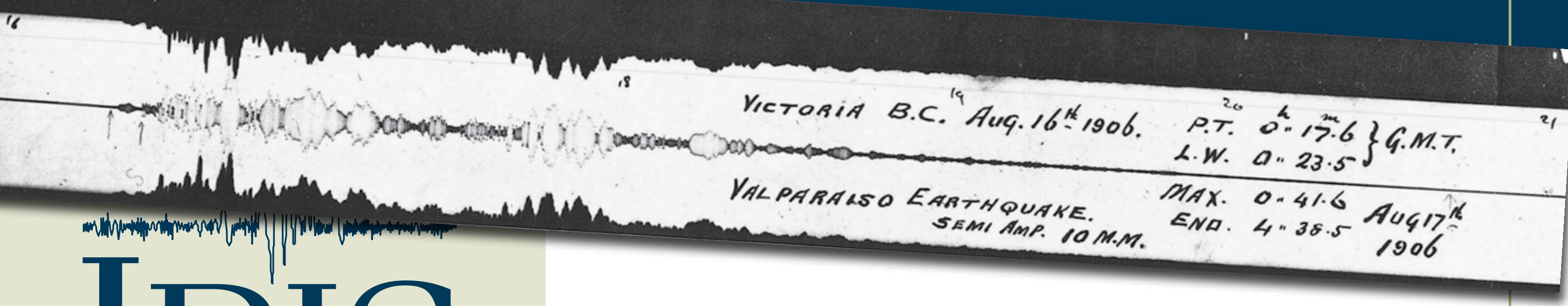


IRIS NEWSLETTER

YEAR 2006 • ISSUE 3

Seismogram from the M_w 8.2 1906 Valparaiso earthquake recorded in Victoria, British Columbia.

**For more information, see inside back cover.*

TABLE OF CONTENTS

USArray Science

Kaye Shedlock • National Science Foundation

"Unprecedented", "Cutting-edge", "… an entirely new venture for the Earth sciences, with an immense vision and scope."

These and other superlatives from the Committee on the Review of EarthScope Science Objective and Implementation Planning are now commonly used in describing EarthScope. The construction of the EarthScope facility is over 60% complete and the scientific promise of EarthScope is already demonstrated. We have drilled across the San Andreas Fault and are now recording earthquakes at depth as well as conducting extensive analysis of rocks from the fault zone. Seismic and geodetic instrumentation have recorded eruptive volcanic sequences from two different types of volcanoes and have captured slow earthquakes in Cascadia and California. USArray continues to collect vast amounts of high-quality data that is made available in near real-time to an ever-increasing community of users.

New and outstanding scientific results are appearing regularly. EarthScope is providing the first detailed, integrated, real-time measurements of natural processes, such as earthquakes and volcanoes, so that the causes and effects of continental deformation may finally be deciphered. The scientific targets for EarthScope include enhanced understanding of continental structure and evolution, lithospheric dynamics, earthquakes and seismic hazards, magmatic systems and volcanic hazards, regional tectonics, fluids in the crust, and associated educational aspects. USArray contributes to all of these, in both new and traditional ways.

Installation of EarthScope's Transportable Array station F07A in south-central Washington, near Prosser. The station came online in early September 2006.

Articles in this issue by Barbara Romanowicz, Ed Garnero, Philip Crotwell and Tom Owens, and Craig Jones and others illustrate just a few current advances and possible exciting new directions. The integration of USArray data with other EarthScope and Earth science data will also foster innovative and exciting developments in education and public outreach such as those described in the articles by Debi Kilb and Matt Fouch.

EarthScope is ushering in a new scientific era in the Earth sciences. USArray scientists are at the forefront of scientific discovery and the development of new approaches to imaging and visualization. The next decade promises to be very exciting and NSF is proud to be supporting the Earth science community as you lead the EarthScope effort. ■

Anisotropic Imaging of North America's Deep Structure

Barbara Romanowicz, Federica Marone, Yuancheng Gung • University of California, Berkeley

One of the main scientific goals of USArray is to provide an unprecedented density of seismic recordings that will help us gain a better understanding of the deep structure of continents and address fundamental questions: How does lithospheric thickness vary with geological age? How is the lithosphere coupled to the underlying convecting mantle? Does a low-velocity asthenospheric layer exist under stable and, in particular, cratonic areas? How deep is upper mantle structure affected by the overlying lithosphere? Among these questions, there are some long standing controversies. For example, does a thick tectosphere translate coherently with the continent, or does SKS splitting originate from fossil anisotropy frozen in the lithosphere or anisotropy in the asthenosphere induced by present-day plate motions?

With its Precambrian core surrounded by progressively younger geological provinces, the North American continent is well suited to address a variety of fundamental questions.

In preparation for the high quality and quantity of USArray data, new analysis tools need to be developed. In this context, we have been working on a waveform-based approach to construct tomographic images of isotropic and anisotropic structure in the upper mantle beneath North America, which we are testing on a collection of three-component seismograms recorded at existing permanent North American stations, complemented by data from PASSCAL deployments.

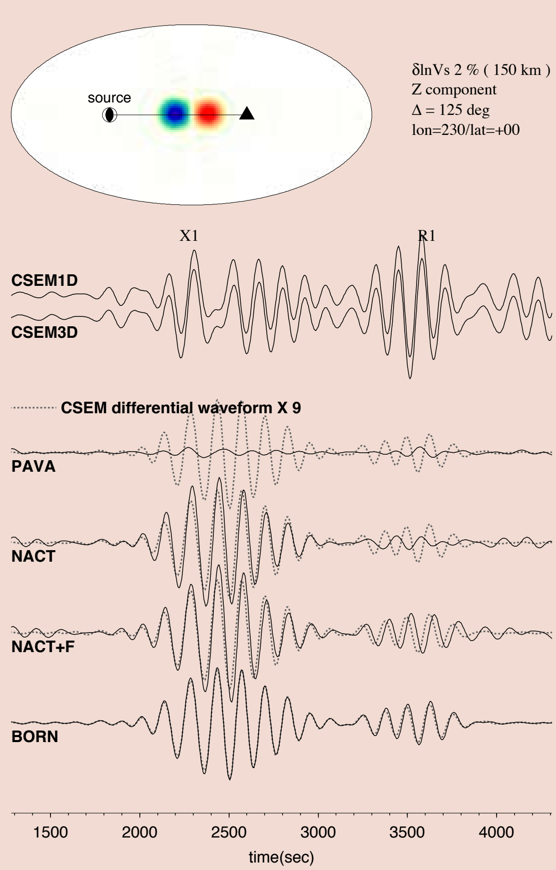
DEVELOPING NEW ANALYSIS TOOLS

Our approach utilizes complete time domain seismograms presently filtered at periods longer than 60 s, appropriate for the analysis of surface waves and their overtones. These seismograms are broken into wave packets of significant energy containing, on the one hand, fundamental mode Rayleigh or Love waves and, on the other, combinations of spheroidal/toroidal overtones. We assign weights to these wave packets to equalize their overall amplitude and compare them to 3-D synthetics computed using normal mode summation and the Non-linear Asymptotic Coupling Theory. In this formalism, the effects of 3-D structure appear in two ways: a non-linear term containing a frequency shift, which includes the effect of average structure between the source and the receiver, and an additional linear correction, which represents across-branch mode coupling. These coupling terms are necessary to describe accurately the depth sensitivity of overtone wave packets, which allows us increased resolution down to transition zone depths. At the spatial and frequency scales of our study, these 2-D effects are generally more important for accurately modeling overtones than "off plane" effects arising from the focusing and defocusing of waves in the horizontal plane.

This study has motivated us to implement non-linear corrections based on the Crust2.0 model to account for the large, sub-regional lateral variations of crustal thickness from the oceanic provinces on the eastern and western margins of North America to the thick crust of the cratonic central core. We find that this non-linear treatment makes a difference, even at large depths in the upper mantle.

ISOTROPIC RESULTS

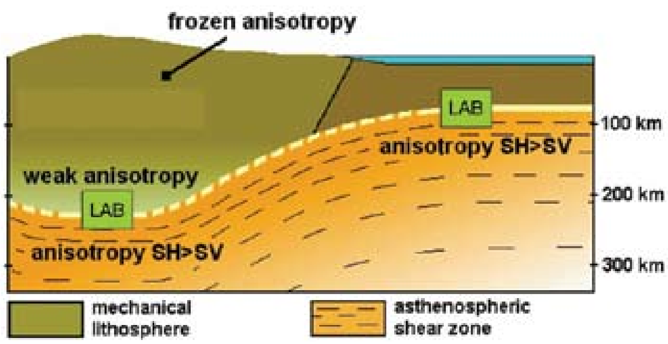
Our preliminary results for the isotropic upper mantle structure confirm previous conclusions that 3-D seismic velocity is correlated with surface tectonics in the first 200 km under the North American continent. In fact, a striking difference between the low-velocity, tectonically active western region and the high-velocity stable central and eastern shields is observed, with a boundary almost perfectly coincident with the Rocky Mountain Front. This pro- ➔



Comparison of vertical component synthetic seismograms for different normal mode-based approximations, computed down to 100s period. The test model consists of two anomalies of strength δ ln *VS* = 5% and opposite sign centered at 150 km depth (50-250km) and of lateral extent ~800km. The reference "exact" seismograms (1-D and 3-D) were computed numerically using a coupled-SEM method [*Capdeville et al.,* 2003]. Differential waveforms with respect to the 1-D seismogram (continuous lines) are compared to the SEM differential seismograms (broken lines), for the Path Average surface wave Approximation (PAVA, 1D kernels), the NACT (2D kernels in the vertical plane), NACT plus out of plane focusing (NACT+F, 2.5D kernels) and finally the Born approximation. PAVA does not "see" the structure. The 2-D sensitivity of the overtone packet (X1) is well captured by NACT, while adding focusing accounts for most of the out-of-plane perturbations in the fundamental mode (R1). What appears as a phase shift in the NACT+F differential trace is actually a small amplitude difference. The Born approximation gives a very good fit in this example, but is computationally much heavier.

nounced contrast persists down to 200-250 km depth, where the 3-D structure changes character and the large velocity perturbations ($\delta \ln V_S > 4\%$) observed in the uppermost mantle make way to anomalies not exceeding ~2%. High heat flow values suggest that the negative velocity perturbations in the western U.S. represent young, hot, upper mantle material.

East of the Rocky Mountain Front, our model, like others, shows a large area of fast isotropic V_S. This anomaly represents the lithospheric root of the North American craton and extends to about 250 km depth in the oldest part of the continent. At 250 km depth, we find a low-velocity anomaly beneath the Appalachians that has been observed previously in both V_P and V_S models. The anomaly may be due to intrusion of asthenosphere into the edge of the continental keel [*Li et al.,* 2003] or it could indicate the presence of water in the mantle, dating back to past subduction [*Van der Lee et al.,* 2005].

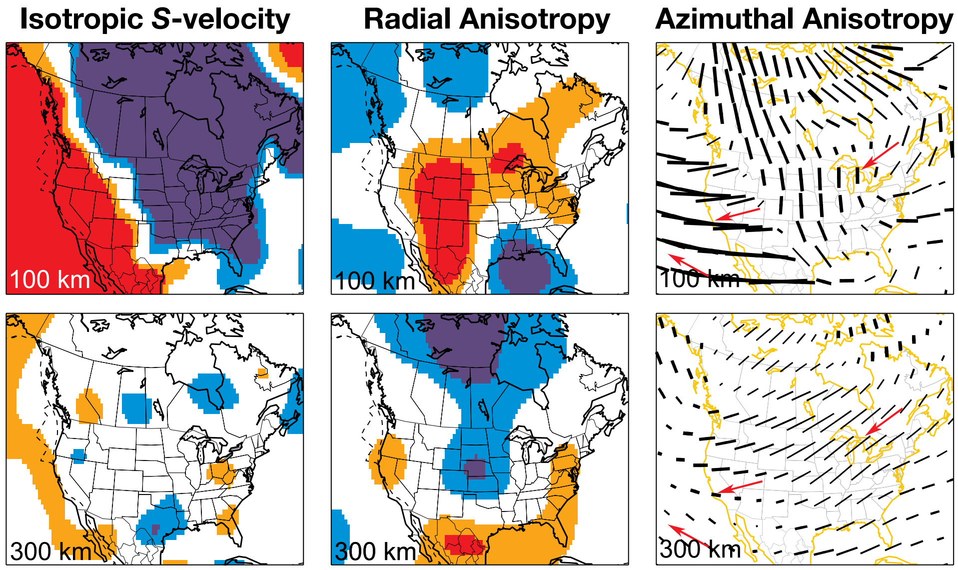


Variations found in upper mantle anisotropy beneath North America suggest the presence of two layers of varying thickness separated by the lithosphere-asthenosphere boundary (LAB), similarly to what has been found under oceans.

