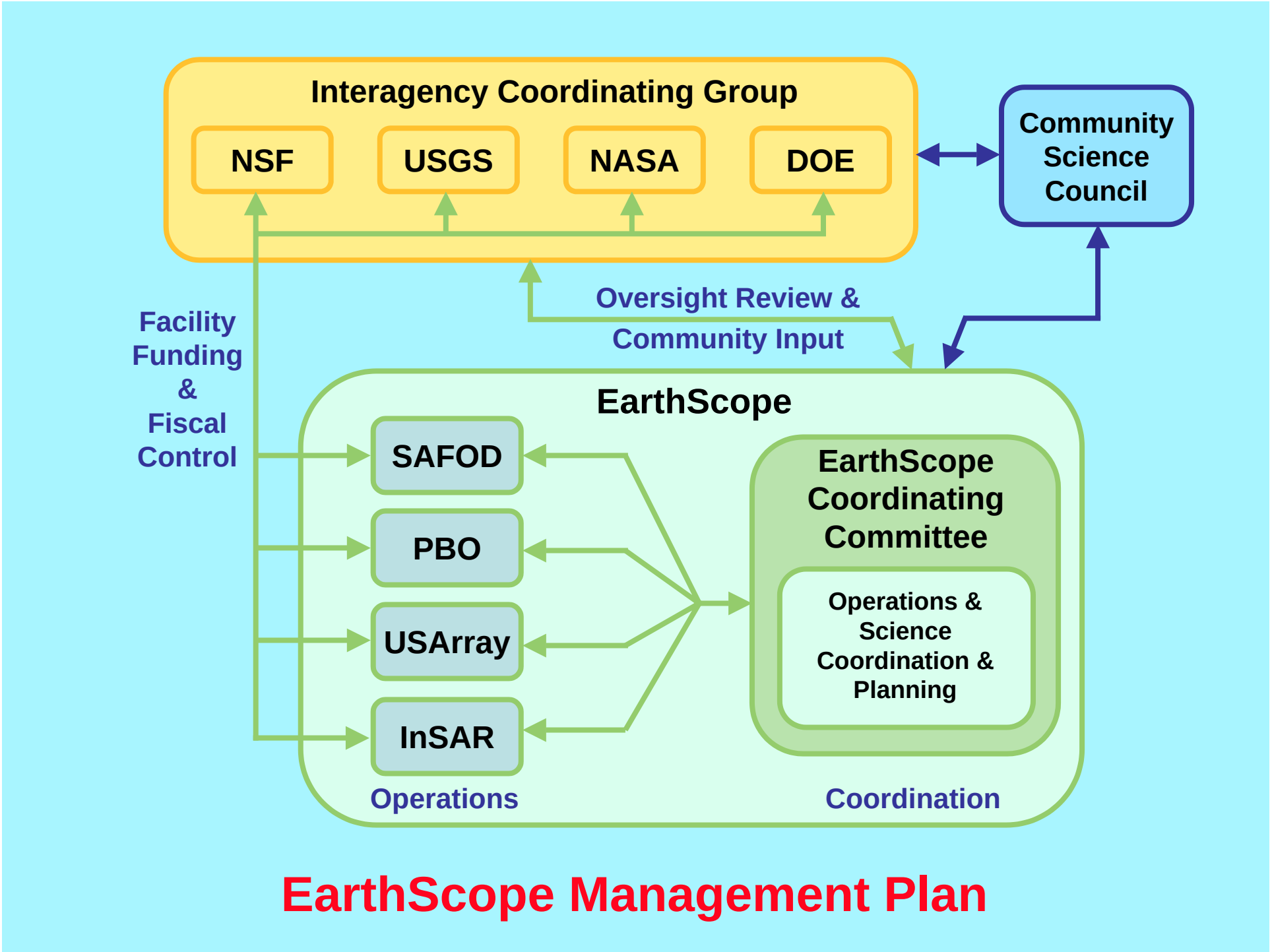
- Goal
  - Data in support of EAR science goals
    - Science directed
    - Community driven
    - Open access
- Product
  - Data
    - Science-appropriate
    - Cutting edge technology
    - Free and open access
    - Quality control

- Management Plan
  - Oversight and governance
    - Coordination and balance
  - Equipment Acquisition
    - Specification
    - Procurement
    - Inventory and control
  - Operations
    - Operation and maintenance
    - Data management
    - Technology R&D
  - Partnerships

EarthScope as an NSF/EAR Science Program

- Goal
  - Fundamental advances in geoscience
    - Science driven
    - Research based
    - Peer reviewed
- Product
  - Scientific results

- Management Plan
  - NSF open program announcement
    - Individual research grants
    - Collaborative research grants
  - Focused research
    - External research direction
    - Integrative research centers
  - Strong partnerships
    - USGS, NASA, DOE
    - State surveys
    - International



EarthScope Management Plan