

Plate Boundary Observatory

the first five years



Plate Boundary Observatory

A Continental-Scale, Integrated Geodetic

By the Numbers (2003–2008)

- Installed 891 permanent Global Positioning System (GPS) stations to monitor the active plate boundary between the North American and Pacific tectonic plates
- Integrated 209 existing GPS stations that were upgraded to EarthScope standards by the PBO Nucleus Project
- Installed 74 deep borehole strainmeters and 78 short-period borehole seismometers within the EarthScope footprint
- Installed five long-baseline laser strainmeters along the San Andreas Fault zone
- Installed 26 tiltmeters on active volcanoes in the western United States and Alaska
- Acquired over 5000 km² of high-resolution airborne LiDAR data
- Acquired over 36,866 InSAR scenes totaling 15 terabytes of data
- Maintained a pool of 100 portable campaign GPS instruments and supported over 50 related science projects
- Cumulative data return for the entire network exceeds 95%
- Collected and archived over 22 terabytes of PBO EarthScope data
- Provided over 2,000,000 data and product files to the scientific research community

The Plate Boundary Observatory (PBO) is the geodetic component of the EarthScope project, designed to study the 3-D strain field across the active boundary zone between the Pacific and North American tectonic plates in the western United States. Core instrumentation consists of a network of GPS receivers and strainmeters, coupled with aerial and satellite imagery. PBO data provide temporal constraints on plate boundary deformation that range from seconds to millennia. Results have improved our knowledge of the fundamental physics that govern deformation, faulting, and fluid transport in the earth's lithosphere. All PBO data are freely available to scientific and educational communities and to the public.



December 22, 2003
6.5M San Simeon earthquake and first GPS installation at P295 Chimney Rock Ranch

October 1, 2003
NSF awards contract to UNAVCO for PBO

September 28, 2004
6.0M Parkfield earthquake

June 29, 2005
First borehole strainmeter/seismometer installation

January 13, 2006
Augustine volcano erupts

June 7, 2007
600th GPS station installed in Priest Valley, CA

May 17, 2007
Borehole strainmeter/seismometer installations half-way complete

May 4, 2008
3rd Episodic Tremor and Slip event detected in Cascadia (also detected on September 6, 2005 and January 7, 2007)

2003

2004

2005

2006

2007

2008

PBO Components

Observatory



■ Permanent GPS Installations

UNAVCO installed 891 permanent and continuously operating Global Positioning System (CGPS) stations and integrated 209 PBO Nucleus stations, which were previously part of legacy GPS networks. Each GPS monument is deeply anchored to ensure high-quality measurements of station positions and velocities. CGPS stations are ideal for measuring volcanic and plate tectonic motions, strain accumulation on faults, earthquake surface displacement, and post-seismic deformation. These data provide constraints on fault zone behavior and the earthquake cycle on time scales of days to decades.



■ Borehole Strainmeters and Seismometers

UNAVCO installed 74 borehole tensor strainmeters (BSM) and 78 short-period borehole seismometers as part of PBO. BSMs measure subtle shape changes of an instrument cemented into bedrock and are highly sensitive to ground deformation at periods of minutes to months, bridging the sensitivity and frequency gap between seismic and GPS measurements. Observations from UNAVCO's borehole seismometers provide low-noise seismic data at depth in remote regions, which have been key in distinguishing wind noise from tremor in the Yellowstone caldera.



■ Long-baseline Laser Strainmeters

The Plate Boundary Observatory installed five long-baseline laser strainmeters (LSM) and took over the operation and maintenance of a legacy station that was built to similar specifications. LSMs use a laser to measure the change in the relative position of end monuments hundreds of meters apart. These very stable and high-precision instruments measure strain change from months to decades and are an important tool for cross-validating long-term GPS measurements and monitoring stored energy near a major fault.



■ Campaign GPS Instruments

PBO operates a pool of 100 portable GPS systems for stand-alone temporary or semi-permanent deployments. These instruments support densification of observations around key tectonic targets and are used for rapid response to volcanic and tectonic events.



■ Aerial and Satellite Imagery and Geochronology

GeoEarthScope included the acquisition of airborne LiDAR imagery for the detailed mapping of Earth's surface, satellite InSAR imagery for the precise mapping of surface change during deformation events, and geochronology data to provide age constraints on prehistoric earthquakes and long-term fault offsets. Combined, these techniques allow the measurement of strain rates over broad time scales.

