

Spring 2007

Episodic Tremor and Slip in the Pacific Northwest

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From The Principal Investigators

EarthScope's multi-disciplinary approach to improving our understanding of the structure and formation of continents and the physical processes that control earthquakes and volcanoes has spurred the development of new techniques for analyzing and interpreting many types of geophysical data. Throughout this issue, we highlight some of EarthScope's integrated activities.

In our science feature, two EarthScope researchers, Ken Creager of the University of Washington and Tim Melbourne of Central Washington University, collaborated to present some of their ongoing work on Episodic Tremor and Slip in the Pacific Northwest. These events, also referred to as 'slow earthquakes,' occur with an amazing degree of predictability. The most recent event took place in January 2007 and was recorded by EarthScope seismometers and strainmeters. Installation of instruments in harsh and sensitive environments poses unique challenges and we describe on page 4 the special GPS monument used in Alaska. Another article provides an overview of the EarthScope National Meeting held earlier this year in Monterey, California. In conjunction with this meeting, a special workshop was conducted for middle and high school teachers to introduce them to EarthScope and to improve their foundation in geophysics. We also report on the completion of the first EarthScope component, the Permanent Array, and announce a new web-based tool that displays when and where future Transportable Array stations will be installed and allows the user to suggest a specific location for an Earthquake Monitoring Station. Updates on the progress of the Transportable Array and the Plate Boundary Observatory are presented in this and every issue of onSite.

We value your continued interest in EarthScope. If there is a topic of special interest to you, please let us know by contacting one of the EarthScope onSite editors (USArray: dorr@iris.edu or PBO: eriksson@unavco.org).

David W. Simpson
USArray Principal Investigator

Michael E. Jackson
Director, Plate Boundary Observatory

featured science:

Episodic Tremor and Slip in the Pacific Northwest

Every 14 months the Pacific Northwest experiences slow slip on a fault that is the equivalent of about a magnitude 6.5 earthquake. While a typical earthquake of this magnitude happens in less than 10 seconds, the duration of these slip events is two to several weeks. The most recent event occurred from January 14 through February 1, 2007.

In the Pacific Northwest, the Juan de Fuca plate is subducting (or dipping) beneath the North American plate from northern California to Vancouver Island. These plates slide past each other along the solid green, dashed

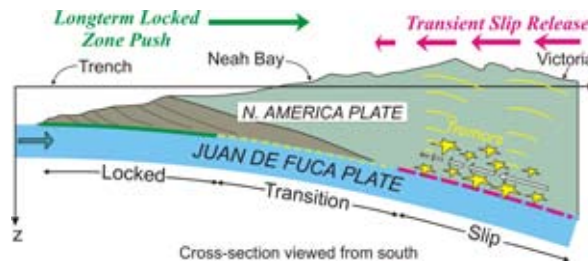


Figure 1. Courtesy of H. Dragert, Geological Survey of Canada

yellow and dashed red lines in Figure 1. The Cascadia subduction zone, as it is called, experiences large earthquakes, perhaps as large as the 2004 Sumatra earthquake, once every 500 years on average. The last one was about 300 years ago in January 1700. The slip during these earthquakes, occurring on the "locked" zone in the figure, is thought to accommodate most, if not all, of the relative motion between the North American plate and the Juan de Fuca plate. Down dip of this locked zone (red dashed lines), the plates must still slide past each other. However, instead of rupturing in devastating earthquakes, much of that slip appears to be occurring during the Episodic Tremor and Slip (ETS) events (labeled "slip" in the figure).

EarthScope and other research projects have installed Global Positioning System (GPS) stations near the Northwest Pacific coast to record ETS events. These instruments are continuously moving to the northeast relative to the stable interior of North America because the Juan de Fuca plate is pushing on the North American plate (green arrow in Figure 1). During an ETS event, the stations above the ETS zone slip backwards (the red arrows in the figure). Seismometers also record the slip. These signals initially were considered to be noise from wind or other sources, however, by filtering and analyzing the seismograms, it was discovered that tremor produces signals that are similar on many seismometers and that the signals move across a network of seismometers at the speed of waves generated by earthquakes. Tremors typically originate where the two plates meet at depths of 30-45 km. These tremors may be related to high fluid pore pressure in the rock resulting from dehydration reactions as the subducting plate heats up and undergoes increasing pressure.