Deeper than 250 km depth, lateral variations significantly decrease throughout the continent. The deep upper mantle is characterized by the presence of fast material beneath western North America, which we relate to subducted slabs: the Juan de Fuca plate in the north and the extinct Farallon plate in the south.

ANISOTROPY IN THE WEST AND EAST

The shallow upper mantle beneath the North American continent and the surrounding oceans is dominated by an anisotropy anomaly suggesting preferential orientation of the fast axis of anisotropic mantle minerals near the horizontal plane. At this depth, the origin of this feature must be lithospheric under the stable continent, but asthenospheric in tectonically active and oceanic areas. Deeper, this widespread anomaly disappears beneath the oceans/active areas and its presence is mainly restricted to the cratonic part of the North American continent.



Preliminary results – including isotropic velocities, radial anisotropy and azimuthal anisotropy – reveal differences in upper mantle structure between eastern and western North America down to asthenospheric depths.

At 250-300 km depth, lateral variations in isotropic velocity have faded out, but widespread persisting radial anisotropy suggests an asthenospheric origin for this feature. The anisotropic anomaly is consistent with horizontal shear flow causing the preferred alignment of anisotropic minerals and confirms the results obtained under cratons at the global scale.

Our preliminary results for the distribution of azimuthal anisotropy under the North American continent further confirm the presence of two distinct depth domains under the central and eastern part of the continent, with different directions of the fast axis, roughly consistent with the depth domains imaged in isotropic V_S and radial anisotropy. We obtain a direction nearly parallel to the absolute plate motion at depths greater than 250km while at shallow depths (~100 km), it is more north-south. In contrast, under the western US, the direction of anisotropy is sub-parallel to the absolute plate motion even at shallow depths.

Thus under central and eastern North America, our results, combined with those of previous studies, indicate the presence of two distinct anisotropy domains differing both in isotropic velocity and in the character of anisotropy. One, at shallower depth, is most likely associated with the lithosphere, while the other, at depths greater than 250 km, is associated with the asthenosphere. The boundary between these two domains, although not precisely mapped, varies laterally, following the surface tectonic and geological structure.

PLANS FOR FURTHER WORK

While the present models are relatively coarse and resolve details at spatial wavelengths of about 800 km, they provide a 3-D reference for finer scale analysis that will be possible by adding shorter period waveforms containing body wave energy. More importantly, the resolution will be improved to wavelengths of 400 km or less with the completion of the backbone USArray/NSN network, which is particularly important for accurate imaging of the progressive transition from the cratonic core of the continent to younger provinces to the south and east.

ACKNOWLEDGEMENTS

Characterizing depth and lateral variations of anisotropy across the North American continent is partially supported by the NSF EarthScope science program through grant EAR-0345481.

REFERENCES

Li, A., D. W. Forsyth and K. M. Fischer (2003). Shear velocity structure and azimuthal anisotropy beneath eastern North America from Rayleigh wave inversion, J. Geophys. Res., 108, 2362, doi:10.1029/2002JB002259.

Van der Lee, S., K. Regenauer-Lieb, D. A. Yuen (2005). The role of water in connecting past and future episodes of subduction, Eos Trans. AGU, 86(52), Fall Meeting Suppl., Abstract DI43A-05.

Automated Estimation of Bulk Crustal Properties Using USArray Data

H. Philip Crotwell, Thomas J. Owens • University of South Carolina

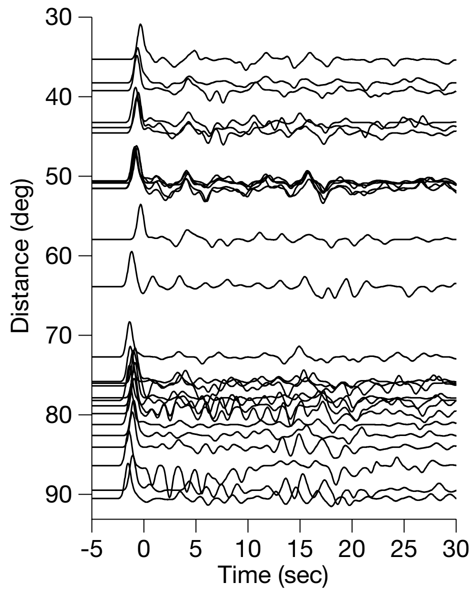
The EarthScope Automated Receiver Survey (EARS) [*Crotwell and Owens, 2005*] is using data collected by USArray to create crustal thickness and V_P/V_S measurements across the United States. EARS has also mined the historical archive of data at the IRIS Data Management Center to enhance the spatial resolution by incorporating stations from existing permanent networks as well as older PASSCAL deployments. While EARS is intended to focus on USArray, expanding the automated calculations to include the entire world is trivial. To date, the EARS database contains over 180,000 receiver functions for over 1700 stations from around the world.

BUILDING ON ESTABLISHED TOOLS

Automated processing is done by Standing Order for Data (SOD), a Data Handling Infrastructure client that automates seismic data handling and processing [*Owens et al, 2004*]. SOD monitors remote servers for new earthquakes and stations and, when it detects new data, creates requests based on events and channels that meet the user's criteria. SOD then retrieves the data and applies the users' processing sequence to each waveform.

From the receiver functions, we calculate HK stacks, based on the technique of Zhu and Kanamori. This technique transforms the receiver functions from amplitude as a function of time into amplitude as a function of crustal thickness, *H*, and the V_P/V_S ratio, *K*, by using predicted travel times of the Ps, PpPs and PsPs/PpPs phases over a suite of single-layer models. In addition, we weight the elements of the stack by the instantaneous phase of the receiver functions following the phase-weighted stacking method of Schimmel and Paulssen.

EARS products are all available from the EARS website (*www.seis.sc.edu/EARS*) and include receiver functions, calculated using the method of Ligorria and Ammon, and the processed seismograms that were used to generated them; crustal thickness versus V_P/V_S ratio (HK stacks); and estimates of crustal thickness and V_P/V_S for each station. The receiver functions and preprocessed seismograms are useful for seismologists wishing to do more detailed



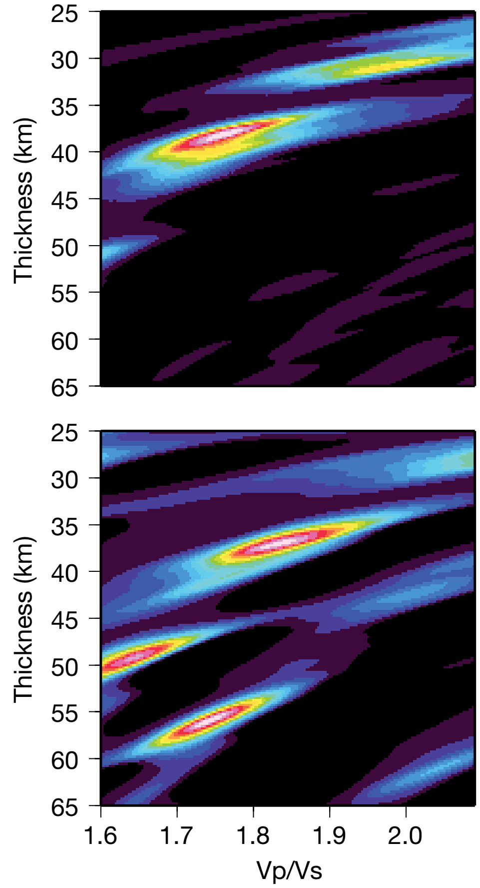
Record section of the 27 radial receiver functions for station TA.S08C. The direct P corresponds to time 0, while the Ps, PpPs and PsPs/PpSs reverberations arrive at about 4, 17 and 22 seconds, respectively.

receiver function studies or reproduce our results, while bulk crustal property estimates appeal to a wider audience.

RESULTS IN THE WESTERN US

Transportable Array station TA.S08C is a good example of our results, with 27 good quality receiver functions that produce an HK stack with a single, well-defined global maximum. The general trend of the maximum from left to right reflects the tradeoff curve of the Ps arrival, and is typical of HK stacks as Ps usually has the largest amplitude. The clear maximum at TA.S08C is consistent with interpretations of Moho thickness in other receiver functions in the area, such as Zandt *et al*. [*2004*], who interpret the Moho at the base of a complex region that potentially includes low-velocity zones. The EARS HK stack includes a second, shallower local maximum with a high V_P/V_S estimate that is consistent with an additional coherent arrival from this interval, illustrating the potential of EARS results to identify unusual structures for additional analysis.

In contrast, a stack for BK.CMB contains multiple maxima of similar size. Unphysical maxima can be caused by a poor quality receiver function at stations where very few individual functions are available, but 480 receiver functions were



Top: HK stack of the receiver functions from station TA.S08C. The maximum value occurs at a thickness of 38 ± 1.3 km and a V_P/V_S of 1.77 ± 0.03. Bottom: HK stack for station BK.CMB illustrating the problem of multiple maxima. The maximum is at 56 km even though the correct crustal thickness probably corresponds to the maximum at 37 km. The color scales from black at zero to white at the global maximum.

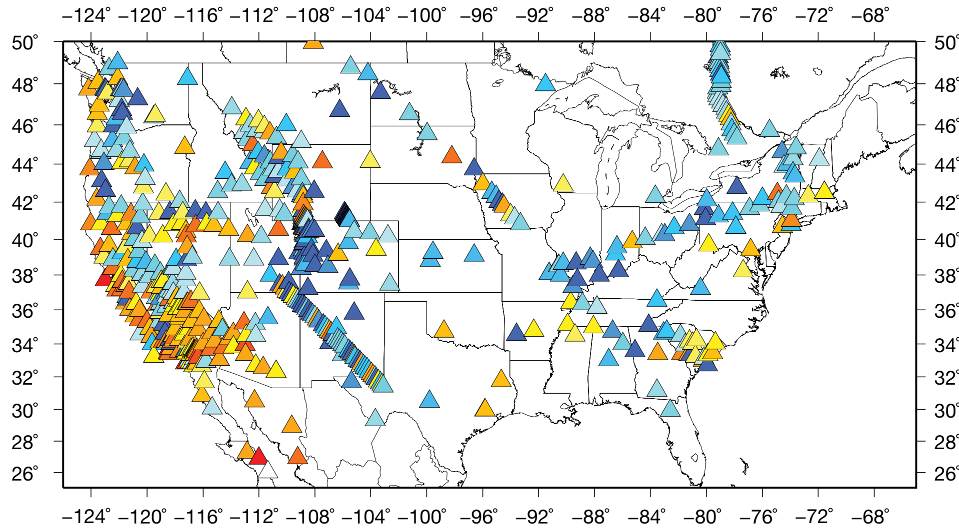
used to create the stack for this long-running permanent station. An analyst can use the range of reasonable crustal thicknesses and results from nearby stations to identify the peak that represents the true bulk crustal properties from multiple maxima with similar amplitudes. In the case of BK.CMB, the maximum at 37 km most likely corresponds to the crust, even though it is smaller in amplitude than the global maximum at 56 km.

Examination of the trends in the western US reveals both the potential for EARS to produce images of the broad variations in crust/upper mantle structure in the region and the need to resist interpretation of all features in terms of continental Moho depth. For example, recent work by Zandt *et. al*. [*2004*] showed that there are complexities in the Moho →

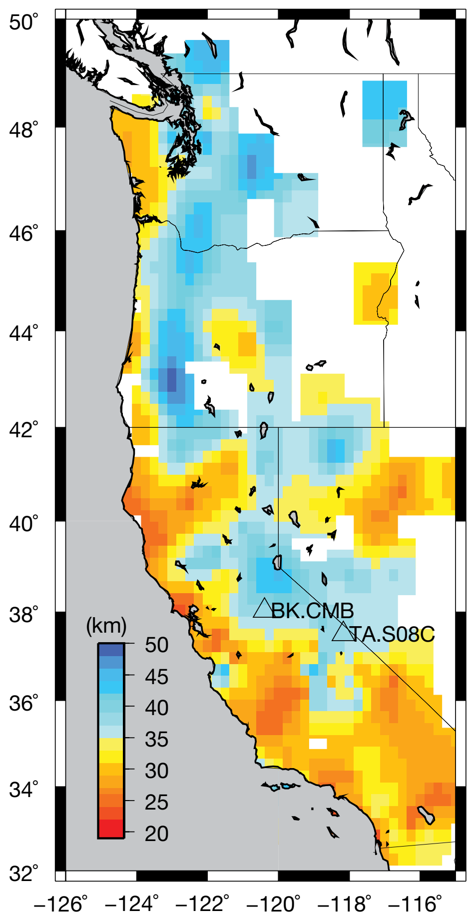
signal in the southern Sierras, just to the west/southwest of TA.S08C, which has been only broadly revealed in EARS. Detailed studies of these structures by the Sierra Nevada EarthScope Project in a densification of the Transportable Array reveal similarly complex structures north of TA.S08C that cannot be resolved in the average structure obtained by EARS.

