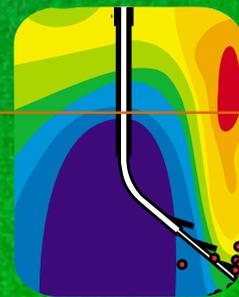
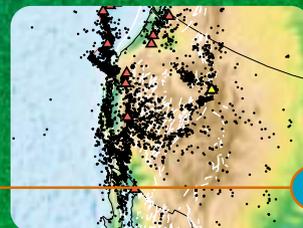
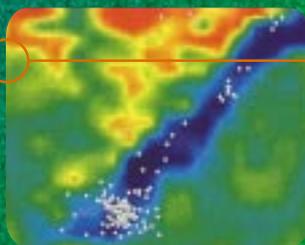
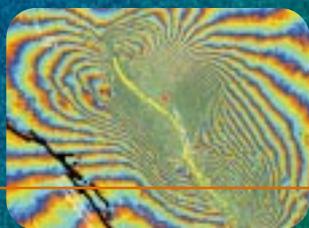


# A New View Into Earth



earth  
scope



**EarthScope** is a bold undertaking to apply modern observational, analytical and telecommunications technologies to investigate the structure and evolution of the North American continent and the physical processes controlling earthquakes and volcanic eruptions.

EarthScope will provide a foundation for fundamental and applied research throughout the United States that will contribute to the mitigation of risks from geological hazards, the development of natural resources, and the public's understanding of the dynamic Earth.

# overview

Geological processes create the rich fabric of our landscape, from the ancient, eroded Appalachian Mountains to the younger, rugged Rockies and the volcanoes of the northwestern Cascades. Most of us rarely think about the forces that formed the majestic beauty of our national parks or produced our bountiful natural resources. Only when earthquakes rattle communities or volcanoes darken the skies are we jarred into considering the great Earth forces that fashion the terrain upon which we live, work and play.

EarthScope is inspired by the need to address longstanding and fundamental questions about the forces that continue to shape our dynamic Earth. EarthScope's network of multipurpose geophysical instruments and observatories will significantly expand capabilities to observe the structure and ongoing deformation of the North American continent.

- Modern digital seismic arrays will produce three-dimensional images of North America's continental crust and the deeper mantle on which it "floats."



- Global positioning satellite receivers, strainmeters and new satellite radar imagery will measure and map the smallest movements across faults, the magma movement inside active volcanoes and the very wide areas of deformation associated with plate tectonic motion.
- An observatory deep within the San Andreas Fault will provide direct measurements of the physical state and mechanical behavior of one of the world's most active faults in a region of known earthquake generation.

EarthScope will combine these geophysical measurements with data and observations from all disciplines of the Earth sciences, permitting enhanced analyses. Improved understanding of the structures and processes that affect our environment will translate into better hazards assessment, more precise estimates of natural resource potential and a deeper appreciation of connections between different aspects of our physical environment.

# scientific rationale

The development of plate tectonic theory during the last half century has provided scientists with a framework for explaining the observed distribution of earthquakes and volcanoes, and the difference in age of the continents and ocean basins. Despite the elegance of this paradigm, gaps in our understanding of fundamental Earth processes remain. EarthScope's use of advanced instrumentation, high-performance computing and real-time data transmission will permit us to answer some of the outstanding questions by looking deeper, increasing resolution, and integrating diverse measurements and observations.

## Why do earthquakes and volcanic eruptions occur?

Scientists have made major progress in the past decade in understanding how fault rupture propagates on time scales of seconds to minutes, and how Earth deforms during an earthquake. We know that faults respond to stresses transmitted from hundreds of kilometers away. Improved understanding of why earthquakes occur and what controls their size requires measuring stress and strain over much broader regions of



Earth's surface, mapping how fault systems are connected at depth, and measuring the physical properties of an active fault in the zone where earthquakes originate. To capture the entire earthquake cycle requires making these measurements over decades or longer.