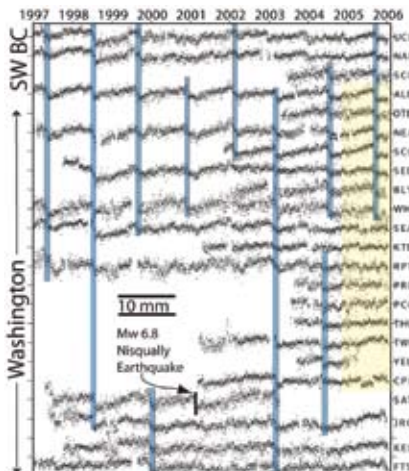


Figure 2. Plot of East-West position vs time for 23 GPS sites (eastward motions are positive). The blue vertical lines mark ETS events where multiple stations temporarily move westward.

One of the most exciting areas of research to emerge from joint GPS and seismic monitoring is the discovery of ETS. Japanese researchers were the first to identify periodic slip events, however, with the installation of more GPS stations, this phenomena has been detected in Cascadia and many other subduction zones around the world. In Cascadia, initial recognition of slow faulting led to the identification of eight additional events with a regular 14-month periodicity and the forecasting of future events. Since then, five predicted events have occurred with the same periodicity. Further study has shown that ETS events likely occur all along the Cascadia subduction zone but with different periodicity (see Figure 2.). For example, ETS events occur beneath Northern California every 11 months and off the

(continued on page 3)

project status: USArray

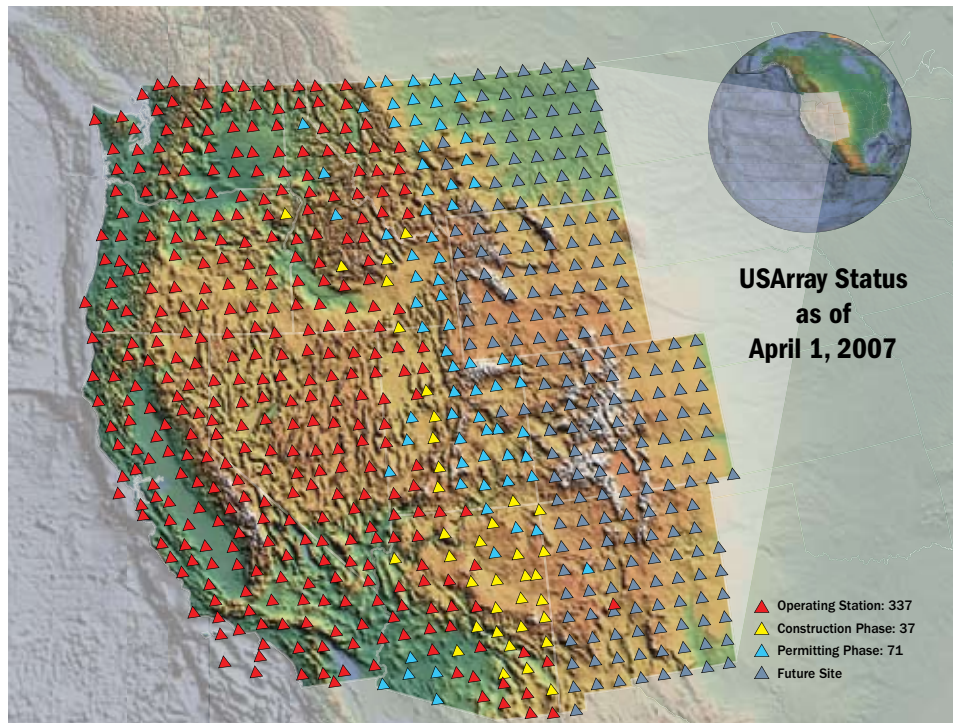
Where is the Transportable Array?

As of April 1, more than 335 earthquake monitoring stations are operating in eight western states. Installation of the Transportable Array network is complete in California, Oregon, Washington and Nevada with stations located approximately 70 km apart in a grid-like fashion. Throughout the fall and winter months, activities migrated from the northern mountain states to the southwest region where both installation and construction crews have been working. Significant progress is being made in Arizona with all installations expected to be completed before the desert heat settles in for the summer. Now that the snow is beginning to melt in the higher elevations, plans are underway to resume station construction in Utah and Idaho. Site reconnaissance activities are taking place in New Mexico and will begin later this spring in Colorado, Wyoming, eastern Montana, and the Big Bend area of Texas.

