fall 2009

earth scope

onSite

newsletter

From the National Science Foundation

It's an exciting time to be at the National Science Foundation and to succeed Kaye Shedlock in overseeing the EarthScope Program. After a five-year effort, EarthScope is now providing continuous deformation measurements across Alaska and the contiguous 48 states in near real time. EarthScope scientists have developed high-resolution images of mantle "drips" under the Great Basin and Sierra Nevada; synoptic views of slow earthquakes and tremor in Cascadia; and direct measurements of the physical properties of an active earthquake zone. Education and outreach activities are another EarthScope hallmark: training workshops for teachers, park rangers, and students; the EarthScope Speaker Series; strong student participation in USArray siting; and, as you can read, the *onSite* newsletter.

Our challenge is: what's next? How do we continue EarthScope's success and keep our focus while expanding into new research areas? Natural growth is one way: over 100 researchers have now received EarthScope funding, and this year there are many sessions involving EarthScope during the AGU Fall Meeting. We can also encourage ourselves to look around and seek new ideas. The EarthScope Steering Committee is working with the community to update the EarthScope Science Plan, starting with the October 2009 workshop. I encourage you to participate actively in this process, which will identify emerging research areas for EarthScope in the coming years.

You can also make your voice heard even more directly: e-mail me at greander@nsf.gov or call me at 703-292-4693. I welcome your thoughts, criticism, and suggestions for continuing EarthScope's success.

Greg Anderson
NSF EarthScope Program Director

featured science:

Heterogeneous Lowermost Mantle Beneath the Pacific Ocean

The seismic stations of the USArray Transportable Array (TA) record earthquakes from around the globe. Seismic waves are affected by the structure and composition along their travel path through the Earth, allowing us to deduce Earth structure between source and station. This article highlights the unique capabilities of the dense TA for deep Earth studies.

Direct P and S waves recorded at ~90°-100° distance (1° = 111 km) from an earthquake are sensitive to the structure near the **core-mantle boundary** (CMB), where these waves bottom and return to the surface (Figure 1). The TA is ideally situated to record waves at these distances from Fiji-Tonga, where the largest number of **deep-focus earthquakes** originate. This permits the investigation of the lowermost mantle (referred to as the D'' region) beneath the central Pacific Ocean, roughly half way between the earthquakes and TA stations.

Earlier studies had established the presence of a large low shear velocity province in the D'' region beneath the Pacific. Recently, the TA enabled several discoveries of a variety of fine-scale complexities. These include isolated and thin ultra-low velocity zones (ULVZs), some tens of km (or less) thick with velocities reduced by 10% and more; directional dependence of seismic wave speed that may be related to mineralogy, rheology, and flow; and discontinuities in velocity that are consistent with the presence of **post-perovskite**. The nature of these low velocity regions is still enigmatic; they appear to have relatively sharp boundaries and possibly consist of material with higher density than the surrounding mantle, which suggests a chemically distinct origin.

We investigate this problem using TA data. Figure 2, as an example, shows seismograms from a Fiji earthquake organized according to direction (azimuth) from the earthquake. We observe broadening of the S waves for azimuths between ~42°-47°; such broadening is consistent with multi-pathing, the phenomena of a seismic wave splitting into two waves when traveling tangential to a sharp velocity contrast. Comparison with global tomography (Figure 1) reveals these waves indeed propagated near a low velocity boundary. Such analyses, along with travel-time studies of various S phases traversing the lowermost mantle, enable us to map the northern edge of the low-velocity material beneath the Pacific (thick black line in Figure 1).

Seismic imaging of deep Earth structure is important because the dynamics and evolution of the deep interior are likely closely linked to Earth's outermost shell(s), including tectonic plates, their motions, and evolution. For example, subduction of dense, cold oceanic lithosphere into the lower mantle could convectively

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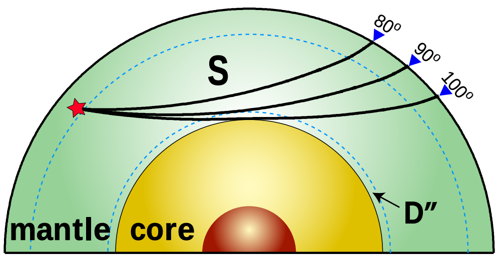