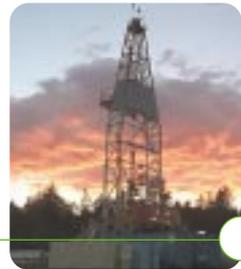
Our understanding of the inner workings of volcanoes, and what triggers eruptions, is similarly incomplete. Limited observations have provided views of short-term deformation leading up to eruptions at some volcanoes, but little is known about the long-term coupling between magma movement within volcanoes, and plate tectonic motion and regional stress fields. New combinations of measurements will clarify distinctions between normal "breathing" of a volcano and inflation prior to an eruption. Data collected over a decade or longer from clusters of precision strainmeters and seismometers, combined with satellite radar imagery, will permit the enhanced analysis required for informed assessments of volcano hazards and eruption prediction.



## How do continents form and evolve?

The continents are the most complex and diverse parts of Earth. The interiors of continents contain the oldest rocks and record the early formation and evolution of our planet. Plate tectonic theory provides a simple explanation for the age and complexity of the continents. Continental crust, which is lighter than oceanic crust, grows progressively outward by addition of new material over billions of years. To understand how Earth's mantle drives plate motion and how features at Earth's surface correlate with structural and compositional differences deep within the planet requires moving beyond simple plate theory to a new generation of data and models.

A dense network of semi-portable seismometers, moved across North America over ten years, combined with a diversity of data from geological experiments, will produce a coherent,



high-resolution, plate-scale image of Earth's crust and underlying mantle. These new observations will permit scientists to relate surface geology and detailed crustal structure to driving forces and thermal processes within the mantle, and to link structures inherited from earlier stages of continental formation and subsequent plate motion to known and potential geologic hazards.

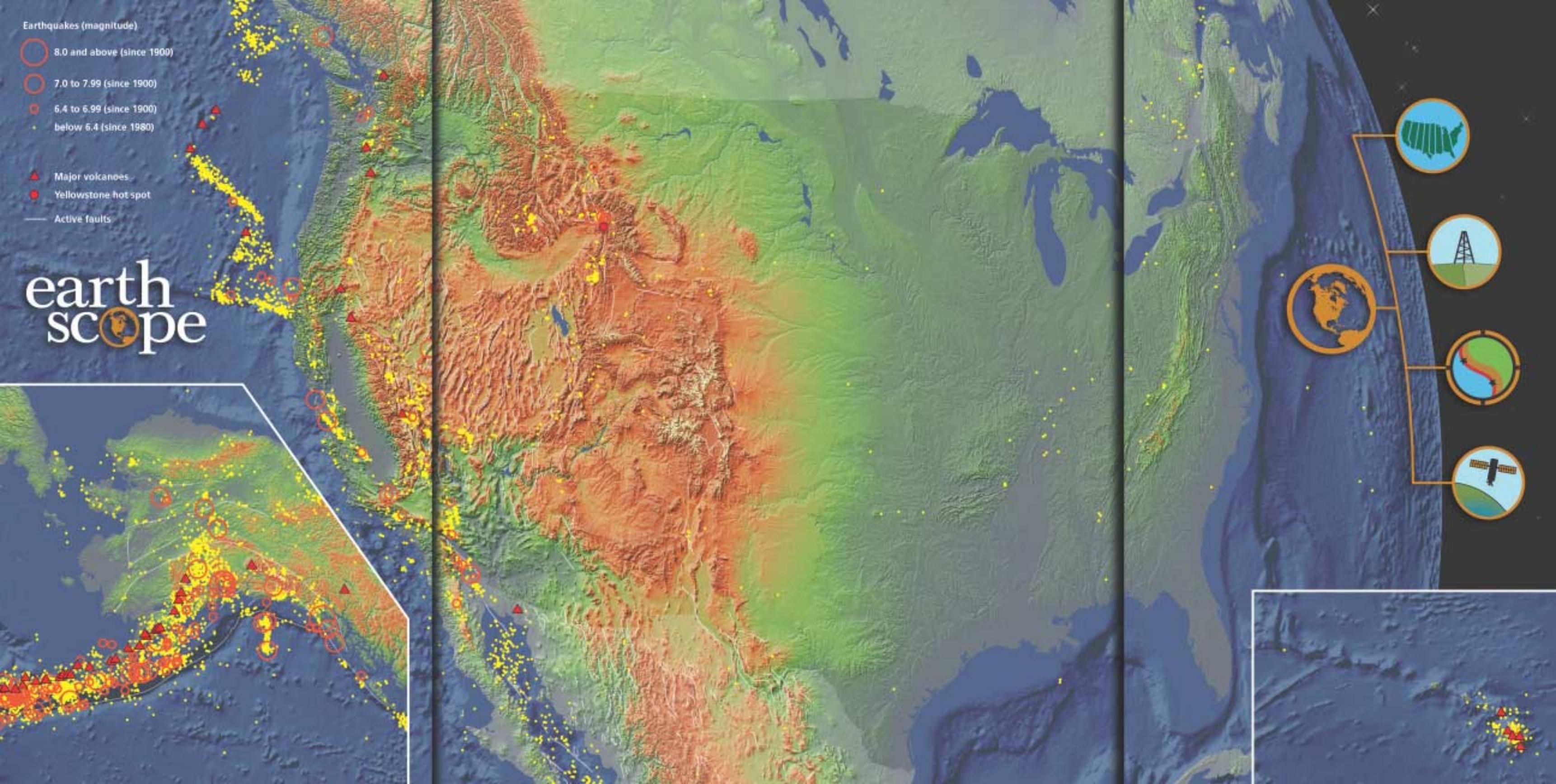
Seismic data recorded by these dense networks of instruments will also illuminate structures deep within Earth. They will provide new information on the nature of three-dimensional flow in the mantle and the transition from brittle fracture within the upper crust to ductile flow at greater depths. By probing all the way to Earth's center, EarthScope will also help unravel the structure and motions within the inner and outer core that give rise to our planet's magnetic field.