In an effort to utilize the safest as well as the most efficient station construction and installation procedures, a two-day "best practices" workshop was recently held in Phoenix, Arizona, for Transportable Array personnel. Construction and installation crews participated in activities which included both the construction of a seismic station and installation of instrumentation and ancillary equipment. During the debriefing sessions, techniques and suggested improvements were discussed. ■



Transportable Array personnel review station installation procedures during the "best practices" workshop.



REAL-TIME STATION STATUS: To view a map of current Transportable Array stations, visit <http://www.earthscope.org> and click on 'Current Status'.

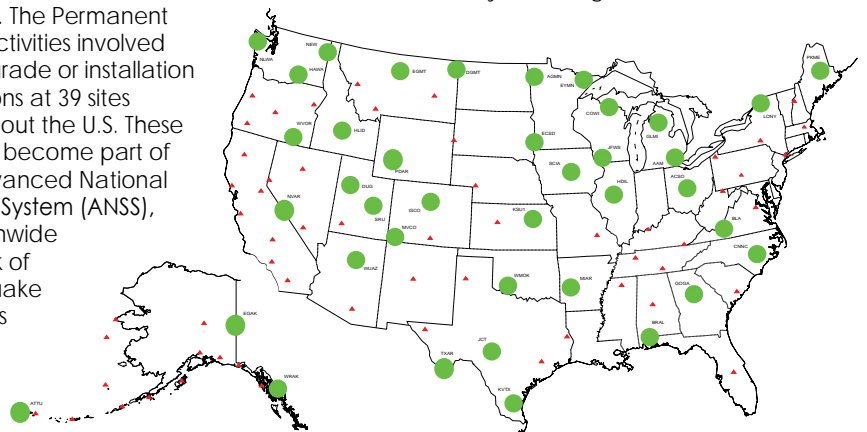
To view seismograms recorded at a USArray station, go to <http://usarray.seis.sc.edu/> and enter the station code. You can also enter a zip code to view the recordings from the USArray station closest to that area.

TRANSPORTABLE ARRAY COORDINATING OFFICE: usarray@iris.edu 1-800-504-0357

On the Move . . . Permanent Array Facility Completed

With the installation of a seismic station near Conover, Wisconsin, in September 2006, EarthScope completed the construction of the EarthScope Permanent Array facility. This is the first EarthScope component to be completed and was constructed on time and within budget. The Permanent Array activities involved the upgrade or installation of stations at 39 sites throughout the U.S. These stations become part of the Advanced National Seismic System (ANSS), a nationwide network of earthquake monitors

operated by the U.S. Geological Survey. Data from the Permanent Array provide high-quality real-time information that is used to help scientists explore the structure of the deep Earth, better understand earthquake processes, and to identify and mitigate seismic hazards. ■



Suggest A Site . . .

When will the Transportable Array be in my friend's community?

As the Transportable Array continues its journey from the west to east, you might wonder when it will arrive in a friend's or family member's neighborhood. You can find out by going to our "Suggest A Site" web page at www.iagt.org/earthscope/suggestasite/. Zoom to a place by entering an address, a zip code, a city and state (City, State), or a latitude and longitude (xx, yy) in the box at the top of the map and then click the "Zoom to Location" button. Or you can use the zoom and directional tools at the bottom of the page to go directly to your location of interest. This web application can be used to learn where future stations will be located or where current stations are installed. Just click on

the bottom left-hand side of the page) to identify the suggested location on the map. Placing a marker will automatically open the site suggestion form, which will slide open on the right-hand side of the map. Or you can click on the 'Show Panel' tab, located in the upper right corner of the map to display the site suggestion form. Next, fill in the required information (denoted with an *) on the site suggestion form and click the 'Send your Suggestion to EarthScope' button at the bottom of the form. Only locations within the blue circle – or buffer zone – will be accepted. The information you enter will be sent to the Transportable Array Coordinating Office in Socorro, New Mexico, for consideration. The "Suggest



a red balloon-shaped marker (a station that is operating or being constructed) or a blue balloon-shaped marker (a future station) for more information. As you zoom in on an area, the blue markers are replaced with blue circles to indicate the area within which a future station will be placed. If you know someone who may be interested in hosting an Earthquake Monitoring Station, you can let us know using this application. Use the "marker" tool (to activate the "marker", click the labeled icon with the green balloon on

A Site" application, developed by IAGT for EarthScope, is updated weekly with current data and offers a fun and convenient way to explore our network of Earthquake Monitoring Stations.