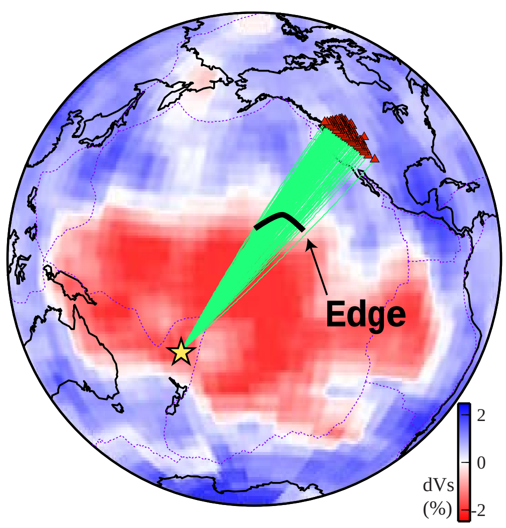


Figure 1: Ray path geometry of S waves (top). Rays penetrate deeper at larger distances, eventually bending around the core for distances greater than 100°. An earthquake that occurred deep beneath Fiji in 2007 sampled the lowermost mantle beneath the Pacific Ocean (bottom globe). Shown are paths (green) from the earthquake (star) to the TA stations (triangles) on top of lowermost mantle S wave velocity perturbations (tomography courtesy of Steve Grand, Univ. Texas, Austin), where red and blue represent lower and higher speeds relative to an average model, respectively. The thick black line denotes a sharp velocity boundary deduced from observed waveform and travel time anomalies.

featured science:

Tectonic Block Motions in Southeast Alaska and Adjacent Canada

Southeast Alaska and the adjacent portion of Canada (Figure 1) form an important segment of the Pacific-North American plate boundary zone and mark the beginning of the transition between a transform margin and subduction along the Aleutian megathrust. The tectonics of this region are driven by the ~50 mm/yr relative motion between the Pacific plate and North America, and the Yakutat block's collision with and accretion to southern Alaska. Active deformation extends significantly inland, even in the boundary's transform segment, and effects of the Yakutat block collision extend far to the northeast.

The observed GPS velocities from campaign and continuous sites (Figure 1) show rapid motion along the coast and a distinct rotational pattern for inland sites. We inverted the GPS data to estimate angular velocities of several rigid blocks and derived a self-consistent set of fault slip rates from the block motions. The Yakutat block has a velocity of 51 ± 3 mm/yr towards N22 ± 3˚W relative to North America, almost identical in rate to that of the Pacific plate but with a more westerly azimuth (Figure 2). The northeastern edge of the Yakutat block, adjacent to the Fairweather fault, is deforming, represented in our model by two small blocks. The Fairweather fault remains almost purely strike-slip, but convergence occurs on faults closer to the coast and offshore. One of these faults may have ruptured as part of the 1899 Yakutat Bay earthquake sequence. East of the Fairweather fault, the Fairweather block rotates clockwise relative to North America, resulting in transpression along the Duke River and Eastern Denali faults. There is a clear strain transfer from the coastal region eastward into the Northern Cordillera, which also rotates clockwise relative to North America.

Both the Fairweather fault and the Queen Charlotte fault have average right-lateral slip rates of 44 ± 2 mm/yr, but the Queen Charlotte fault also displays transpression with southward-increasing fault-normal motion that reaches 16 ± 4 mm/yr near the Queen Charlotte Islands. Relative motion between the Yakutat block and the Pacific plate is accommodated by left-lateral oblique slip on an offshore fault such as the Transition fault zone. The collision of the leading edge of the Yakutat block with southern Alaska results in 45 mm/yr of shortening across the St. Elias Range, which contains some of the steepest coastal mountains in the world.

The coastal regions of Alaska and Canada are actively deforming at least as far south as the Queen Charlotte Islands. Our block model shows that active deformation occurs throughout the entire coastal region of southeast Alaska. Work by Stephane Mazzotti and others showed that the same is true for the Queen Charlotte Islands region of British Columbia, although that region moves independently of the Fairweather block.