August 1, 2008

Colorado Rio Grande Rift
GPS Campaign begins

August 4, 2008

LiDAR surveys completed throughout
the western United States

September 30, 2008

PBO construction completed
on time and on budget

Future: New and unprecedented
opportunities for scientists and
students will arise from the long-
term acquisition of PBO data.

2009

2010

2011

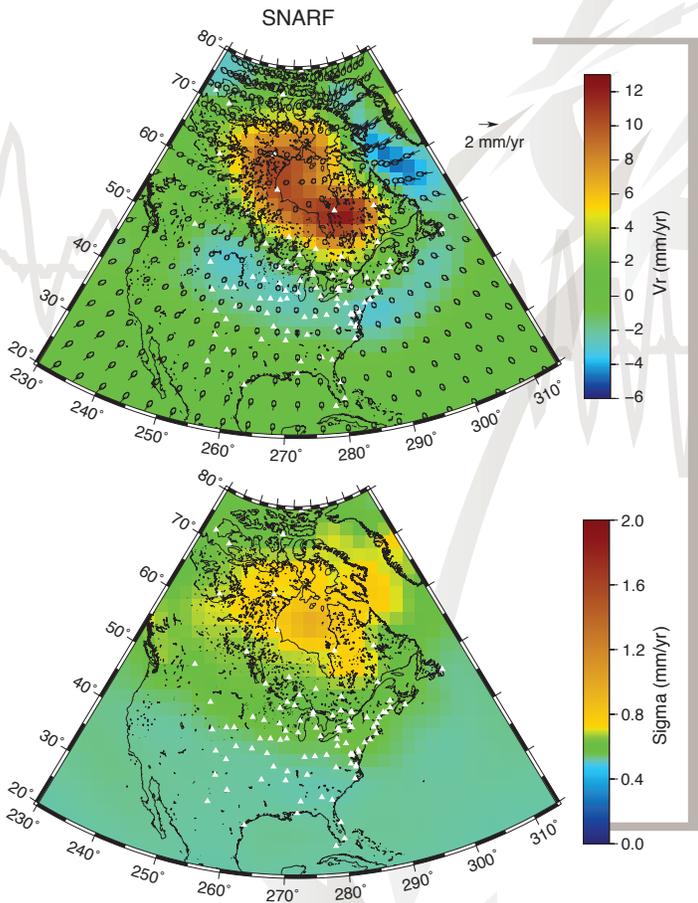
2012

2013

The Science and Discoveries of PBO

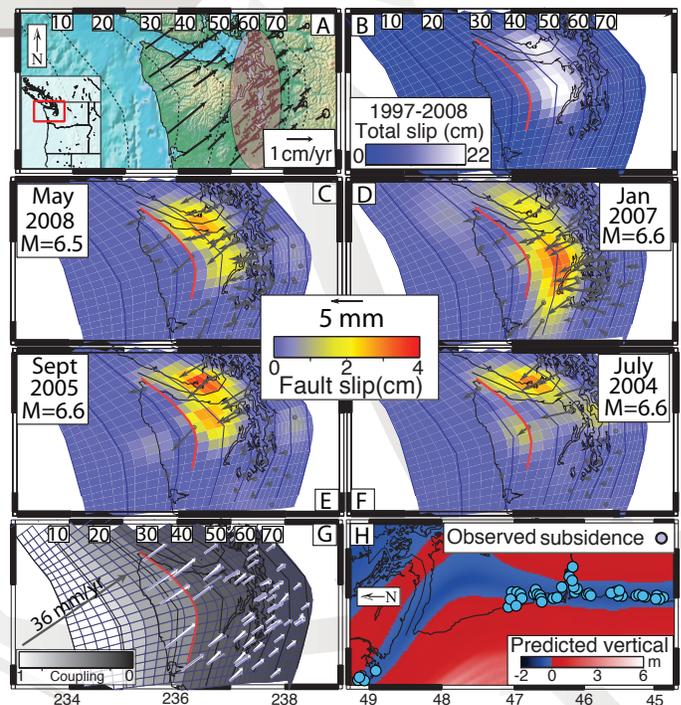
SNARF

The Stable North American Reference Frame (SNARF) working group has developed for PBO a regional reference frame that is fixed to the stable interior of the North American tectonic plate. SNARF was developed to help address questions of where relative plate motion is being accommodated, how deeply plate boundary dynamics penetrate into the plate interior, and the nature of non-rigid interior plate behavior such as mid-continent rebound and coastal subsidence from the last glacial retreat. SNARF provides a common frame by which to compare results from different analysis groups. It is anticipated that the National Geodetic Survey will adopt SNARF as the successor to the current North American reference frame (NAD83). The figure to the left shows the SNARF 1.0 velocity field adjusted for glacial rebound. *Blewitt et al. (2005)*