IMPROVING AND EXTENDING THE PROCESS

Brocher *et al.* [*2003*] proposed that serpentinization in the upper mantle in a large area of the Pacific Northwest may complicate, obscure or even invert the signal from the base of the continental crust. Previous work by Crosson and Owens showed that the top of the subducted



EARS automated crustal thickness estimates at almost 600 stations within the continental US.



"Unreviewed" crustal thickness estimates for the western U.S. compiled from the EARS website. Thicknesses are generated by averaging thicknesses from HK maxima for all stations with 0.25 degree cells when possible. Cells over 0.75 degrees from an included station are shown in white.

plate can generate large converted phases. Taken in combination, our fully-automated "crustal thickness" estimates should be viewed with some skepticism since these known complications have yet to be taken into account.

Nevertheless, the EARS project provides a wealth of data and information and is ready to be exploited by the seismological community. We will continue to expand the database as new stations and new data become available. In addition, we plan to increase the quality assurance features within the system, both through improved software and through establishment of systematic analyst review.

The EARS software can effectively eliminate problem seismograms, but it does not eliminate all problems. At present, the software does not apply criteria based by geologic reasoning to evaluate the results; therefore, some analyst review will be necessary in a "production level" automated EARS system. Analyst review to accept or reject individual receiver functions flagged by EARS as marginal in the automated quality assessment will not be difficult.

The application of reasonable criteria for selecting the "Crustal Ps" arrival from multiple maxima in HK stacks based on *a priori* knowledge within a region is more challenging for both software and analysts. Our plans to address this include an on-line "polling" system to allow external users to weigh in on quality and interpretation issues. By enabling outside input, we hope to both improve the results as well as establish the notion of EARS as a community resource.

EARS is an ongoing project. The potential of this approach extends well beyond the current USArray footprint to the entire continental US and, in fact, the entire globe. Recent advances in seismological tools such as SOD and on-line tools for sharing community knowledge combined with the influx of new data from USArray have created the opportunity for products like receiver reference models to be a truly shared resource that can significantly enhance our effort to examine the details of our continent. ■

ACKNOWLEDGEMENTS

EARS is funded by the NSF EarthScope science program through grant EAR-0346114 to the University of South Carolina. Researchers publishing results that incorporate EARS results are requested to reference Crotwell and Owens [2005].

REFERENCES

Brocher, T. M., T. Parsons, A. M. Trehu, C. M. Snelson and M. A. Fisher (2003), Seismic evidence for widespread serpentinized forearc upper mantle along the Cascadia margin, Geology, 31, 267-270.

Crotwell, H. P., and T. J. Owens (2005), Automated receiver function processing, Seis. Res. Lett., 76, 702-708.

Owens, T. J., H. P. Crotwell, C. Groves and P. Oliver-Paull (2004), SOD: Standing Order for Data, Seis. Res. Lett., 75, 515-520.

Zandt, G., H. Gilbert, T. J. Owens, M. Ducea, J. Saleeby and C. H. Jones (2004), Active foundering of a continental arc root beneath the southern Sierra Nevada in California, Nature, 431, 41-46.

Interrogating the Deep Earth with USArray

Edward J. Garnero • Arizona State University

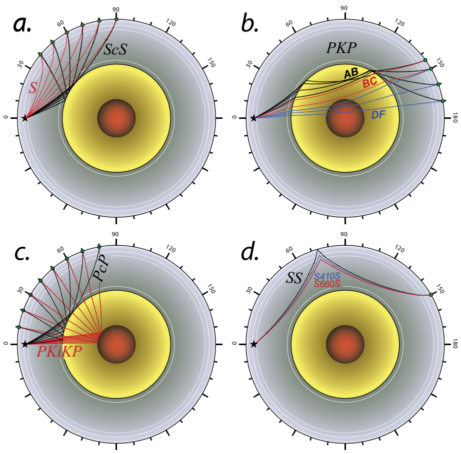
Investigating the deep, inaccessible realms within Earth is important since questions regarding the dynamics and evolution of the coupled crust-mantle and mantle-core systems cannot be answered without detailed knowledge of the interior. Active debate on a number of topics indicates that fundamental questions remain unresolved, such as the origin depth of mantle plumes that give rise to hot spot volcanism, the fate of subducted slabs, the properties of deep-mantle structures that appear related to large-scale mantle circulation, and the structure and evolution of the inner core.

Seismic methods currently provide the most detailed information on the interior. For decades, seismic tomography has depicted global mantle structure at relatively long wavelengths (e.g., lateral scales greater than a thousand km), and regional studies have revealed structures at shorter scales (less than 1000 km and in some cases hundreds of km). Limiting factors in the minimum resolvable scale length include the distance between seismic instruments (i.e., density of recorders) and the aperture or extent of the recording array.

WHAT AND WHERE CAN USARRAY PROBE?

USArray offers unprecedented density and aperture, especially in combination with broadband stations from regional networks, PASSCAL experiments, and Flexible Array deployments. Thus, it is now possible to employ classic array methodologies that involve stacking seismic data, including wavefield migration, which were generally not feasible for deep Earth studies in the past. Subtle seismic phases that take long paths through the interior can now be utilized with much greater confidence, owing to the vast data abundance and sampling density which enhances coherent signal energy in stacking procedures.

A variety of seismic phases, such as *ScS, SS, PcP, PKiKP,* and *PKP*, are used at different epicentral distances to study Earth's interior. For example, *ScS* is usually compared to the direct *S* wave at epicentral distances between 65° and 80° to investigate fine-scale structure of the D″ layer. Thus, USArray data from deep focus earthquakes in Fiji-Tonga, South America, and the northwest Pacific can be analyzed to study D″ and the core mantle boundary structure beneath the central Pacific Ocean, Central America and the Caribbean, and Alaska including the northernmost Pacific.

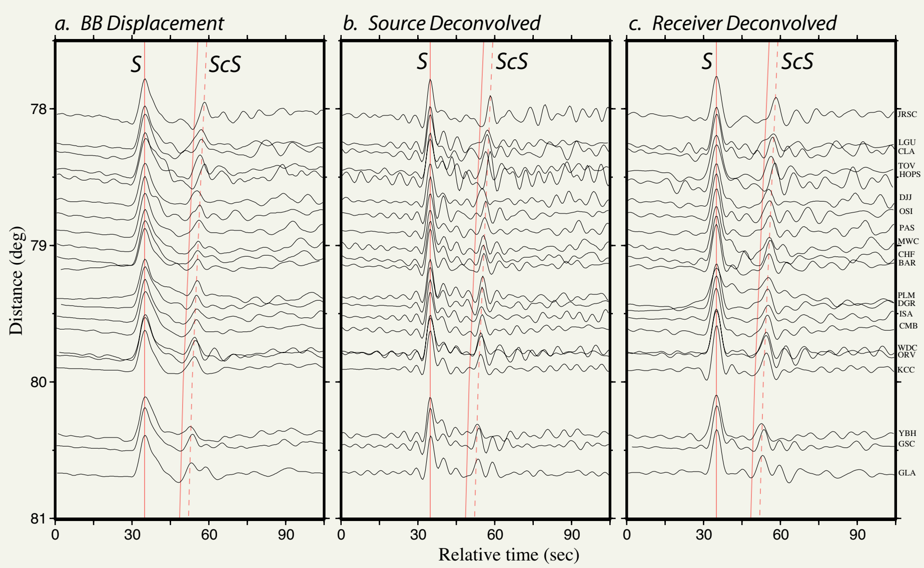


Different raypaths to USArray can be used as deep Earth probes only in restricted distance ranges from specific earthquake source regions, thus the deep interior will be sampled in disparate locations around the globe.

WAVEFORMS FROM DIFFERENT EARTHQUAKES AND RECEIVERS

One challenge in USArray research of the deep interior involves combining data from different stages of the array. As the Transportable Array (TA) marches east, new earthquakes will be recorded with wave paths sampling slightly different deep Earth regions. The different regions sampled may distinctly (differently) alter the waveform. Isolation of contributions to signal complexity from the Earth structure we seek to model first requires estimation of possible contributions from the earthquake source and receiver structure.

Removal of source and receiver effects is not trivial and typically requires some form of deconvolution. If enough receivers record a given earthquake, then an empirical source wavelet can be constructed from stacking a reference phase recorded across the network. This can then be ➔



Transverse component of the direct *S* wave and the core-reflected *ScS* on 21 broadband seismometers in California from a deep Fiji earthquake on November 11, 2004, aligned in time and amplitude on the *S* wave. Solid red lines denote arrival time predictions from the PREM reference model; the dashed red line denotes approximate delayed arrival times of observed *ScS* indicating reduced deep mantle velocities beneath the central Pacific. Instrument deconvolved displacement is displayed in panel (a). Panel (b) shows the same data after deconvolution of an empirical source constructed from stacking the cleanest, narrowly windowed *ScS* pulses. This results in a narrower pulse width, but the deconvolution introduces slight ringing. However, abundant recordings at many California stations exist for Fiji-Tonga earthquakes and thus stacking recordings at each station permits estimation of empirical station responses. These are subsequently deconvolved from traces in (b), and shown in panel (c). Key points from this experiment are: (i) energy between *S* and *ScS* is commonly imaged as due to deep mantle reflectance, however, receiver structure and earthquake source must first be addressed; note the variability of such energy from panel (a) through (c); and (ii) in some cases, significant coda energy following *ScS* persists, but is not found after *S*, and is thus most likely due to deep mantle heterogeneity.

deconvolved from the data for that earthquake. Similarly, if enough earthquakes are recorded at a specific seismic station, the earthquake-deconvolved records at that station can be used in the same fashion – stacking a reference seismic phase, and applying a second deconvolution of the empirical station response.

The success of this approach depends on the data quantity and quality, for which there is no objective measure. Nonetheless, preliminary experiments using USArray data recordings from the Fiji-Tonga earthquakes are encouraging. The double-deconvolution approach results in more impulse and simpler waveforms. Experiments such as this one will likely be very important as the TA marches east, if subtle waveform features are to be confidently modeled.

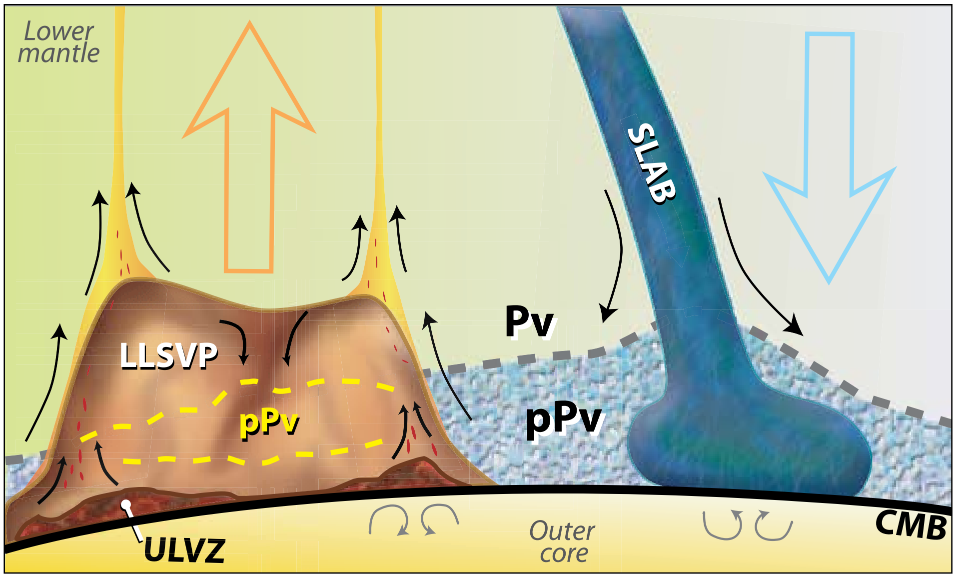
HANDLING ENORMOUS DATA SETS

The amount of USArray data available and appropriate for deep Earth studies is already well beyond that used in many past waveform studies. There is a natural tendency towards automated processing procedures to handle the copious data. But nearly any automation scheme can be defied by unexpected and interesting waveform or noise effects in data, resulting in averaging away, or worse, contaminating, the subtle sought-after waveform features, particularly at periods less than 10 s.