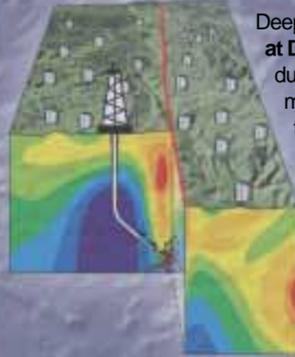
Earthquakes (magnitude)

- 8.0 and above (since 1900)
- 7.0 to 7.99 (since 1900)
- 6.4 to 6.99 (since 1900)
- below 6.4 (since 1980)

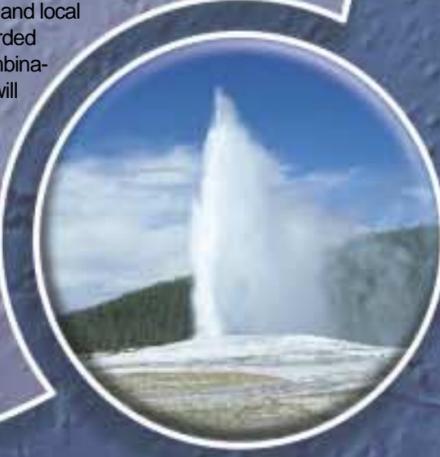
- Major volcanoes
- Yellowstone hot spot
- Active faults