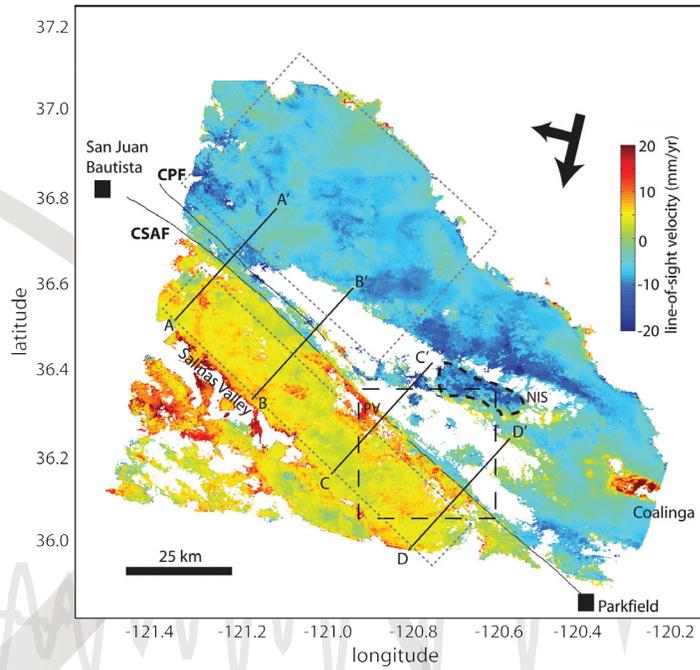


Episodic Tremor and Slip

Episodic Tremor and Slip (ETS), a process involving very slow slip and nearly silent tremors on deep subducting faults, was discovered in Cascadia by geodesists during the planning stage of EarthScope. PBO observations of surface deformation have been used to define areas where fault slip is released by ETS and to predict where strain accumulation will be released in the next great Cascadia earthquake, estimated to be of magnitude 9. Plot B in the figure to the right shows the total slow slip from ETS events in white. The red line marks the lower limit of seismogenic coupling, and the area to the west (or left) of the line is above the expected rupture zone for the next large earthquake. These results suggest that the next subduction zone earthquake will rupture farther inland than previously thought, closer to the large population area of the Puget Sound. *Chapman and Melbourne (2009)*



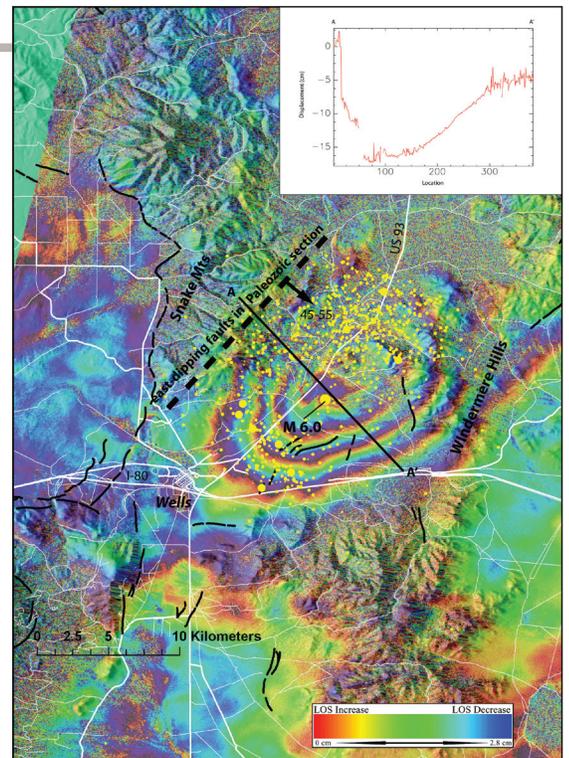
The Creeping San Andreas Fault



PBO data yield new information about the creeping section of the central San Andreas Fault. A creeping fault section does not store seismic energy that would otherwise contribute to large earthquakes. Sequential radar satellite passes were used to image the accumulation of slip along the fault (figure, left) to confirm that the creeping segment experiences almost full fault slip each year, nearly equivalent to the deep slip rate between the North American and Pacific plates. If the fault were locked, the seismic stress accumulation over 150 years would be sufficient to generate a M7.2 to M7.4 earthquake. To the north in the Bay Area, and to the south in Parkfield, more typical fault behavior shows an annual slip deficit reflecting stored seismic energy that will contribute to future earthquakes. The integrated and high-precision data from PBO have helped researchers observe these phenomena in unprecedented detail. *Ryder and Burgmann (2008)*