By spending slightly extra time to preview records, greater confidence is gained in results. Most automation approaches are easily adaptable for outreach and sharing, and this is facilitated by common freeware such as IRIS's data collection tools (*http://www.iris.edu/data/data.htm*), Seismic Analysis Code (*http://www.llnl.gov/sac*), the TauP Toolkit (*http://www.seis.sc.edu/software/TauP*), and Generic Mapping Tools, *GMT* (*http://gmt.soest.hawaii.edu*).

DEEP EARTH TARGETS WITH USARRAY

There is no shortage of attempts to unravel Earth's enigmatic interior (e.g., any of the recent monographs in *Further Reading*). Recent studies paint a picture of an extremely complex boundary layer at the base of the mantle that rivals Earth's surface boundary layer in implied chemical, structural, and dynamical behavior diversity. Some key structural components recently suggested for the base of the mantle includes chemically distinct piles,



Ancient subducted oceanic lithosphere (slab) may descend to the CMB in large-scale downwellings. The lowest few hundred km of the mantle is predicted to have a phase transformation from perovskite (*Pv*) to a post-perovskite (*pPv*) structure, which explains past evidence for a D″ discontinuity. Large, low shear velocity provinces (LLSVP), as seen in tomographic images, may be chemically distinct piles, whose sides guide upwelling motions and mantle plume initiation. *pPv* may be present in the piles, with the possibility of a second (deeper) phase transition back to *Pv* due to the large temperature increase in the thermal boundary within the LLSVP. Thin ultra-low velocity zones (ULVZ) with possible origin of partially molten material should be geographically correlated with these hottest zones.

a phase transition from Mg-Si perovskite to a "post-perovskite" structure, ultra-low velocity zones, anisotropy, and strong heterogeneity. While debate is still active on most of these features, they have been related to important whole mantle processes, such as plume initiation and a resting place for subducted slabs.

Higher up in the mantle, similar complexities and questions exist. For example, fine layering above the 410 km discontinuity, topography of the 410 and 660 phase boundaries, and heterogeneities and/or scattering in the transition zone and below, are all actively pursued and relate to important chemical and dynamical questions. Essential questions remain concerning the detailed structure of the outer and inner cores. With its unparalleled data volume and geographical coverage, USArray is uniquely suited to advance our knowledge on all these topics.

Large uncertainties still exist in deep Earth research due to long seismic wave paths and lateral averaging through the very structures we seek to image. USArray presents an opportunity for seismologists to work with researchers from other disciplines including geochemistry, geodynamics, and mineral physics. A multidisciplinary approach reduces the solution space of viable models and, increasingly, results from those disciplines guide our seismological research goals and interpretations. ■

ACKNOWLEDGEMENTS

High resolution imaging of deep mantle structure using USArray data is partially supported by the NSF EarthScope science program through grant EAR-0453944.

FOR FURTHER READING

Dehant, V., K. C. Creager, S-I. Karato, and S. Zatman, eds. (2003), Earth's Core: Dynamics, Structure, Rotation, 277 pp., AGU, Washington, D.C.

Gurnis, M., M. Wysession, E. Knittle and B. Buffet, eds. (1998), The Core-Mantle Boundary Region, 334 pp., AGU, Washington, D.C.

Karato, S., A. M. Forte, R. C. Liebermann, G. Masters, and L. Stixrude, eds. (2000), Earth's Deep Interior: Mineral Physics and Tomography From the Atomic to the Global Scale, 289 pp., AGU, Washington, D.C.

Manghnani, M. H., and T. Yagi, eds. (1998), Properties of Earth and Planetary Materials at High Pressure and Temperature, 562 pp., AGU, Washington, D.C.

van der Hilst, R. D., J. D. Bass, J. Matas, and J. Trampert, eds. (2005), Earth's Deep Mantle: Structure, Composition, and Evolution, 334 pp., AGU, Washington, D.C.

Imaging Continental Deformation:

EarthScope in the Field and the Classroom

Matthew J. Fouch • Arizona State University

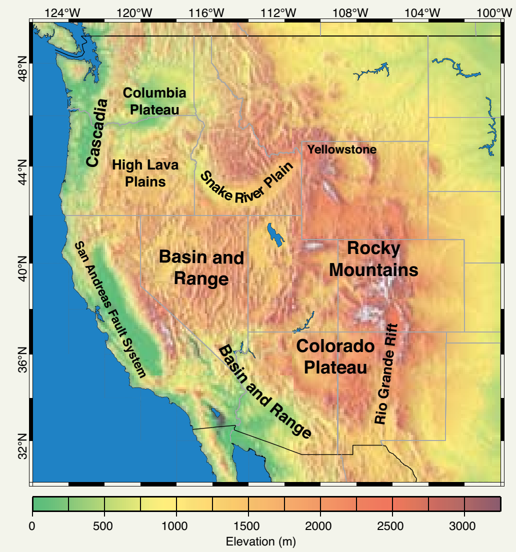
Understanding the connections between deformation in the lithosphere and asthenosphere is a critical pathway toward further development of plate tectonic theory. A particularly intriguing region on Earth is exhibited within the geologic structure of western North America, which does not follow conventional wisdom of a simple plate boundary and limited crustal deformation away from the plate margin. The ~2000-km-wide zone of surface deformation across this region therefore provides an excellent opportunity to examine the extent of both crust/mantle and lithosphere/asthenosphere coupling.

A research project recently funded with an NSF-EarthScope Early Faculty Career grant (NSF-CAREER) will focus on providing new constraints on coupling between the crust/mantle and lithosphere/asthenosphere systems. The primary goal is to develop a new range of methodologies to measure and model seismic anisotropy using USArray waveform data. In parallel, new data analysis tools for Earth science classrooms will be developed to enable students to process USArray and other publicly available seismic datasets.

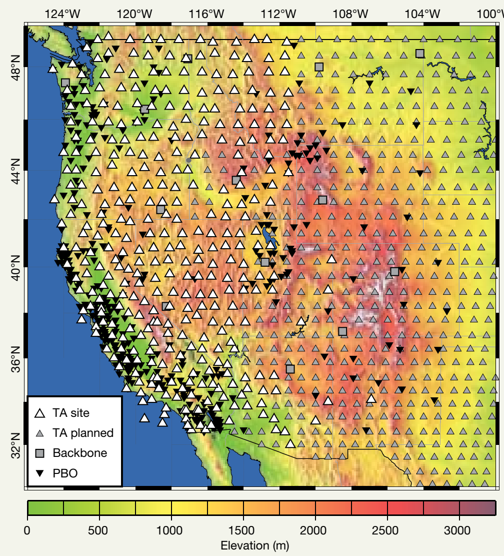
COMPLEMENTARY DATASETS

A unique aspect of EarthScope is its ability to image structure and deformation related to plate tectonics from the bottom up using seismological constraints provided by USArray data, while in concert providing the necessary geodetic dataset of surface deformation provided by the Plate Boundary Observatory (PBO). Thus, over the coming decade, EarthScope will supply the necessary datasets to investigate deformation in western North America in graphic detail.

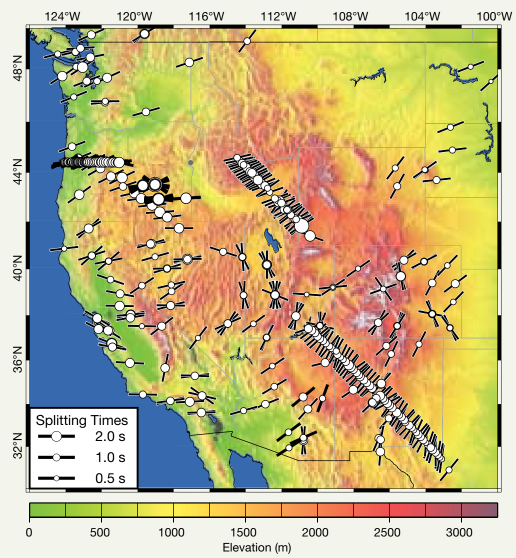
A key measure of the broader success of EarthScope will be the ability to inject this diverse range of datasets into the classrooms of Earth science students at a range of levels. For instance, the near real-time availability of these datasets provides a unique opportunity to develop new teaching modules for college-level courses. Data analysis methods such as receiver function imaging, shear wave splitting, and relative delay-time tomography are now ➔



The topography of western North America shows broad variations in tectonic structure. This region is particularly interesting for examination of crust and mantle deformation as it displays a complex range of tectonic settings over a broad zone, including the convergent margin of the Cascadia subduction zone, the transform plate boundary of the San Andreas and surrounding faults, the highly extended Basin and Range, the essentially undeformed Colorado Plateau, and the actively deforming Rocky Mountains.



Current and future status of EarthScope as of August 2006. White triangles denote installed or permitted USArray Transportable Array (TA) stations; gray triangles denote nominal future TA locations. Gray squares denote USArray Permanent Array stations; inverted black triangles mark locations of PBO GPS stations. Significant improvements in constraints of deformation across the entire western U.S. will be afforded by this dense coverage.



Published, in press, and unpublished shear wave splitting results compiled as part of the ASU upper mantle anisotropy database (*http://geophysics.asu.edu/anisotropy/upper*). Shear wave splitting fast polarization direction is denoted by azimuth of white bar; circle is scaled to splitting time. Measurements are plotted at each station location. While regional variations in shear wave splitting are evident, the extent of both small-scale variations and the effects of crustal anisotropy are not known. The increased coverage afforded by USArray will ameliorate much of this problem.

sufficiently developed. These methods can be utilized by non-seismologists with relatively little difficulty and are excellent candidates for developing course-related research projects.

CRUST AND MANTLE DEFORMATION

Our modern understanding of surface deformation has been provided by GPS data coupled with numerical modeling [*e.g., Calais et al*., 2003]. Similarly, our understanding of deformation in the deep crust and mantle is provided by a host of seismic analyses, most notably observations of seismic anisotropy [*e.g., Fouch and Rondenay,* 2006 and references therein]. A fundamental gap exists, however, in linking these disparate datasets.

Of particular importance is the effect of crustal anisotropy on methods generally utilized for measuring mantle anisotropy. For instance, although it is rarely addressed in shear wave splitting studies, crustal anisotropy can significantly contaminate splitting analyses, if it is present [*e.g., Okaya and Wu*, 2006]. In the western U.S., for example, deformation in the crust is clearly widespread, but constraints of crustal anisotropy are severely limited. Shear wave splitting results for the area exhibit clear variations from region to region, but it is still uncertain to what degree these measurements are influenced by crustal structure.

A primary goal of this project is to utilize USArray and other regional seismic station data to develop better models of crustal anisotropy and to evaluate how this structure influences shear wave splitting measurements. A range of methods is being explored to provide these constraints, including shear wave splitting measurements using local crustal earthquake data and those that utilize receiver functions for a range of backazimuths [*e.g., Frederiksen et al*., 2003]. The current database of published shear wave splitting results is based on a diverse set of approaches, but new measurements for USArray stations in the western U.S. will be taken with a single, consistent method [*Fouch*, 2006].

These efforts will be expanded to examine discrepancies in shear wave splitting measurements across the range of currently utilized methodologies. The results of these studies will enable correction of waveforms for crustal anisotropy before further evaluation for mantle anisotropy. These models of deformation can then be utilized in a series of forward- and inverse-modeling efforts that examine the link between surface and crustal deformation.

CLASSROOM DATA ANALYSIS

The second component of this effort will be to automate a series of existing seismic data analysis tools, which are a standard component of any broadband field seismology deployment. The automation of these tools will also benefit the broader community from a teaching perspective, as these codes will be available for use as part of course modules. The tools include shear wave splitting analysis, receiver function analysis, and body wave relative delay-time tomography.