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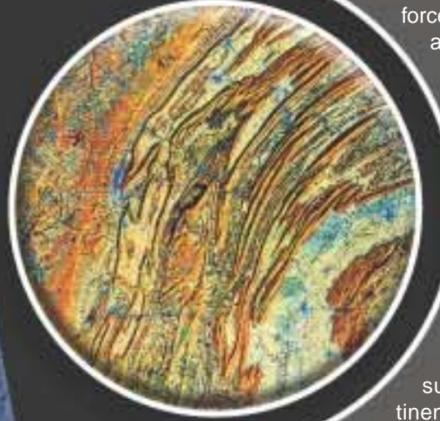
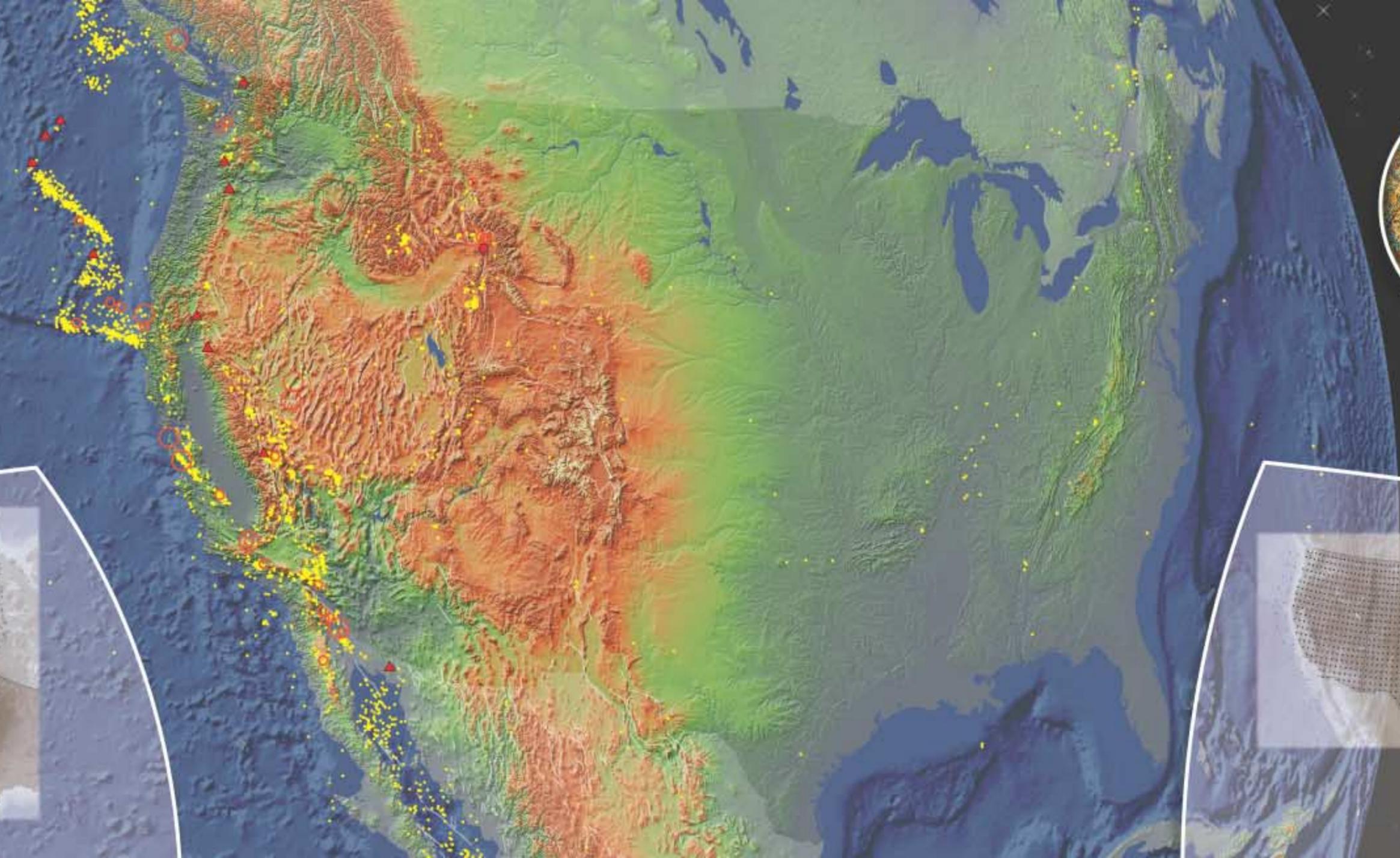


Deep within an active fault zone, the **San Andreas Fault Observatory at Depth (SAFOD)** will measure changes in rock properties before, during and after earthquakes. Linked to other EarthScope measurements at the surface, these direct observations will, for the first time, monitor how an active fault and its environment respond to regional and local changes in stress. Recorded over a decade, this combination of measurements will provide important new insights on earthquake nucleation and rupture.



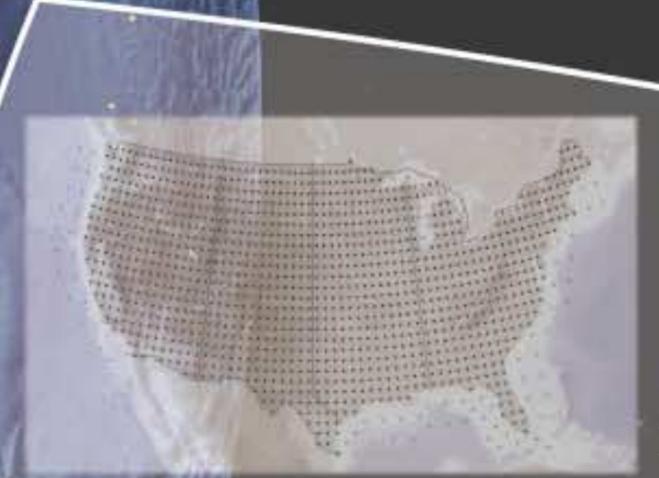
The backbone of the **Plate Boundary Observatory** is an array of permanent stations equipped with global positioning satellite receivers and strainmeters, extending along the western margin of North America from Mexico to Alaska.