While the motion of coastal blocks further south is much better known, the entire Pacific coastal region may be mobile and part of a continuous plate boundary zone system. Future data from several PBO sites located south of the Fairweather-Queen Charlotte junction (Figure 2) will help provide additional insights. However, the PBO network is very sparse in the region, making coastal Alaska and Canada a promising target for future EarthScope densification and focused studies. ■

By Julie L. Elliott, Christopher F. Larsen, Jeffrey T. Freymueller, and Roman J. Motyka, Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska

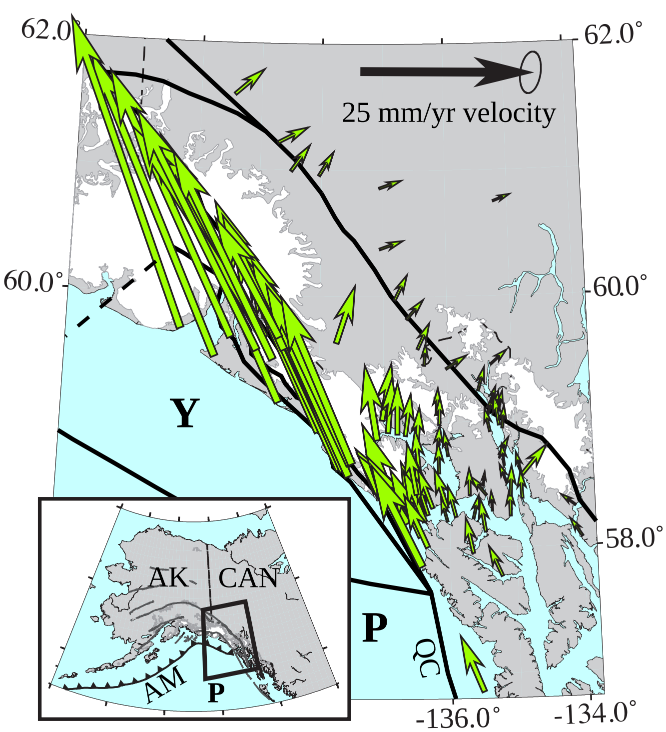


Figure 1: Observed GPS velocities (green arrows) in southeast Alaska relative to North America. For clarity, no velocity error ellipses are shown; the scale vector shows a typical error ellipse. Inset map box shows area covered on data map. AM is the Aleutian Megathrust, P the Pacific plate, Y the Yakutat block, and QC the Queen Charlotte fault.

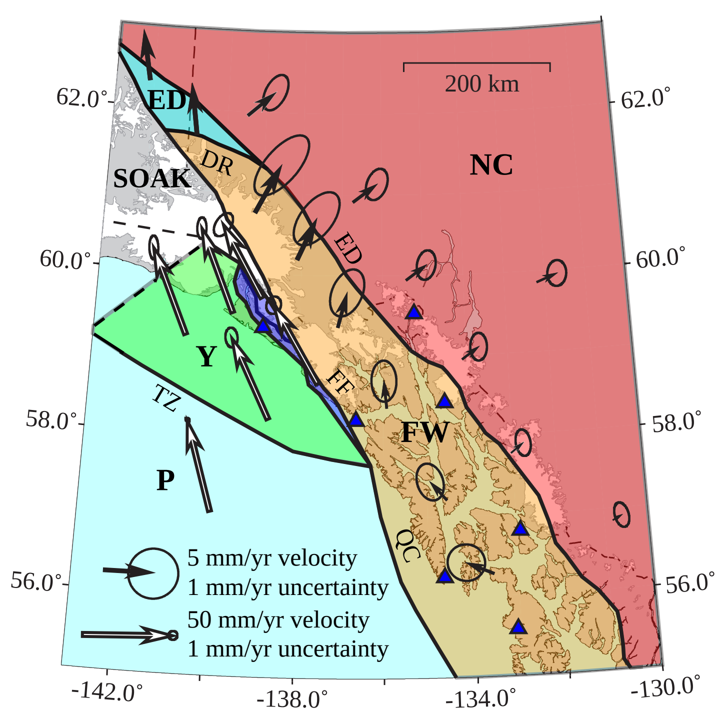
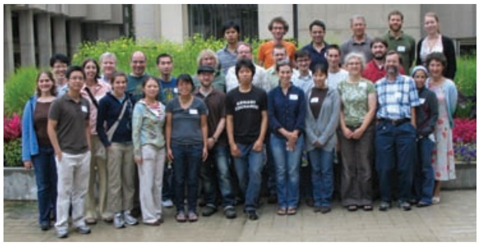
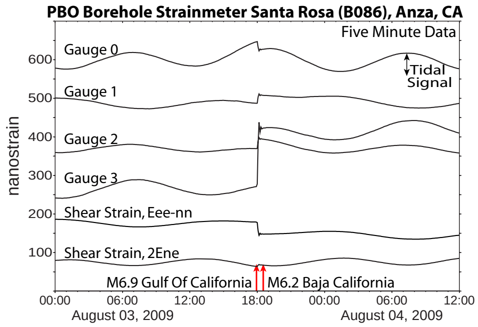