Data will be obtained using the "Standing Order for Data" application (*http://www.seis.sc.edu/SOD/*) and imported into a Graphical User Interface (GUI) that enables the user to select data windows for further processing. For most analyses, processing will be performed either at the user's home institution or through a server housed at Arizona State University (ASU). A set of web-based tutorials for each of these processing methods will be made available to guide new users.

Most importantly, development of these tools will be focused toward institutions that may not have the computing infrastructure necessary for some of the calculations. The broader benefit of this effort is that a wide range of college courses should be able to utilize these data analysis modules.

ACKNOWLEDGEMENTS

The efforts outlined in this article are supported primarily by NSF-EarthScope CAREER grant 0548288.

REFERENCES

Calais, E., C. DeMets, and J.M. Nocquet (2003), Evidence for a post-3.16-Ma change in Nubia Eurasia North America plate motions?, Earth Planet. Sci. Lett., 216, 81-92.

Fouch, M.J. (2006), Shear wave splitting across the western U.S.: Application of high data volume processing tools, IRIS National Meeting, Tucson, AZ.

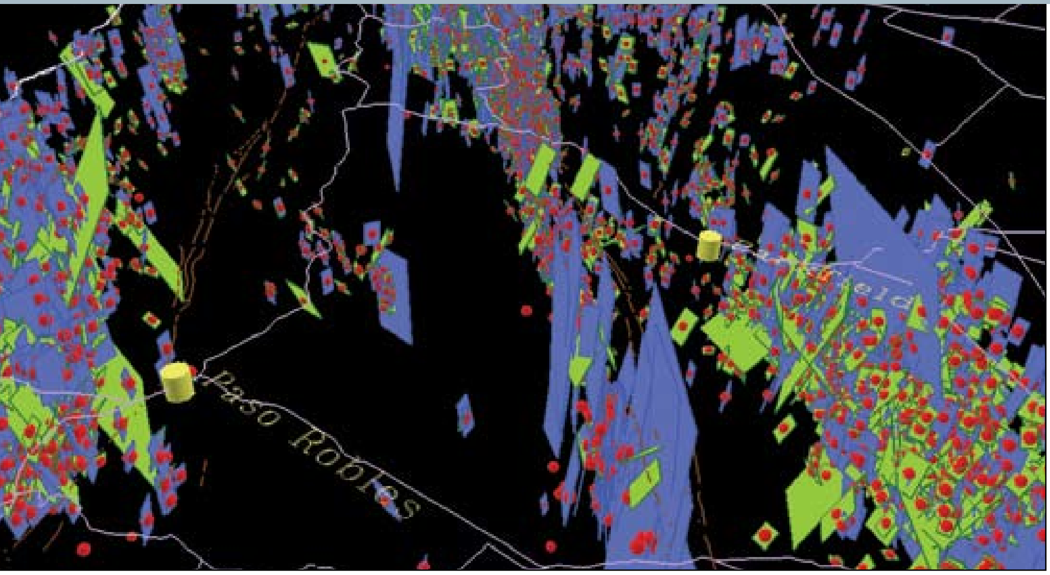
Fouch, M.J., and S. Rondenay (2006), Seismic anisotropy of stable continental interiors, Phys. Earth Planet. Int., 158, 292-320, doi:10.1016/j.pepi.2006.03.024.

Frederiksen, A.W., H. Folsom, and G. Zandt (2003), Neighbourhood inversion of teleseismic Ps conversions for anisotropy and layer dip, Geophys. J. Int., 155, 200-212.

Okaya, D., and F. Wu (2006), Imprint of crustal seismic anisotropy onto mantle shear-wave splits: Calibrated numerical tests, IRIS National Meeting, Tucson, AZ.

Scientific Visualizations of Multidimensional Data from USArray

Debi Kilb, Atul Nayak • University of California, San Diego



Seismicity distribution (red spheres) and associated nodal planes (squares) near Parkfield, California. Steeply dipping planes (>60°) are blue and shallow dipping planes (<60°) are green.

The EarthScope community is experiencing a revolution in the volume and quality of data currently being collected, including heterogeneous datasets from varied subdisciplines. These include earthquakes, sediment thickness, focal mechanisms, topography, tomography, Moho depth, aquifers, mines, geology, magnetics, faults, gravity, InSAR, and photo-imagery. Identifying similarities and differences within these data streams should help us advance our fields of research, but translation between file formats and domain knowledge often makes these comparisons challenging.

Using interactive 3-D visualization can help improve our understanding of the interdependencies between collected datasets. For example, to evaluate the evolution of the noise field over time as the USArray network expands, researchers at the Center for Imaging the Earth's Interior at the University of Colorado at Boulder, interpolate between data recorded at USArray stations to create temporal snapshots of surface wave tomography derived from ambient seismic noise. Similarly, the seismic displacement, velocity or acceleration of the wavefield generated by an earthquake recorded by USArray seismic stations can be depicted. These visualizations can be augmented with imagery from earthquake locations (latitude, longitude and depth), surface fault traces, and seismic instrument locations.

We can also assess the complexity of fault systems in well-instrumented regions using 3-D interactive visualizations of the two nodal planes (strike and dip) of first motion focal mechanism data, represented as two rectangles. A visual inspection can easily identify regions of high fault complexity (e.g., near Coalinga, CA) and regions of relative simplicity (e.g., near Parkfield, CA). We have experimented with many of these and other visualizations, which are available for free download through the visual objects library at the Scripps Institution of Oceanography's Visualization Center (*http://siovizcenter.ucsd.edu/library.php*). These include 3-D interactive visualizations, Quicktime movies and on-line tools, all of which can be explored using readily available freeware that runs on multiple platforms [*e.g., Windows, Mac OS X, SGI, Linux*].

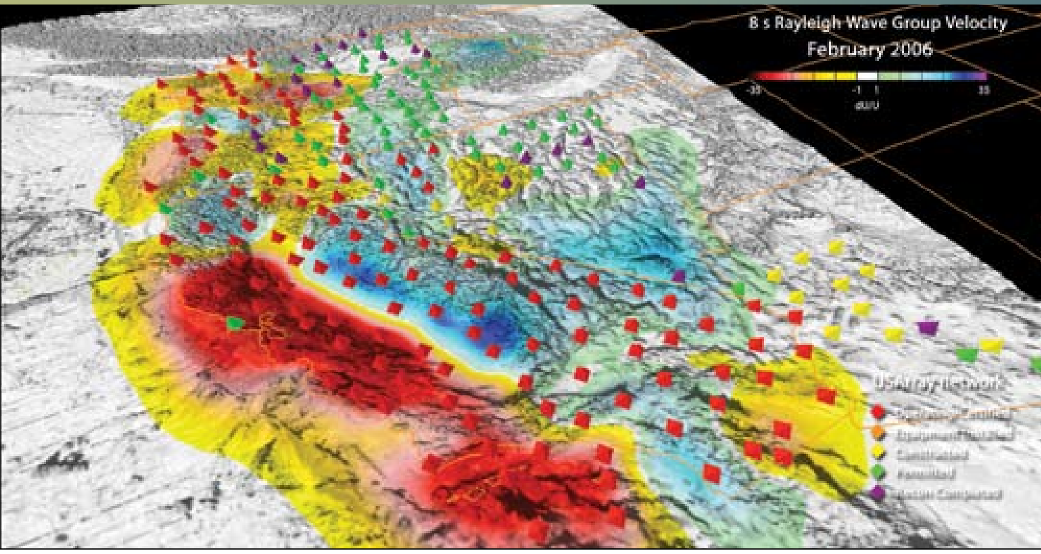
SOME CURRENT VISUALIZATIONS

Rayleigh Wave Dispersion: High-resolution ambient-noise surface wave tomography is determined monthly from USArray data and visualized as maps of Rayleigh wave group velocity at periods of 8 s, 16 s, and 24 s. From these results, we generate high-resolution maps of the temporal evolution (of the Rayleigh wave group velocity dispersion) throughout the California region. The Rayleigh wave groups recorded in the 8-s period movie are sensitive to shear wave speed to depths of ~10 km, those in the 16-s period movie are sensitive to shear wave speed to depths of ~20 km, and those in the 24-s period movie are sensitive to shear wave speed to depths of ~30 km.

Local Seismicity: Monthly records of earthquake data collected by the USArray network sensors are used to create movies of the temporal evolution of local seismicity as well as to chart the expansion of the network. Looking at data from perspectives other than map view or standard cross sections can help researchers refine their models.

Global Seismicity: Temporal evolution of earthquakes all around the world that are detected and recorded by USArray stations show an abundance of small magnitude ➔

Scripps Institution of Oceanography graduate student Jose Otero using the OptIPuter iCluster visualization wall in discussions with local media following the 8 October 2005 Pakistan earthquake.



Snapshot from a QuickTime movie sequence depicting the spatial variability of Rayleigh-wave group velocities determined from data collected by the USArray network in February 2006 draped on the regional topography. Diamonds represent station locations and are color-coded by status.

events close to the USArray network, which overwhelms the visualization. When we limit the data to events greater than magnitude 5.5 (the assumed completeness level), prominent mainshock/aftershock sequences that occurred during the study period are more easily identified (e.g., the 2004 Sumatra sequence).

Teleseismic Wavefield Evolution: Using the USArray station spacing as a semi-irregular grid, we create a 3-D mesh depicting the displacement, velocity or acceleration of teleseismic waves. From this, we can judge the coherency of the seismic waves across the network, easily identify any station polarity problems and assess how the waves become modified as they traverse large-scale tomography and topography variations, such as basins and mountain rages. These visualizations can be augmented with imagery from earthquake locations, surface fault traces, and seismic instrument locations.

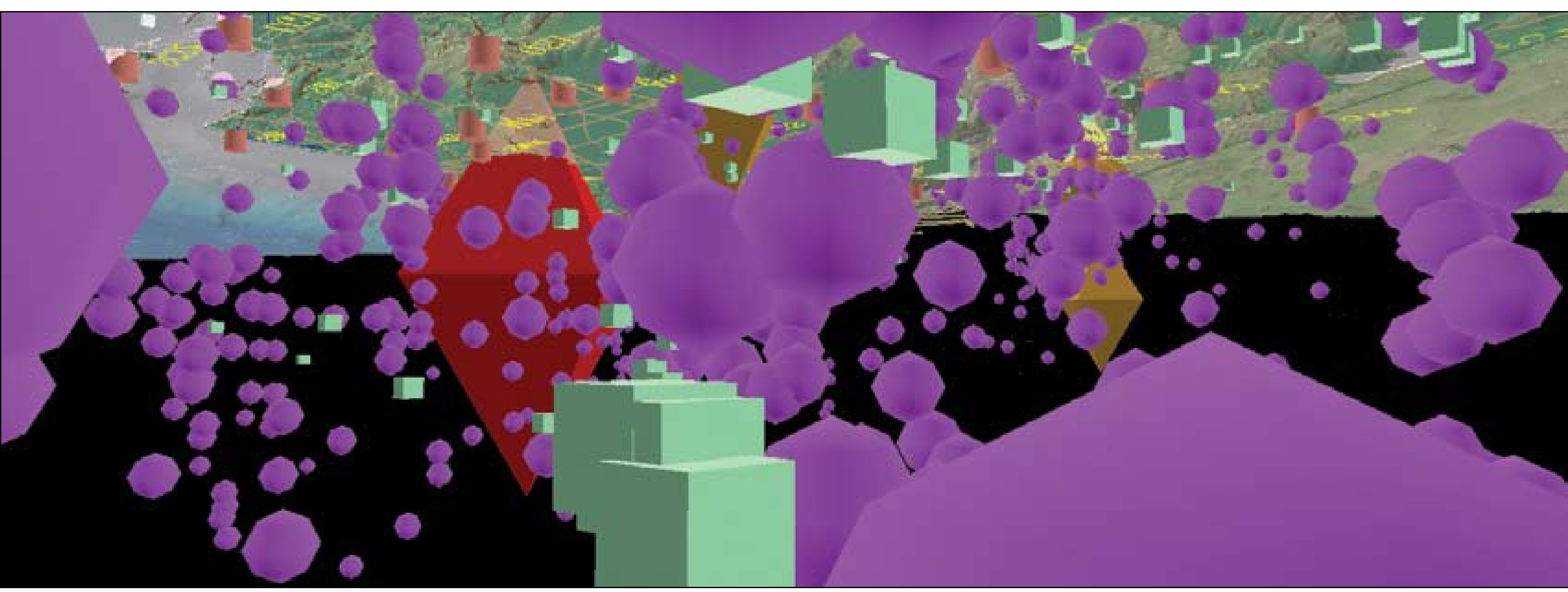
California Fault Planes: An interactive 3-D visualization of California seismicity includes earthquake hypocenters and each earthquake's two nodal planes (depicted as squares oriented with respect to the fault's strike and dip). Of the two possible nodal planes for each earthquake, usually we select the plane that aligns with the trend of the mapped faults in the region. These images can be used to assess the heterogeneity of the California fault structure and to test different focal mechanism determination techniques (e.g., comparing the FPFIT method with the HASH method). Near the SAFOD drill site, for example, the similar fault orientation of events along the San Andreas Fault, where rupture planes are primarily steeply dipping, contrast with the more heterogeneous fault cluster off the San Andreas Fault, near the Coalinga and San Simeon Faults, confirming the simplicity of the San Andreas Fault zone.