In the conterminous US and Alaska, existing sites (orange) will be augmented with 800 new sites (black) to provide continuous observations at a spacing of approximately 150 km. Complete coverage of the plate boundary will require collaborative programs to install stations (gray) in Canada and Mexico. Clusters of additional instruments will be installed on volcanoes, along the San Andreas system and near other major faults, to provide increased resolution in areas of rapid deformation.



The face of North America reflects the variety of geological forces that have sculpted our continent. Active volcanoes and earthquake zones continue to shape the rugged and geologically young mountain ranges of Hawaii, many of the western states and Alaska. In the east, the remnants of old and eroded mountain ranges border the coastline, and scattered pockets of earthquake activity testify to the ongoing deformation of the continental interior. Written in the sediments and structures of the Great Plains is a complex history of even older cycles of deformation and erosion.

EarthScope will create a linked infrastructure for a continent-scale observatory of remote sensing geophysical instruments to probe deep beneath the surface, illuminate the underlying structure of the continent and help understand the processes that continue to build and change the North American continent.



At the core of **USArray** will be a transportable array of 400 instruments that will gradually roll across the entire US over a ten-year period, making observations for one to two years at some 2000 sites.

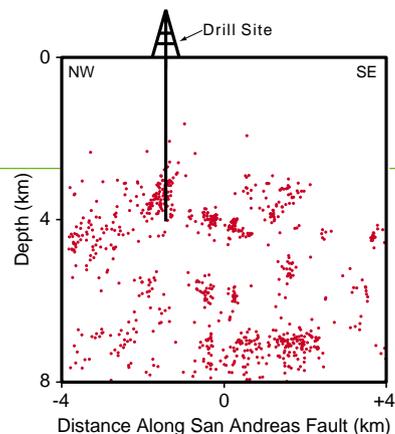
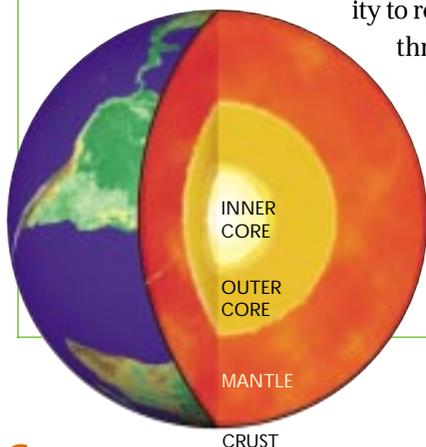
A permanent network of approximately 120 stations will provide long-term continuity, linking together data from the temporary deployments. Additional high-resolution instruments will permit special experiments in areas of particular geological interest.

# EarthScope components



## USArray (United States Seismic Array)

USArray is a dense network of portable and permanent seismic stations that will allow scientists to image the details of Earth structure beneath North America. Over the course of a decade, using a rolling deployment, a transportable array of 400 broadband seismometers will cover the continent with a uniform grid of 2000 sites. As the array moves across the country, 2000 additional sensors will support high-resolution investigations of key geological features. At some sites, special instruments will record electrical and magnetic fields to provide constraints on temperatures and fluid content within the lithosphere. In coordination with the US Geological Survey's Advanced National Seismic System, observatory-quality permanent stations will be installed to extend the temporal and spatial continuity of earthquake monitoring. By studying the recorded waveforms of hundreds of local, regional and global earthquakes, and large explosions from mines and quarries, scientists will be able to identify and map subtle differences in the velocity and amplitude of seismic energy traveling through Earth. These observations will result in a vastly improved ability to resolve geological structures throughout the entire crust and upper mantle and into Earth's deepest interior.