Help us improve this application by providing your suggestions to Bill Schultz, IAGT "Suggest A Site" manager, at bschultz@iagt.org or to Perle Dorr, onSite co-editor, at dorr@iris.edu.

By Matt Mercurio, Institute for the Application of Geospatial Technology. ■

featured science: Episodic Tremor and Slip in the Pacific Northwest

(continued from front)

coast of central Oregon approximately every 18 months.

The 2007 ETS event began under the southern Puget Sound area to the southwest of Seattle and propagated north northwest into Vancouver Island, Canada at a rate of 10 km per day (Figure 3). Over a three-week period, it is estimated that there was 3 cm of slip and that the amount of energy released was equivalent to a magnitude 6.6 earthquake. An account of this event and two previous ETS events as they unfolded can be found at <http://www.pnsn.org/WEBICORDER/DEEPTREM/fall2006.html>. These ETS events can effect the magnitude and timing of future large earthquakes within the subduction zone and thus are important in advancing our understanding of the seismic hazards in the region. As more GPS, strainmeters and seismometers are installed in Cascadia and near other subduction zones, it is hoped that answers to many more questions about these events will be found.

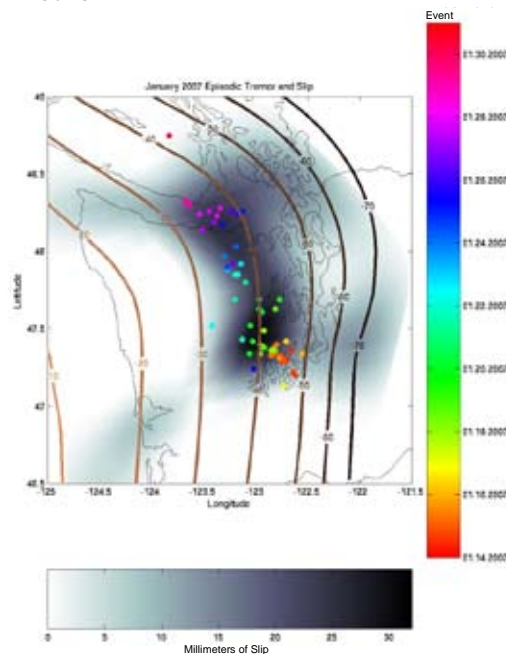
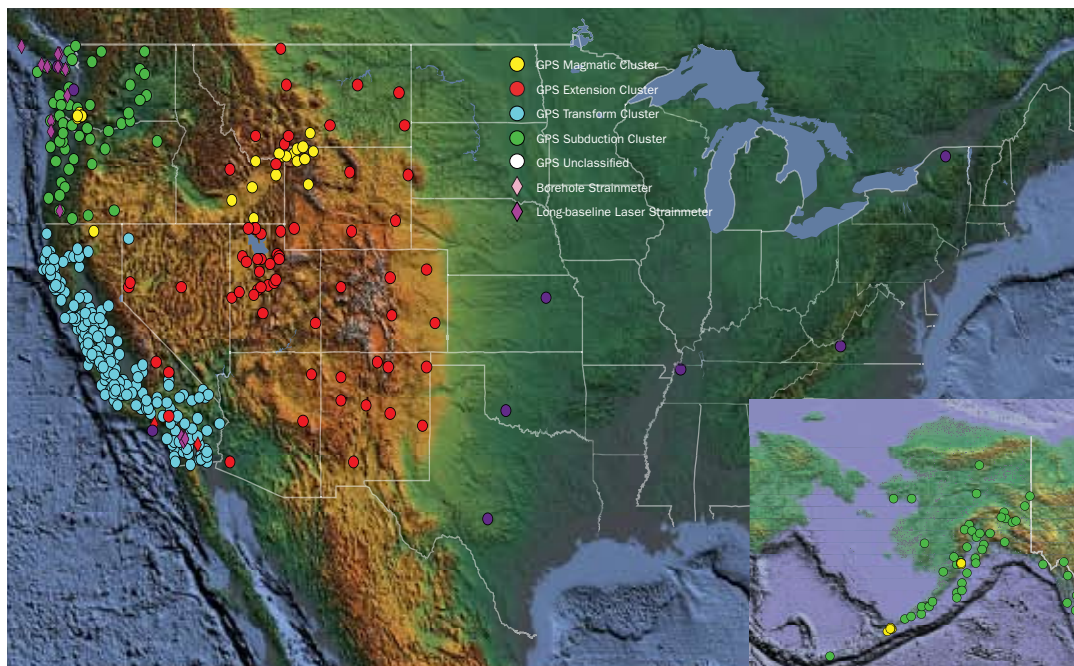


Figure 3. From January 14, 2007 until February 2, 2007, tremor migrated from the south Puget Sound region to southern Vancouver Island at about 10 km per day (colored dots). Amount of slip is inferred from GPS data.