Notable Earthquakes: Interactive 3-D visualization of notable local, regional and global earthquakes include, but are not limited to, the location of the mainshock epicenter, mainshock hypocenter, historical seismicity, USArray seismic station locations and station codes, geographic boundaries, and topography of the region. These visualizations are typically posted in our visual objects library within a day or two of the mainshock event so they can be used in classrooms, outreach venues and for media response.

The visualizations described in this article as well as other visualizations and examples of USArray science can be downloaded and viewed using freeware from the SIO Visualization Center library at *http://www.siovizcenter.ucsd.edu/library.php*. If you would like help visualizing your EarthScope data please contact us at vizinfo@ucsd.edu.■

ACKNOWLEDGEMENTS

Community access to visualizations is partially supported by the NSF EarthScope science program through grant EAR-0545250.



Snapshot from an interactive 3-D visualization of earthquakes recorded near the San Jacinto Fault in southern California viewed from below ground. Larger earthquakes are depicted by larger symbols. Topography, roads, faults and bathymetry assist with georeferencing.

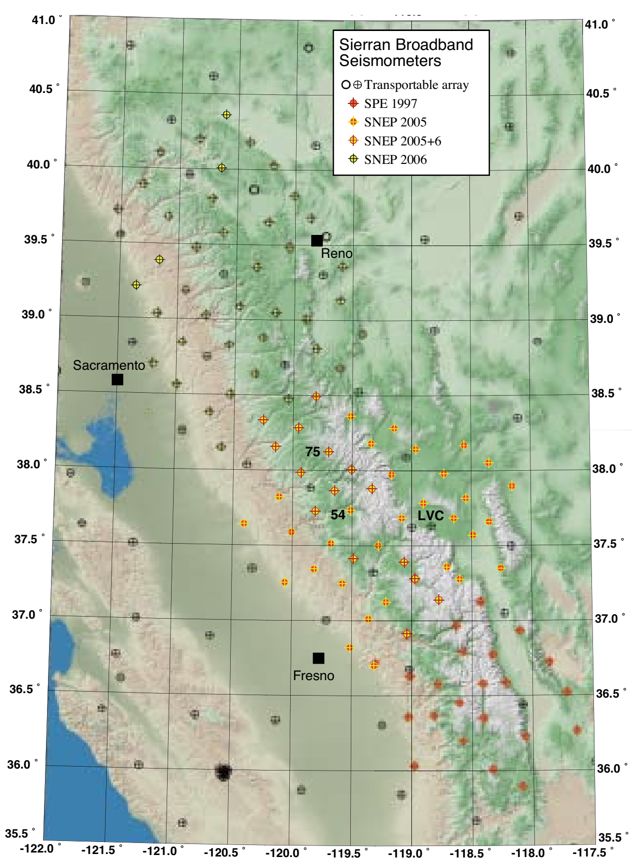
The Sierra Nevada EarthScope Project:

A First Report from the Broadband FlexArray

Craig H. Jones • University of Colorado at Boulder; Hersh Gilbert • Purdue University; George Zandt • University of Arizona; Tom Owens • University of South Carolina

One of the most exciting developments in field seismology over the past several years has been the funding of EarthScope and the creation of a new pool of portable seismometers to complement the Transportable Array. The broadband component of this FlexArray began with 40 stations in 2005 and will grow to about 200 stations over the next 3 years. The first use of this equipment has been to illuminate the structure of the central and northern Sierra Nevada, building upon earlier experiments in the southern Sierra.

The Sierra Nevada EarthScope project (SNEP; *http://cires.colorado.edu/people/jones.craig/SNEP/index.html*) has been undertaken to understand the removal of mantle lithosphere from under the Sierra Nevada. Our goals include imaging the Sierra tomographically with travel times and attenuation, providing a 3-D view of variations in discontinuity structure, and locating earthquakes in the region to better understand the seismotectonics. SNEP's seismology is paired with other disciplines funded as part of the Continental Dynamics project to learn the extent, signature, and impact of removal of dense mantle lithosphere with the intent of better characterizing the physical and chemical process of lithospheric foundering. This, in turn, should greatly improve our ability to test for this widely invoked, but ill-defined, process in other orogens.



Map of the SNEP deployments.

CHALLENGES IN A QUICK DEPLOYMENT

The logistics of the FlexArray and EarthScope funding mandate a quick transition from writing a proposal to deploying seismometers – just nine months for SNEP. Although the difficulty in rearranging schedules to mount a major field program in a few months is notable, gaining permission to deploy the seismometers in the short time required by EarthScope is most difficult.

Having only a few months lead-time can be troublesome with nearly any landowner, but land owned by the government, especially the federal government, produces the greatest difficulties. Land managers for Forest Service and BLM units dominated by recreational rather than extractive uses are the most hard-pressed for funds to process a deployment application in a short time period. To expedite permits, sites can be shifted to private landowners when practical, or they can be shifted to previously degraded areas (e.g., old mines), though care is required as such "sacrifice zones" also can be hotbeds of vandalism. Sites that cannot be shifted to either private or degraded lands require a well-developed justification. In one case, assistance from our Congressional representatives had a liberating effect on one land management agency.

Future EarthScope principal investigators might consider two options that we did not take. First, they might alert land managers when a proposal is submitted that there could be a specific deployment request with a short timeline. Second, although we escaped making payments for permits, budgeting for these costs may be wise. Previous deployments did not require fee payments for deployments in the Sierra, but litigation and changes to federal budgets are making such payments more and more necessary.

Proof of insurance and indemnification agreements are a common need for private sites. Some universities are unable to provide such documents and we recommend that IRIS consider serving as the umbrella for these needs.

INSTRUMENTATION

Once permitted, our deployments had to survive a Sierran winter. Most of the FlexArray equipment is familiar to PASSCAL researchers, with the possible exception of the flashcard-based RT130 data recorders. Previous experiments avoided the Sierra winters and their thick, heavy snow packs. Melting snow and heavy downpours occasionally flooded boxes containing the data acquisition system and other electronics, with generally disastrous consequences. Heavy snows often ➔

Solar panel at SNEP 75 (northwestern edge of Yosemite National Park) before (left) and after (right) a winter with probably more than 8.5m peak snow depth.

Tree-mounted solar panel being installed at SNEP 54 (Little Yosemite Valley). This station ran through the winter without interruption.

interrupted power by covering the solar panel for weeks or months. At the most extreme, equipment was destroyed by the weight of the snow.

Some sites successfully survived winter snows up to 6 m deep by either placing panels in trees, both gaining height and taking advantage of the depressed snow depths beneath trees, or post-mounted panels positioned where trees protected the panel from great snow depths. One site at near 3000 m elevation ran through the winter on a panel mounted on the ground at the top of a cliff. Curiously, the best protection against water was a heavy, carefully placed tarp, though this too can fail. To minimize flooding of electronics, we are now using an equipment vault based upon our sensor vault with a watertight lid. Our hope is to make the vaults airtight so that rising groundwater will be unable to rise into the pocket of air in the vault.

New vault design for SNEP phase 2 uses airtight top with open bottom for both sensor and electronics.

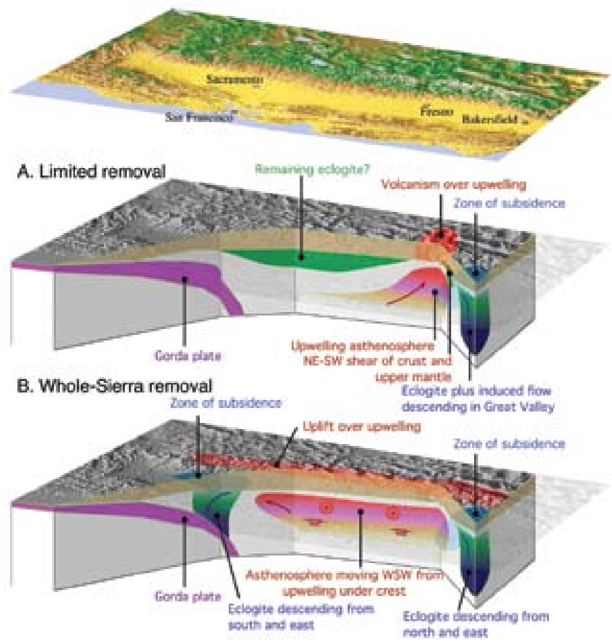
Unfortunately, some equipment problems amplified the environmental issues. Some stations' internal batteries died when the solar power system was cut off; the stations would not resume recording when power was restored. Other stations had complete failures of the GPS units. Revised default parameters and repaired GPS units will hopefully eliminate these issues.

EARLY SCIENCE

We entered the experiment with two principal concepts of the importance of the foundering of mantle lithosphere: (1) that it was limited to an area in the southern Sierra and consequently had a minor effect on elevations and tectonics [*Zandt*, 2003] or (2) that it was widespread in the eastern Sierra and westernmost Great Basin and responsible for substantial topographic uplift and tectonism [*Jones et al*., 2004]. Our very earliest examinations of the data are insufficient to reject either hypothesis, but some curious signals are clearly present.

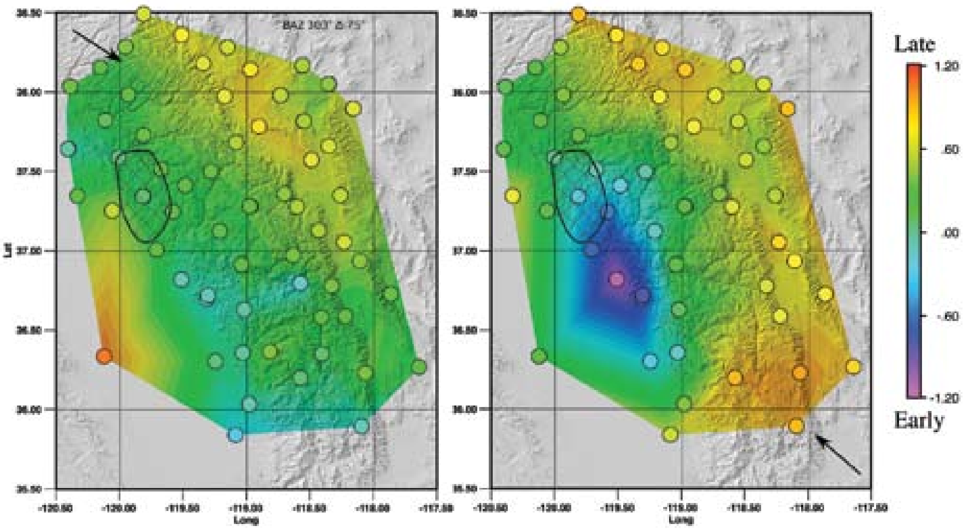
Analyses are underway for body wave tomography, surface wave tomography, shear-wave splitting, converted wave imaging, attenuation tomography, and local seismicity. It appears from the early results that the bulk of the seismological variations in the region lie within the Sierra and not to the east in the western Basin and Range.

Combining observations from our previous experiments in the Sierra, we are now able to view travel-time residuals along more than 300 km of the Sierra at stations separated by 25 km or less. The raw residuals provide interesting insights. Events to the northwest reveal a broad region of early arrivals along the Sierran foothills from about Fresno south to near the Garlock Fault. In contrast, events from the southeast generate a very compact area of exceptionally large early arrivals. The combination strongly indicates a body inclined to the southeast with a top near the Moho near Fresno. This peculiar geometry is difficult to reconcile with previous ideas of this body's original location, descent, and interaction with the asthenosphere.