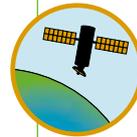
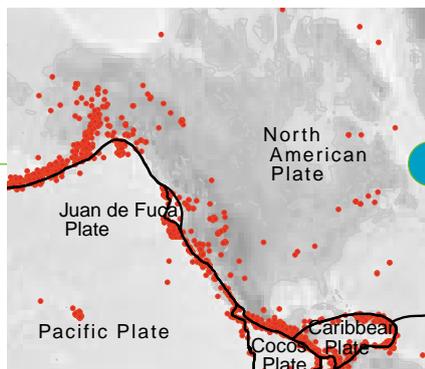
## SAFOD (San Andreas Fault Observatory at Depth)

SAFOD is a 4-km-deep observatory drilled directly into the San Andreas fault zone near the nucleation point of the 1966 magnitude 6 Parkfield earthquake. The project will reveal the physical and chemical processes acting deep within a seismically active fault. Initially, fault-zone rocks and fluids will be retrieved for laboratory analyses, and intensive downhole geophysical measurements will be taken within and adjacent to the active fault zone. The observatory's long-term monitoring activities will include decades of detailed seismological observations of small- to moderate-sized earthquakes, and continuous measurement of pore pressure, temperature and strain during the earthquake cycle. SAFOD will provide direct information on the composition and mechanical properties of faulted rocks, the nature of stresses responsible for earthquakes, the role of fluids in controlling faulting and earthquake recurrence and the physics of earthquake initiation and growth. Drilling, sampling, downhole measurements and long-term monitoring will allow testing of a wide range of hypotheses about faulting and earthquake generation, and the pursuit of a scientific basis for earthquake hazards assessment and prediction.



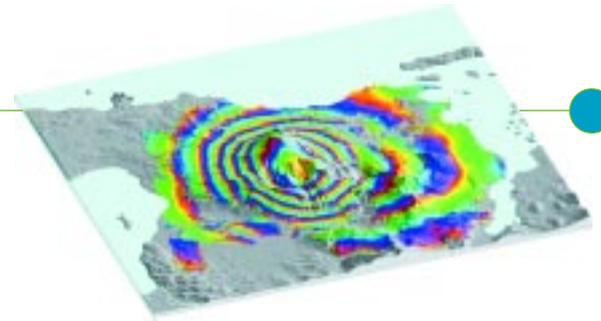
## PBO (Plate Boundary Observatory)

PBO is a distributed observatory of high-precision geodetic instruments designed to image the ongoing deformation of western North America. The geodetic network will extend from the Pacific coast to the eastern edge of the Rocky Mountains, and from Alaska to Mexico. Two complementary instrumentation systems—Global Positioning System (GPS) technology at about 1000 sites, and ultra-low-noise strainmeters at 200 locations—will provide superior time resolution. A sparse GPS network at 100-200 km spacing, connecting about 20 dense clusters located at active volcanoes and the most active earthquake faults, will provide complete spatial coverage. PBO will significantly improve our ability to image and characterize the slow deformation that accompanies earthquakes and volcanic events. These data will elucidate the poorly understood processes that precede earthquakes and volcanic eruptions, and could provide a firm basis for their prediction. The broad geographic coverage will permit quantitative understanding of tantalizing connections observed between activity in different regions. Complementary geological investigations will link present-day deformation to longer-term processes that have shaped the plate-boundary region.



## InSAR (Interferometric Synthetic Aperture Radar)

InSAR is a dedicated, science-driven satellite mission that will provide dense spatial (30 to 100 m) and temporal (every 8 days) measurements of the North American and Pacific plates as they move past each other and deform the surrounding regions. Precise comparisons of images acquired at different times (repeat-pass interferometry) can reveal differential horizontal and vertical motions accurate to 1 mm over all terrain types. This new radar imagery, in concert with PBO's continuous GPS and strainmeter measurements, will enable mapping of surface displacements before, during and after earthquakes and volcanic eruptions, providing insights into fault mechanics and earthquake rupture. InSAR will enable mapping of earthquake strain accumulation across broad, actively deforming zones, highlighting regions of highest risk for future earthquakes. InSAR will permit imaging of the location and migration of magma through a volcanic system that may lead to an eruption, and will also provide a tool for mapping subsidence induced by petroleum production and ground water withdrawal.