GeoEarthScope

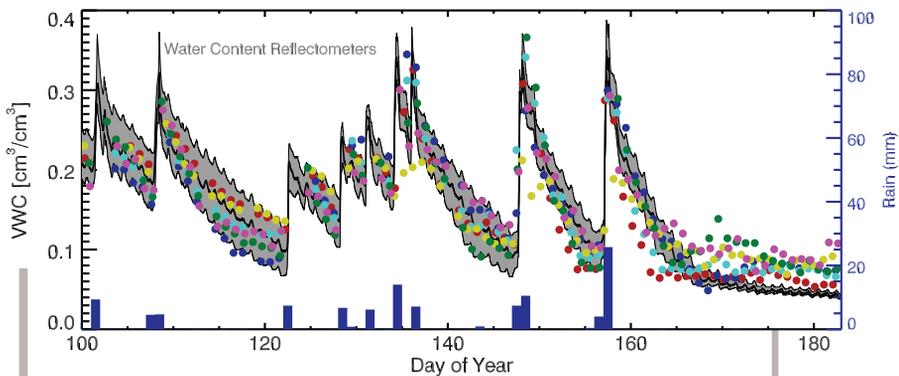
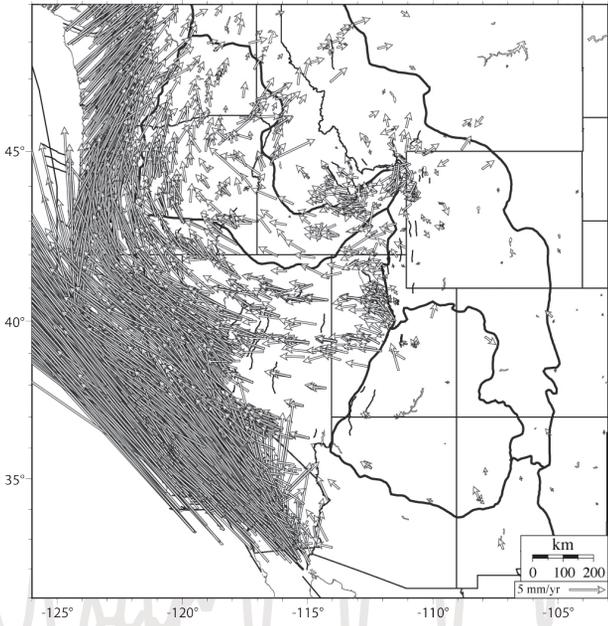
InSAR images acquired under PBO GeoEarthScope dramatically improved strain resolution and coverage of the 3-D deformation field in the western United States. The InSAR interferogram at right was generated using GeoEarthScope data and shows surface deformation associated with the Wells, Nevada, earthquake of February 21, 2008. InSAR data were used to determine the extent and location of the ruptured southeast-dipping fault bounding the eastern flank of the Snake Mountains, and the pattern of uplift and subsidence caused by the earthquake. The Wells earthquake was typical of others in the Basin and Range of the United States. *Amelung and Bell (2008)*



Envisat Track 127 Frame 2781 Descending Orbits 28738-31744
8/29/2007-3/26/2008

Geodynamics

Many graduate students use PBO data in their research. For her PhD thesis, Christine Puskas integrated PBO Global Positioning System (GPS) data with other observations to create a snapshot of annual surface motion due to faulting and volcanic deformation in and around Yellowstone caldera (figure, left). In 2004, the caldera began to uplift and subside without accompanying earthquakes due to the accumulation and migration of fluids derived from a magma reservoir that is tens of kilometers deep. Puskas' work revealed the contributions of volcanic forces, fault and plate boundary motions, and the gravitational force of high-standing mountain ranges to the GPS-determined regional deformation. *Puskas and Smith (2009)*