Cartoon of contrasting hypotheses prior to the SNEP experiment.

Early receiver function stacks confirm that the western foothills have a weak to absent conversion from the Moho; this "Moho hole" was proposed to be caused by a cusp on the Moho induced by downward flow [*Zandt et al*., 2004]. Farther north we find that the area with a weak Moho is far wider and so less likely to reflect disruption of a conversion by Moho geometry. However, as in the south, it appears that a bright Moho conversion commonly found in the Basin and Range extends well into the Sierra, suggesting some Cenozoic modification of the Moho. These variations from south to north might indicate either original variations in the character of the Moho reflected in the appearance of the Foothills Metamorphic Belt to the north or variations related to a less well-developed drip under the central Sierra. ➔

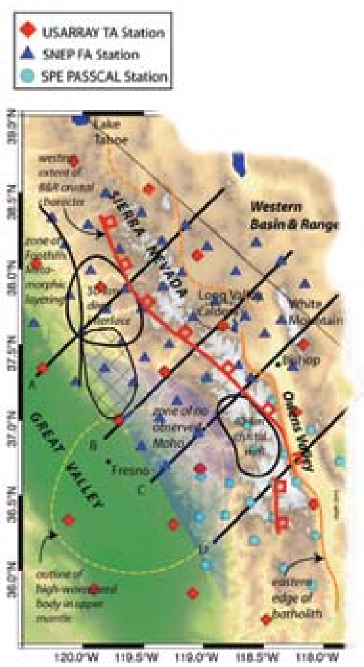


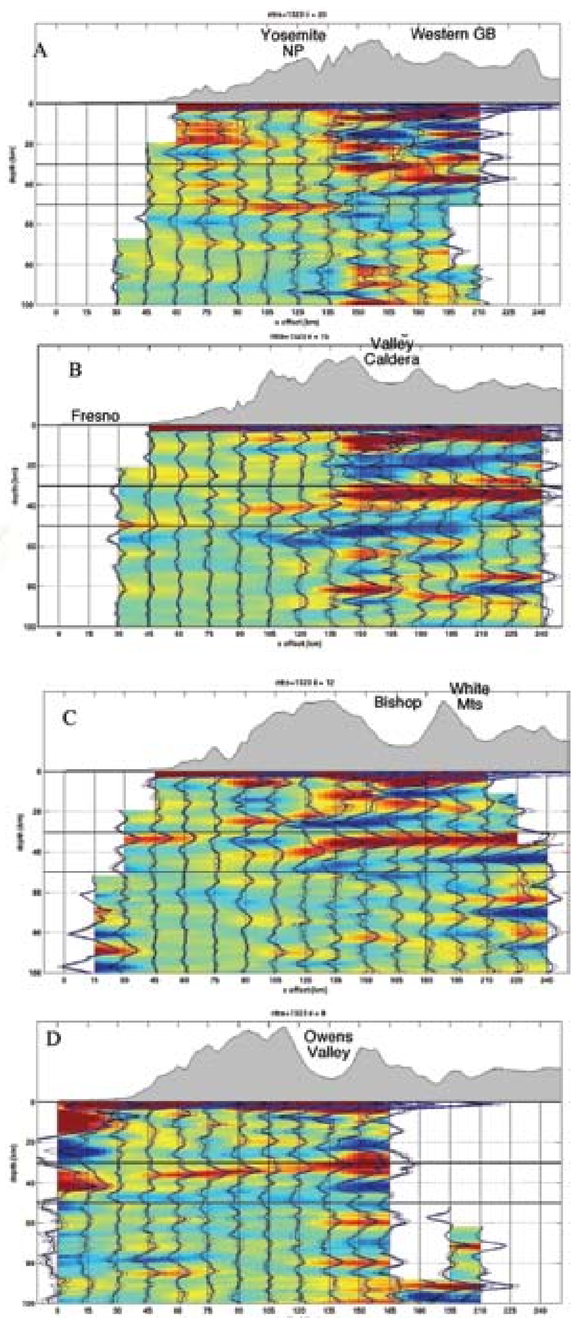
Maps of P-wave travel time residuals for 1997 SPE and 2005 SNEP deployments. Northwestern back-azimuths (left) show a broadly smeared area of early arrivals (light blue) in the southern foothills, but southeastern back-azimuths (right) reveal a compact area of profoundly early arrivals. Cross-hatched area has numerous deep (>20 km) earthquakes. Picks from a 1988 experiment extending to the Garlock Fault will be included later.

Lower crustal earthquakes have been recognized from a significant part of the western Sierra, but a concentration of small earthquakes, many with identical waveforms, are present at depths greater than 20 km in an area northeast of Fresno. This cluster of lower crustal earthquakes is on the northern edge of several features: the original “Moho Hole”, the Isabella anomaly’s shallowest extent, and the drowned topography at the western edge of the Sierra. All these relations suggest that this seismicity could well be generated by the foundering process.

Although both local and full-range foundering hypotheses remain viable at present, we are considering riffs on these ideas. Instead of the Isabella Anomaly being a single, limited foundering event, it might be the oldest of a northward younging series of instabilities in the mantle lithosphere. If this proves true, the Sierra displays a full evolution in lithospheric foundering from initiation in the north to descent into the asthenosphere in the south. Alternatively, if the whole Sierra lost lithosphere, it seems likely that there is considerable connection between the pre-existing crustal geology (e.g., Foothills metamorphic belt and Miocene Cascadia arc) and the subsequent evolution of the foundering. The second phase of the Flexible Array deployment has been adjusted to reflect this evolution in our thinking.

As seismological fieldwork winds down in 2007, our colleagues on the Sierra Drips Continental Dynamics Project will be collecting and analyzing a large variety of complementary information. As we attempt to define the places where subsurface loads were present and have been removed the geomorphological and stratigraphic work will consider the impact of these loads on the topography of the region. Refinements of the anisotropic fabrics in the mantle will bear on geodynamic models developed to explore the magmatism associated with these events, and both of these, in turn, will be examined in the light of petrologic and geochemical studies of Late Cenozoic magmatism in the region. We look forward to productive collaborations with these colleagues and the development of a detailed and multidisciplinary view of the geodynamics of foundering of continental lithosphere.





Cross sections of stacked receiver functions. Cross-hatched area between profiles A and B with >20 km deep earthquakes.

ACKNOWLEDGEMENTS

Study of Lithospheric Foundering Beneath the Sierra Nevada is partially supported by the NSF EarthScope Science Program through grants EAR 04-54524, 04-54535, and 04-54554.

Workshop at the University of São Paulo

Managing Waveform Data and Related Metadata for Seismic Networks

Mari Francissen • IRIS Consortium

The Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo.

Network operators from 22 Caribbean, Central American and South American countries met in July with a primary goal of increasing collaboration and fostering open exchange and access of data, both regionally and with the worldwide community. The National Science Foundation, through the IRIS Data Management System, was the major sponsor of the workshop; CERESIS, IASPEI, and the University of São Paulo provided additional support.

The second in a series to disseminate experience and expertise in seismological data management, this workshop focused on networks from the Americas. Next year, IRIS plans to conduct a similar workshop in Southeast Asia. Directed at network managers, the goal is to provide training in the fundamentals of seismic instrumentation, network operation and data management, including advanced data management systems, the scientific basis of modern seismometry and a short introduction to modern analysis methods. Participants leave the workshop prepared to establish and maintain their own data center and to link access data from the growing global network.

The Convening Committee consisted of Christa von Hillebrandt-Andrade (Puerto Rico Seismic Network), Jesus Berrocal and Marcelo Assumpçao (University of São Paulo), and Tim Ahern (IRIS). Logistics were arranged by Mari Francissen (IRIS) and, locally, Jesus Berrocal. Complete information about the workshop is available at *www.iris.edu/workshops/2006saopaulo/*.

WORKSHOP TOPICS

Jim Fowler and Mark Alvarez from the PASSCAL Instrument Center presented a well-received lecture on site selection for broadband instrumentation. Their review of "best practices" for sensor hardware and site selection, installation, and communication options focused on ways to avoid noisy or unstable configurations, using real-world examples were used to illustrate how these practices can eliminate problems early and improve data quality at the source.

Erhard Weilandt (Stuttgart University) gave lectures on seismometry, measurement of noise and seismometer calibration. Reinoud Sleeman (ORFEUS) presented information on digitizers and quality control. Joachim Wasserman's (University of München) talks focused on digital filter theory. Göran Ekström (Columbia University) lectured on the use of broadband seismic data in moment tensor determination, noise and quality control, and new discoveries found in continuously recorded seismic data.

Rick Benson and Chad Trabant of the DMC gave lectures on quality control and data manipulation utilities, including the storage of information in SEED format. They also introduced the Portable Data Collection Center (PDCC), an application that allows networks to manage their metadata. Hands-on computer sessions were an integral part of the workshop and participants used publicly available software for digital filtering and other data processing, as well as PDCC.

REGIONAL NETWORKING

During the workshop, participants from Argentina, Brazil, Cuba, Dominican Republic, Jamaica, Mexico, Nicaragua, Panama, Peru, Puerto Rico and Venezuela gave briefings on the status of the networks in their countries. These presentations helped improve mutual understanding of seismological activities occurring across Latin America.

Chad Trabant offers advice during a hands-on computer session.

Workshop participants also enjoyed social events organized by the local hosts at the University of São Paulo. Although Brazil was not playing in the World Cup final on the first day of the workshop, football enthusiasm persisted during a barbeque at the University of São Paulo, complete with a large-screen projection video system showing the match. After the third day of the workshop, a banquet was held at a local Churrascaria. Lively camaraderie and excellent food continued throughout the week. ■

ACKNOWLEDGEMENTS

IRIS extends its thanks to the local organizers at the University of São Paulo and special thanks to Jesus Berrocal, Marcelo Assumpçao and Marcelo di Bianchi for all of their work and effort that made the workshop a great success.

The IRIS Undergraduate Internship Program Gets "Orientated" with New Funding from NSF

Michael Hubenthal • IRIS Consortium; Rick Aster • New Mexico Tech

IRIS interns explore a trench across the Holocene Socorro Fault as part of a week-long orientation that is a new addition to the Internship Program. (Photo: Kyle Jones)

The 2006 IRIS undergraduate internship class, representing nine different U.S. institutions, participated in an intensive, weeklong orientation from May 28 to June 3, on the campus of New Mexico Tech. With funding from the National Science Foundation, the IRIS Education and Outreach program is developing a novel approach to internships. This new approach blends the spirit of traditional Research Experience for Undergraduates (REU) programs, which traditionally host participants in a single location, with IRIS's successful experience both hosting students at widely separated institutions and working closely with individual researchers [*Hubenthal et al., 2004*]. This blending is being achieved through the use of web-based communications technology and other enhancements based on the program's ongoing evaluation efforts. Key to the IRIS "blended REU" model is a combination of:

- One-on-one mentoring by researchers at IRIS institutions across the US;
- Developing a strong learning community among interns through both face-to-face and virtual interactions;
- Developing interns' abilities to self-evaluate and work independently, through carefully designed web-based tools;
- Increasing interns' awareness of the IRIS community, its activities, and general current Earth science;
- Introduction to professional career opportunities in Earth science.

Thus, beginning with this summer's internship class, IRIS interns will reap the benefits of a proven, refined internship program, as well as experiencing valuable remote interactions with their peers that more closely represent the intensive computer and networking culture of modern scientific research and the technological workplace in general.