# anticipated results

As a large-scale national program, EarthScope can catalyze solid Earth science research and substantially contribute to our understanding of North American geology. The scientific and organizational structure underlying this multidisciplinary effort can serve as an umbrella for Earth science studies of continental structure, dynamics and evolution, and the deeper Earth.

Advances in facilities, techniques, theory and data integration have made, and will continue to make, dramatic progress possible. An exciting aspect of the EarthScope initiative is the prospect of unanticipated discovery, the unveiling of results and insights that we cannot yet imagine.



## EarthScope will ...

**unravel the structure**, evolution and dynamics of North America.

**probe the behavior** of active fault systems.

**study the details** of the earthquake nucleation and rupture process.

**advance our understanding** of natural hazards.

**explore the inner workings** of volcanoes, and magmatic processes leading to eruption.

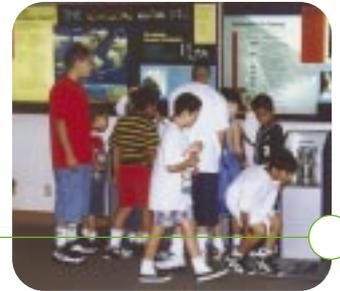
**investigate the relationship** between mantle structure and dynamics, and crustal tectonics, and between tectonics and fluids in the crust.

**stimulate the investigation** of entire geosystems through broad, integrated studies across the Earth Sciences.

**integrate observations and results**, manage vast arrays of data, and provide easy access to tools for manipulation and visualization of those data.

**build upon existing partnerships** between the academic Earth science community and many other organizations including NSF, USGS, NASA, DOE, regional seismic networks, state geological surveys and university consortia.

# benefits and applications



While EarthScope's principal scientific goal is to increase understanding of North America's structure, dynamics and evolution, the data to be collected through this initiative will have numerous practical applications and benefits.

## geological hazards mitigation

The plate boundary of western North America—the San Andreas fault system, the Cascadia and Aleutian subduction zones, and the Intermountain seismic belt—includes significant regions of earthquake, volcanic and landslide hazards. All EarthScope components will provide data that bear directly on the assessment and mitigation of the risks from these hazards. These data will advance our knowledge of the mechanics of volcanic eruption and earthquake generation, and increase the possibility of earthquake prediction.

## resource exploration and management

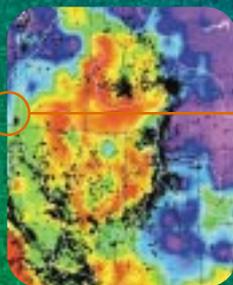
As USArray crosses the nation, there will be opportunities for EarthScope scientists to interact with federal and state agencies involved in regional mapping, education, public policy and resource assessment. The high-resolution component of USArray will be an important tool for probing the geological framework of the continental crust and the structural details of sedimentary basins. Subsurface maps, developed from various types of geological investigations and merged with high-resolution seismic images, will be an invaluable resource in collaborative and multidisciplinary research projects aimed at a wide range of topics related to the assessment and exploitation of groundwater, mineral and energy resources.

## education and outreach

With widespread public interest in earthquakes, volcanoes and the environment, a highly visible, science-driven initiative such as EarthScope is a natural vehicle to enhance Earth science education at all levels. Students will be encouraged to work with real data and participate in the exploration that underlies the EarthScope initiative. Outreach programs will engage communities as EarthScope facilities are established in different parts of the country. Involving the public in Earth science research will increase appreciation of how research can lead to improvements in understanding of the environment and a better quality of life.

EarthScope's outreach program will ...

- bring the goals and results of EarthScope to the public, locally and nationally, through use of a full spectrum of media, including the www, TV, museums and print;
- provide schools and museums with live feeds to data and products;
- develop educational materials to help integrate these data into standard curricula and special projects.



# earth scope

EarthScope is a partnership extending throughout the Earth science community, including more than 100 universities, the National Science Foundation, US Geological Survey, National Aeronautics and Space Administration, Department of Energy, regional seismic networks and state geological surveys.

This brochure was prepared by the EarthScope Working Group, April 2001. Editing and design by Geosciences Professional Services, Inc. Centerpiece map by Equator Graphics.

[www.earthscope.org](http://www.earthscope.org)