Figure 2: Block boundaries and predicted block motions (arrows). Colors denote blocks. Labeled faults are the Duke River (DR), the Eastern Denali (ED), the Fairweather (FF), the Queen Charlotte (QC), and the Transition fault zone (TZ). Labeled blocks are Southern Alaska (SOAK), Pacific (P), Yakutat (Y), Fairweather (FW), Eastern Denali (ED), and Northern Cordillera (NC). Blue triangles are PBO GPS sites.

EarthScope News



Participants in the USArray Data Handling Short Course.



- **USArray** conducted its first data processing short course this past August. During the week-long session hosted by Northwestern University, 10 instructors introduced advanced techniques for handling large data sets to 21 graduate and post-graduate students. Participants felt the course was extremely worthwhile and plans are being made to offer it again next year.

- **Plate Boundary Observatory** strainmeters in Southern California recorded significant offsets following the passage of seismic waves from a magnitude 6.9 Gulf of California earthquake on August 3, 2009. Although the earthquake was too small and too distant (at 600+ km) to directly influence static strain at the site, earthquake-triggered slip on nearby faults may have been responsible for the observed strain anomalies.

- The **New EarthScope Science Plan** workshop was held on October 7-9. You can still participate by providing comments. Visit www.earthscope.org/meetings/science_planning_workshop for updates. Send comments to earthscope@coas.oregonstate.edu.

- The 2009 **Magnetotelluric** transportable array field season has ended. This summer, 51 sites in Montana and Wyoming have extended continuous 3-D coverage farther east (see www.earthscope.org/publications/onsite for Fall 2008 MT article).

- Don't miss the **2009 American Geophysical Union Fall Meeting** in San Francisco, December 14-18 (www.agu.org/meetings/fm09/) with exciting EarthScope sessions! Visit the booth and attend the Town Hall Meeting (visit www.earthscope.org for updates) for news from the Science Planning Workshop.

featured science: Heterogeneous Lowermost Mantle Beneath the Pacific Ocean

(continued from front)

sweep dense material such as the large-scale low shear velocity provinces towards regions underlying upwelling return flow. Thus, imaging dense stable structures can inform us about global mantle flow. Smaller scale structures, such as ULVZs, may similarly track smaller scale mixing in the deepest mantle. Furthermore, mantle plumes may originate from boundaries between the chemically distinct low-velocity material and surrounding mantle.

Just a few decades ago seismic imaging of the deep mantle utilized relatively few stations, often hundreds to thousands of km apart. USArray's TA is enabling scientists to image structure at nearly an order of magnitude greater detail. Hence, we anticipate continued advancement and discovery associated with deep Earth investigations, particularly those that elucidate the structure, dynamics, and evolution of the planet as a whole. ■

By Ed Garnero and Chunpeng Zhao, School of Earth and Space Exploration, Arizona State University

Glossary

Deep-focus earthquakes: Earthquakes occur from the surface down to about 700 km depth. Most earthquakes have a "shallow" focus of less than 70 km depth; earthquakes between 70 and 300 km depth are called "intermediate-depth" and for depths exceeding 300 km "deep". Intermediate and deep earthquakes are generally observed in subduction zones.

Core-mantle boundary (CMB): The CMB at approximately 2900 km depth separates the silicate mantle from the liquid, predominantly iron, outer core. A sharp observed P-wave velocity decrease across the boundary led to discovery of the CMB in the early 20th century.

Post-perovskite: Olivine, a magnesium iron silicate, is the most common mineral in the upper mantle. As temperature and pressure increase with depth, the mineral undergoes several phase transitions – packing the atoms tighter and tighter – to perovskite in the lower mantle. Only very recently was it discovered that perovskite transforms at the very high pressures near the CMB to the post-perovskite mineral phase.