By Kenneth C. Creager, Department of Earth and Space Sciences, University of Washington, and Timothy I. Melbourne, Department of Geological Sciences, Central Washington University. ■

project status:

Plate Boundary Observatory



PBO Status as of April 1, 2007:

Magmatic stations: 73
 Transform stations: 250
 Subduction stations: 112
 Extension stations: 113
 Borehole strainmeters: 30
 Long-baseline laser strainmeters: 3
 Eastern Backbone: 8

PBO REGIONAL OFFICES:

Alaska 907-346-1522
 Pacific Northwest 509-933-3221
 Basin and Range 801-466-4634
 Northern California 510-215-8100
 Southern California 951-779-6400

PBO Installs First of Four Permafrost GPS Stations in Alaska

In areas of permafrost, establishing a stable geodetic monument is tricky due to extensive seasonal freezing and thawing of soils. The PBO Alaska Regional Office installed the first of four Permafrost GPS monuments planned for Alaska in the town of Kotzebue in early March 2007. A special monument was designed specifically for EarthScope and UNAVCO because the standard metal tripod would not have remained stable in permafrost. The active permafrost layer in the Kotzebue area is typically 3 to 4 feet deep and, with the annual freeze-thaw cycles and constant movement of the ground surface, the legs and entire monument would have permanently deformed in only a few years.



Lowering the 250-pound thermopile into position.

The permafrost monument is constructed with a thermopile. The purpose of the thermopile is to maintain

a relatively stable temperature within the monument and reduce the stress and metal fatigue that results from the freezing and thawing of the permafrost layer. The thermopile consists of a sealed 4.5-inch outside diameter steel pipe that is 21 feet in length and filled with carbon dioxide at a pressure that allows the carbon dioxide to exist in both its liquid and vapor states at all times. When the top of the thermopile is cooled by winter air, the vapor in the thermopile condenses and flows down the sides of the pipe by gravity. When condensation forms and moves toward the bottom of the pipe, the pressure on the vapor is reduced, causing the warmer liquid to boil. The vapor at the top of the thermopile is then cooled by the winter air and a cycle of condensation and vaporization is established. Thermopiles are highly effective systems to transfer heat and have been used in Alaska since 1960 with great success.

To minimize disturbance of the permafrost, the GPS station was installed during the winter when the ground was completely frozen. After drilling a 12-inch hole to a depth of nearly 17 feet, the thermopile was lowered into it with the aid of a large fork lift. A slurry consisting of warm potable water, natural soil cuttings and gravel was poured back in to the hole around the thermopile. Given the cold temperatures at the time of the



The completed permafrost monument with the drill rig in the background.

installation, the slurry began freezing and locking the thermopile into place with 20 minutes.

The installation of the Kotzebue PBO Station (station code AB18) from start to finish took only a few hours to complete. It is located on land owned by the Kikiktagrak Inupiat Corporation (KIC) and leased to the Kotzebue Telephone Cooperative (OTZ) who operates and maintains a cellular phone tower on the property. Installation of two additional permafrost monuments are planned for 2007 in Arctic Village and Sagwon and a third permafrost monument in Fort Yukon will be installed in early 2008.