Soil Moisture

PBO data are being used in applications that reach beyond understanding the deformation of the solid earth. Kristine Larson and her colleagues at the University of Colorado at Boulder used GPS signal reflections (which are a source of unwanted noise in geodetic applications) to measure near-surface soil moisture and its change with time. Soil moisture observations are critical for weather and climate forecasts, both to improve agricultural yields and to mitigate the impact of drought and extreme weather events. A GPS-based soil moisture network would complement planned satellite soil moisture missions, providing thousands of calibration points across the globe. At a PBO station in Marshall, Colorado, the reflected GPS signals (colored dots in figure, above) show a strong correlation with in situ soil moisture measurements (gray band); both display soil drying after discrete rainfall events (blue bars). *Larson et al. (2008)*



People Make it Happen

The construction of the Plate Boundary Observatory, on time and on budget, was a result of the combined efforts of a large group of talented, dedicated, and enthusiastic people: professionals who managed the program and implemented outreach activities; field staff who provided siting, reconnaissance, and installation; many members of the scientific community who volunteered their time to make sure the scientific goals of PBO were met; private, state, and federal landowners who allowed stations to be installed on their property; numerous vendors who provided drilling and helicopter support; contracting officers and purchasing agents who acquired critical equipment and services; accounting staff who provided payroll and budget services; and data-delivery and data-quality analysts and software developers who built tools for public data access. These efforts led to the successful construction, acquisition, and transition to the operations and maintenance of 1100 Global Positioning System stations, 74 borehole strainmeters, 78 seismic systems, 26 tiltmeters, six long-baseline laser strainmeters, and delivery of over 22 terabytes of instrument and imagery data.



The PBO Facility



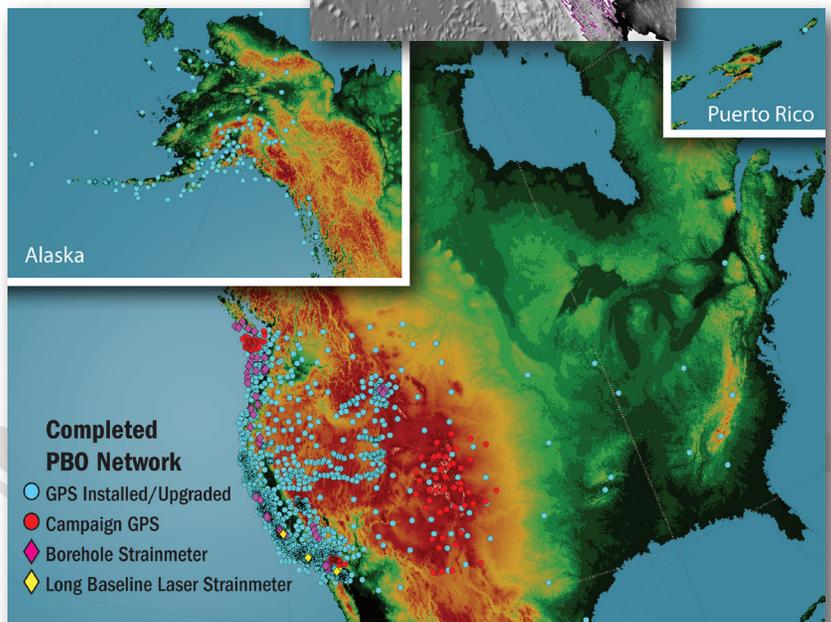
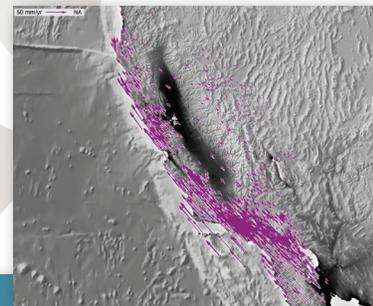
Sponsored by NSF



The National Science Foundation has supported many researchers and students through EarthScope's Plate Boundary Observatory. Scientific advancements resulting from this support include the identification of multiple Episodic Tremor and Slip events in the Cascadia subduction zone, the identification of strain transients along the creeping segment of the San Andreas Fault, and the recording of multiple eruptive episodes at active volcanoes in the United States. One such volcano, Alaska's Augustine volcano, erupted in January of 2006.