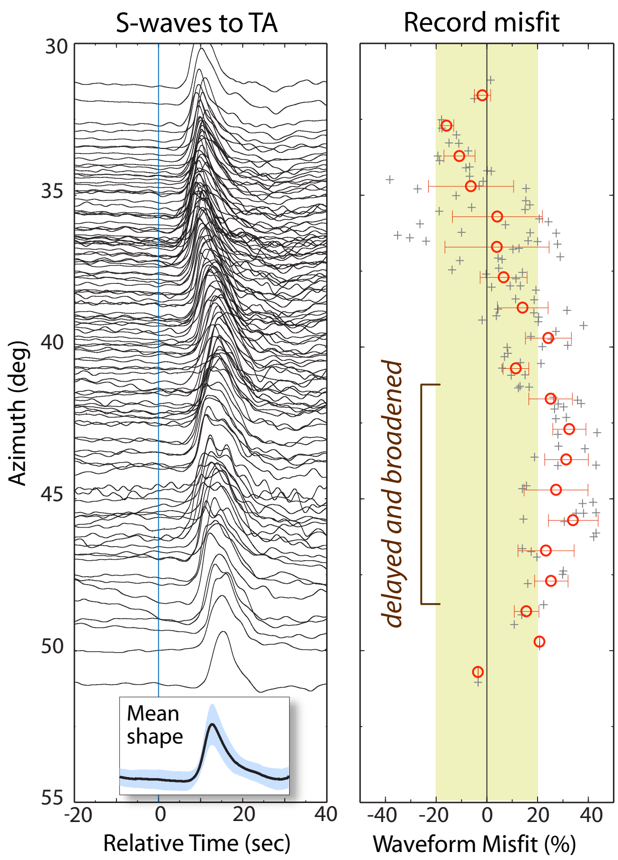


Figure 2: Left Column. The observed S-waves (SH displacement) for the earthquake in Figure 1 are plotted relative to their predicted arrival time (blue line at time=0) and as a function of direction from the source. The arrival times change systematically. The bottom inset is the average shape of the observed waves, which we subtract from each individual trace to obtain a 'Waveform Misfit' shown in the Right Column; positive values document waveform broadening and crosses are individual measurements. Averaging over several measurements results in robust estimates (red circles) that show significant waveform broadening (circles outside shaded region) corresponding to sharp changes in seismic velocities.

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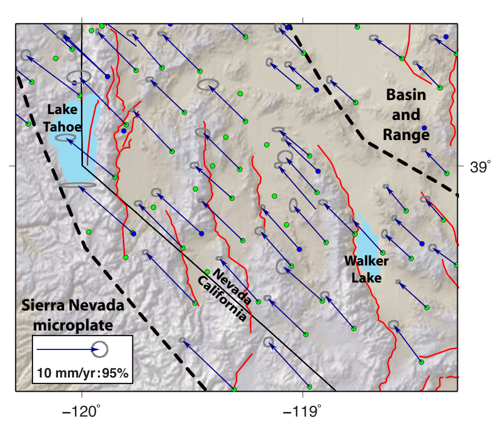
EarthScope Targets the Walker Lane



GPS velocities relative to North America. MAGNET (green) and PBO (blue circles) velocities show right-lateral shear and extension accommodated by Quaternary faults (red lines) within Walker Lane (dashed lines). Sites with no vector will have enough data by the project's end to obtain a velocity.

The Walker Lane (WL) is a zone of active intracontinental transtension that separates the Basin and Range from the rigid Sierra Nevada block. It accommodates ~10 mm/yr of right-lateral deformation or ~25% of Pacific-North America relative plate motion. Between Walker Lake and Lake Tahoe, WL lacks optimally oriented strike-slip faults to accommodate northwest-directed right-lateral shear, and Quaternary deformation appears concentrated in a northwest–trending series of north-striking normal faults. Key questions regarding WL kinematics include the role of vertical axis rotation of fault-bounded blocks and deformation accommodation by slip on basin-bounding faults. As part of a study comparing geodetically measured strain accumulation and geologically recorded strain release, EarthScope funding allowed us to survey semi-continuous GPS sites in the Nevada Geodetic Laboratory's MAGNET network. Initial results from the spatially dense MAGNET supplement PBO data and show a smooth, continuous increase in shear across the WL in addition to NW-SE directed extension. The GPS data will be combined with geologic observations to develop block and continuum models of WL deformation. ■

By Jayne Bormann (co-winner of the student poster competition at the 2009 EarthScope National Meeting), Bill Hammond, Corné Kreemer and Steve Wesnousky, Nevada Bureau of Mines and Geology and Center for Neotectonic Studies, University of Nevada, Reno