For more information on the PBO Project, please visit the PBO website at <http://pboweb.unavco.org/>. ■

project news:

EarthScope National Meeting

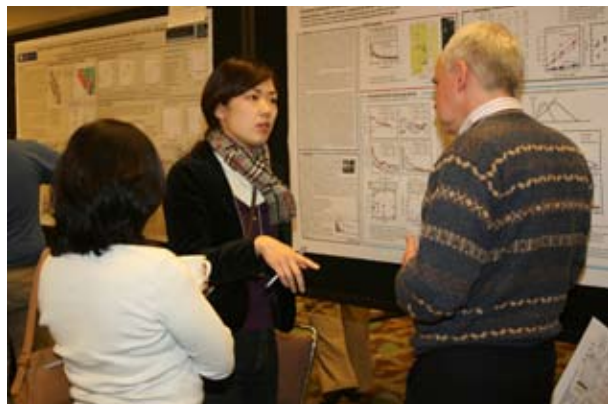
Exciting Science Presented at EarthScope National Meeting

EarthScope instruments are providing an enormous amount of data about the Earth every day. Even while the observatories are being constructed – the facility is roughly 70% complete – scientists are accessing and analyzing the recorded data to discover more about earthquakes; faults; and the structure, evolution and dynamics of the Earth. In March, nearly 400 researchers, students, and other representatives from universities, government agencies, and related organizations gathered in Monterey, California, to share preliminary findings and emerging techniques enabled by the EarthScope facility.

The extraordinary potential of EarthScope was apparent throughout the 2.5-day meeting. During that time, there were 35 presentations in plenary sessions, more than 275 poster presentations, and numerous panel discussions and small group exchanges. The scientific results demonstrated that the integration of EarthScope's geophysical observations with other geoscience data is providing exciting opportunities and new insights. Topics included the growth and evolution of volcanoes, such as Mount St. Helens in Oregon and Augustine in Alaska; the mechanics of earthquakes and what triggers an earthquake to start and propagate; and the fundamental

processes involved in tremor and episodic slip events, such as that observed in the Cascadia region of the Pacific Northwest (see our featured science article on the front page). Other sessions focused on the role of the Earth's mantle in the development of topographic features, continental formation and deformation, and the movement of tectonic plates; the rate and magnitude of the forces that produce deformation in the Western US; and the procedures currently available to provide, maintain, and retrieve high-quality data.

On the day prior to the meeting, attendees had the opportunity to participate in a variety of workshops and mini-courses. Nine workshops were offered that provided in-depth information on a specific topic, such as how to access EarthScope data and preparations for the next phase of the San Andreas Fault Observatory at Depth (SAFOD). The 45-minute mini-courses provided an overview of several topics of interest, including seismic imaging and satellite imaging. Attendees could also choose to take a half-day field trip to



the San Juan Bautista and Hollister areas to observe first-hand the deformation caused by movement along the San Andreas and Calaveras Faults. The meeting's special event was a reception held at the Monterey Bay Aquarium where Marcia McNutt, president and CEO of the Monterey Bay Aquarium Research Institute, made a presentation about the Monterey Accelerated Research System (MARS) observatory. This facility, when completed, will support oceanographic research and serve as a testing ground for new deep-sea technology including seismographs and oceanographic monitoring stations.

The next EarthScope National Meeting will be held in two years, in 2009. ■

Teachers Learn to use EarthScope Data

Fifteen middle and high school teachers traveled from several states to the EarthScope National Meeting in Monterey to attend a specially

designed workshop. The purpose of the workshop was to introduce the teachers to EarthScope and to improve their foundation in geophysics. The day

provided them with a variety of activities involving EarthScope data that they could take back to their classrooms. They learned how seismic data can be used to determine Earth structure and how GPS data can be used to measure tectonic plate movement. Science presentations by EarthScope researchers were interspersed between the activities to give teachers an introduction to EarthScope research. A highlight of the day was a field trip to several locations on the San Andreas fault, including the creeping section in Hollister, where buildings, sidewalks and roads are being slowly deformed as the two sides of the fault slowly slide past each other. The field trip was part of the main meeting giving teachers a chance to interact with scientists who are using EarthScope data in their research. After the workshop, many teachers stayed for the plenary talks the next day, which gave an overview of several areas of EarthScope related research. ■



EarthScope onSite is published four times a year by EarthScope (www.earthscope.org)

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Transportable Array station Y15A located northwest of Phoenix in Morristown, Arizona. The station became operational in March 2007.



EarthScope is funded by the National Science Foundation and conducted in partnership with the US Geological Survey and NASA. EarthScope is being constructed, operated, and maintained as a collaborative effort with UNAVCO Inc., the Incorporated Research Institutions for Seismology, and Stanford University, with contributions from several other national and international organizations. This material is based upon work supported by the National Science Foundation under Grants No. EAR-0323310, EAR-0323309, EAR-0323700, EAR-0323938, EAR-0323311, and EAR-0323704. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.



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