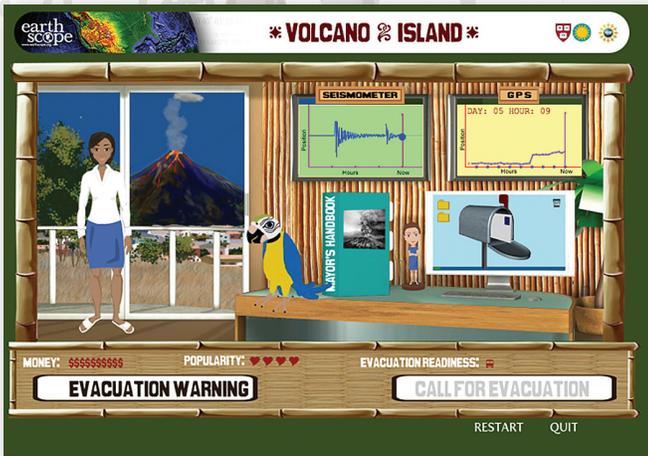
Data For Research and Education

Quality-controlled data and data products from all PBO instruments are openly available to the scientific research and education communities and to the public through NSF-supported data archives, including the UNAVCO Data Management Center, the IRIS Data Management Center, and the Northern California Earthquake Data Center. The large PBO data holdings encourage new data processing approaches and data analysis techniques, as well as integration of Global Positioning System, seismic, and strainmeter data sets. The near real-time availability of PBO data and rapid data processing capabilities enhance sharing of results among scientists. This open data access promotes deeper collaborations within the earth science community and provides essential next-generation opportunities for student research.



Education

Reaching Out to the Public



EarthScope data are being used by researchers, students, and educators to learn more about earth science and our active Earth. Volcano Island (<http://www.cfa.harvard.edu/earthscope/>) is an interactive computer game developed by the Harvard-Smithsonian Center for Astrophysics to engage and enlighten young people about EarthScope-related science, people, and projects. In the game, the user takes on the role of mayor for the fictional Volcano Island, home to the rumbling Mt. Leakytop volcano. The mayor must decide when to evacuate the island using the information from EarthScope Global Positioning System (GPS) stations and seismometers. However, the mayor must simultaneously

keep the townspeople happy and the budget healthy. Along the way, animations and video clips of scientists from the EarthScope community provide insight into the mechanics of volcanic eruptions and how GPS and seismic data are collected and interpreted to understand volcanic activity.

Working with Educators

PBO data are not just for researchers. EarthScope supports and develops a variety of educational materials for educators and the general public. EarthScope holds teacher workshops for high school and undergraduate educators on how to access and use PBO data in the classroom. UNAVCO's Data for Educators Web page (http://www.unavco.org/edu_outreach/data.html) presents data, activities, and lesson plans in a simple navigational format. EarthScope Voyager Jr. (<http://jules.unavco.org/VoyagerJr/EarthScope>) is an interactive online map tool that allows users to create visualizations of EarthScope data along with geological features, such as plate tectonic boundaries, locations of volcanoes and calderas, and earthquake focal mechanisms. EarthScope is developing materials for the Active Earth Display, a touch-screen kiosk intended for museums and public areas, which will teach the public about EarthScope in the Pacific Northwest and the Basin and Range.



A screenshot of the UNAVCO Data for Educators website. The page features a navigation menu on the left, a main content area with sections like 'GPS data that show...', 'tectonic plates moving', 'movement on different sides of a fault', 'rebound of plates after an earthquake!', and 'movement on a subduction zone'. A map of the Pacific Northwest and Basin and Range region is shown on the right, with several GPS stations marked. The bottom right corner contains a 'General GPS Education Materials' link.

About earth scope

EarthScope is a set of integrated and distributed multipurpose geophysical instruments that provide observational data to significantly enhance our knowledge of the structure and evolution of the North American continent and the processes controlling earthquakes and volcanic eruptions. Three components being implemented in parallel define EarthScope:

- The **Plate Boundary Observatory** is a network of geodetic and strain instrumentation that is imaging fast and slow deformation in the lithosphere along the western United States and Alaska.
- **USArray** is a dense network of permanent and portable seismographs and magnetotelluric sensors that are being installed across the continental United States to record earthquakes and naturally occurring variations in Earth's electric and magnetic fields.
- The **San Andreas Fault Observatory at Depth** is a three-kilometer-deep hole drilled through the San Andreas Fault in an area between San Francisco and Los Angeles near Parkfield, California, that has ruptured seven times since 1857.



The EarthScope facilities were constructed under the National Science Foundation's Major Research Equipment and Facilities Construction account.



The Plate Boundary Observatory was constructed by UNAVCO for EarthScope with support from the National Science Foundation through the MREFC (EAR-0350028), relying on services provided with support from NSF and NASA under NSF Cooperative Agreement No. EAR-0735156.