2006 ORIENTATION

The goal of the new week-long orientation is to provide interns with an introduction to some of the most exciting aspects of modern seismology and to foster a strong sense of community prior to sending them to their internship site to conduct their summer research. New Mexico Tech was selected as the site for the initial student orientation because of its excellent location for field experiences in the Rio Grande rift valley, its research and computational facilities, its extensive field equipment and the availability of dormitory housing. Scientists from IRIS and the broader Earth science community shared their time and expertise to lead a variety of interactive intern-development sessions designed to enhance student understanding and to improve student collaboration. Topics included in the intensive orientation program included:

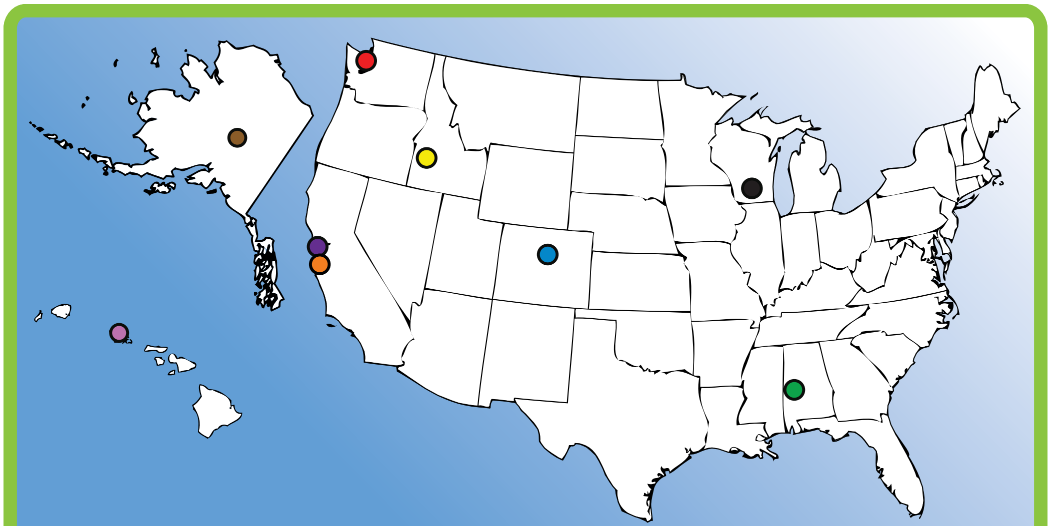
- A broad overview of seismology, seismometry, and related fields such as geodetics and cutting-edge research topics;
- A refraction-based field experiment and data analysis project;
- Field trips to regional tectonic/geologic sites in central New Mexico;
- An IRIS internship alumni/careers panel discussion with participants ranging from incipient graduates to long-standing professionals and academics;
- Primers in focal mechanisms, geophysical inverse theory, and receiver functions;
- Computer programming for signal processing and waveform analysis using the Matlab software and;
- A comprehensive tour of the IRIS PASSCAL Instrument Center.

Interns explore the "Seismogram-of-the-day" with Sue Bilek of New Mexico Tech. (Photo: Kyle Jones)

In addition to introducing new science content, the IRIS internship orientation included ample opportunities for interns to get to know one another, have fun and make friends. These included evening social activities; shared dorms; pool night featuring "bad geophysics" movies; field trips to the New Mexican desert and Albuquerque Seismological Lab; a tram ride to the top of the Sandias Mountains, with an afternoon talk on extensional tectonics; and an afternoon to explore the New Mexico Museum of Natural History and to see the *Everest* IMAX film. At the end of the week, all the interns agreed the orientation had been a fun and valuable experience that helped them feel prepared to get the most out of their summer experience. Perhaps most importantly, the majority of the interns felt that one of the best parts of the orientation was getting to be "part of a group." ➔

CONNECTING THROUGH TECHNOLOGY

Face-to-face contact is no longer the only way to connect individuals working on related problems as a community of learners. In 2002, 81% of all U.S. institutions of higher learning offered at least one fully on-line or "blended" course (combined face-to-face and on-line media in distance learning). This translates into over 1.6 million students gaining experience with distance learning by taking at least one on-line course during the fall of 2002 alone [*Allen et al., 2003*]. Hence, current technology and recent research on distance learning and building on-line learning communities, combined with a generation of students that are comfortable using technology to communicate and learn, makes the time ripe for IRIS to help students maintain a sense of cohesion despite being placed throughout the U.S. for their internships. To ensure that this connection occurs, a key aspect of the orientation agenda was several sessions that provided training in the use of web-based message boards and blogs.



Key	Student	S. Instituion	Host	Host Institution	Topic of Study
●	Derek Grimm	Colorado School of Mines	Greg Beroza	Stanford University	Non-volcanic tremor in N. California
●	Adam Halpart	Rice University	Lee Liberty	Boise State University	Imaging active faults in the Puget Lowlands
●	Whitney Harris	Montana Tech	Andrew Goodlife	U. Alabama	Transition from continental rifting to seafloor spreading in the Woodlark Basin, Papua New Guinea
●	James Hebden	Northwestern University	Robert Dunn	U. Hawaii	Seismic Wave Propagation along Mid-Ocean Ridges
●	Will Levandowski	Princeton	Craig Jones	U. Colorado	Role and process of removal of mafic crust in the Sierra Nevadas
●	Dylan Mathieu	Washington University	Cliff Thurber	U. Wisconsin-Madison	Flexible Array project at SAFOD
●	Rachel Murphy	Norte Dame	Doug Christensen	U. Alaska Fairbanks	ARCTIC and MOOS experiments in Alaska
●	Rob Porritt	Michigan Tech	Richard Allen	U. California, Berkeley	ETS in Northern California
●	Carl Ulberg	Carleton College	Ken Creager	U. Washington	Cascadia Subduction in Western Washington

The distributed nature of the IRIS Consortium requires innovative solutions to help students remain connected during their internships.

These tools are used to maintain contact between interns during the summer and as a source of peer-based assistance and collaboration. At the beginning of the summer, interns responded to specific questions in their blogs posed by Andy Frassetto, a graduate student mentor who is an alumnus of the IRIS internship program. Such questions focused on encouraging interns to identify goals for the summer and to develop plans with their hosts to reach these goals. To date, the use of blogs by the interns has ranged from a post every week to every other day. For the most frequent users, the blogs transitioned from responses to questions into a documentation of the students' thinking including planning how to approach a given learning task, monitoring comprehension, and evaluating progress toward the completion of a task. The blogs also allowed internship hosts to gain insights into interns' current thinking and development.

The internship discussion boards enable students to quickly and easily post topics of interest or reply to posts from their peers. Most on-line discussions were both initiated and responded by the interns, though the intern alumnus offered advice, directed interns to additional resources or made suggestions. Topics of discussion from this summer have ranged from the social "How is it going?" to technical discussions of the easiest way to get data from the IRIS Data Management Center and parse it into useable quantities to conceptual discussion on subjects like tremor. The discussion boards remain available to the students throughout the fall semester to help encourage interaction between the students as they prepare for the Fall AGU Meeting where they will present the results of their summer work. The interns will meet again as a group at the IRIS Undergraduate Internship Alumni Gathering held during the AGU meeting.

For further information on the IRIS Undergraduate Internship Program, how to participate in 2007, and the 2006 orientation agenda, or to view the lab activities used by orientation staff, please visit: *www.iris.edu/internship* ■

2006 ORIENTATION STAFF

Rick Aster	New Mexico Tech
Andy Frassetto†♥	U. of Arizona
Michael Hubenthal	IRIS
Peter Mozley	New Mexico Tech
Glenn Spinelli	New Mexico Tech
Anne Sheehan	U. of Colorado
Susan Bilek	New Mexico Tech
Bruce Harrison	New Mexico Tech
Kate Miller	UTEP
Mark Murray	New Mexico Tech
John Taber	IRIS
Lind Gee	USGS
Kyle Jones✦	New Mexico Tech
Danny Bowman✦♥	MacAlester College
Bruce Beaudoin	New Mexico Tech
Mousumi Roy	U. of New Mexico

✦ Undergrad student assistants
† Grad Student assistants
♥ Program Alumni

ACKNOWLEDGEMENTS

The IRIS internship orientation, hosted by the NMT Geophysics Program and the IRIS PASSCAL Instrument Center was a new addition as a result of grant EAR-0453427 from the National Science Foundation to the IRIS Education and Outreach Program.

REFERENCES

Allen, E. I., K. R. Joyce, and J. Seaman (2003), Sizing the Opportunity: The Quality and Extent of On-line Education in the United States, 2002 and 2003, Sloan Center for On-line Education (SCOLE), United States.

Hubenthal, M., Taber, J., Aster, R., Schwartz, S. (2004). Inputs to the Seismology Student Pipeline: The IRIS Undergraduate Internship Program. Poster presented at Annual IRIS Workshop, Tucson, AZ.

The USGS Earthquake Hazards Program:

Support for Academic Seismology Research and Earthquake Monitoring

William Leith, Elizabeth Lemersal • U.S. Geological Survey, Reston, VA; Harley Benz • U.S. Geological Survey, Golden, CO

This year, the USGS Earthquake Hazards Program will provide approximately $11 million in funding, competitively awarded to IRIS member institutions, for earthquake and related research and for the operation of regional seismic and geodetic networks. This amount approaches one-quarter of the Program's net funding, and comprises more than 80% of the total awards made by the Earthquake Hazards Program to private and public institutions as part of the National Earthquake Hazards Reduction Program (NEHRP).

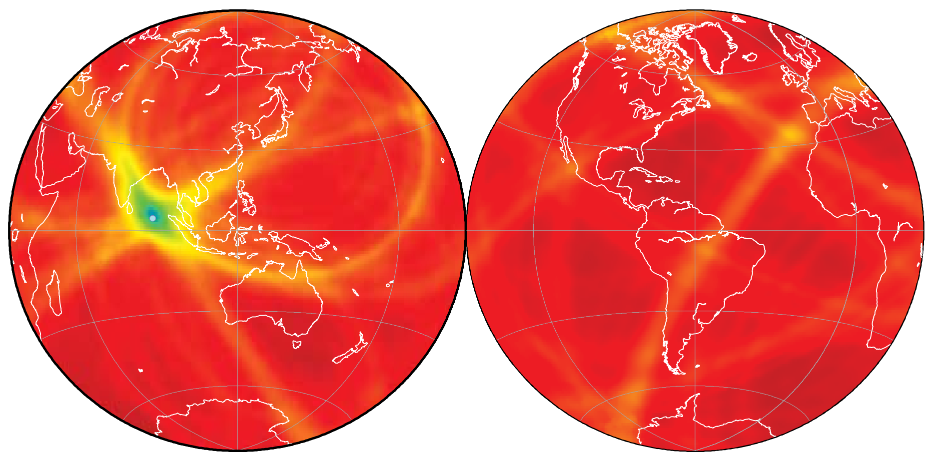
The goal of NEHRP is to mitigate earthquake losses that can occur in many parts of the nation by providing Earth science data and assessments essential for land-use planning, engineering design, and emergency preparedness decisions. The USGS participates in the NEHRP with the National Science Foundation (NSF), the Federal Emergency Management Agency, and the National Institute of Standards and Technology, which has the lead role to plan and coordinate the national effort. In addition to activities performed by USGS staff, expertise in earthquake studies that exist outside the Federal Government is applied through a substantial program of grants, cooperative agreements, and/or contracts with universities, state, regional and local government agencies, and the private sector. Within NEHRP, USGS provides support for targeted research in seismology, earthquake hazard assessments, earthquake effects, and tectonics – facilitating the application of fundamental research in seismology and engineering supported by NSF.

In 2006, the USGS Earthquake Hazards Program awarded $4.4 million in research grants, $2.4 million in cooperative agreements for research (including $1.1 million for research activity at Southern California Earthquake Center), and $5.5 million in cooperative agreements for seismic monitoring. Of 272 research proposals received, 96 (35%) were awarded grants.

Each year, the Earthquake Hazards Program issues an announcement of the availability of funds for universities, regional and local government agencies, private-sector companies, and non-profit organizations to carry out research related to earthquake studies. External research is solicited to develop information, knowledge, and methods relevant to the major program elements:

- National and regional earthquake hazards assessments;
- Earthquake information, monitoring, and notification;
- Research on earthquake occurrence, physics, and effects; and
- Earthquake safety policy

The information and monitoring element is primarily related to the network operations and development of the ANSS and is carried out under three-year cooperative agreements, but also includes geodetic monitoring, applied research in monitoring technology, and earthquake source characterization. The Earthquake→



Global grid of stacked amplitudes at the centroid time of the December 2004 Sumatra-Andaman Islands earthquake. The light blue circle indicates the location of the maximum amplitude at this time. (Courtesy of Jascha Polet.)

For the last three years, USGS external research has included projects that apply directly to improving the services of the National Earthquake Information Center (NEIC). These improvements include earthquake notification and response functions as well as the quality and content of earthquake information products for research applications and general interest. In addition to funding internal improvements at NEIC, the President's Tsunami Risk Reduction Initiative has made it possible to fund external research during 2005-2006. The research has focused on improved source characterization (locations, moment tensors, finite fault modeling, etc.) and rapid impact assessment (global *ShakeMaps*, population exposure, and so on). Presently, there are eight ongoing research projects with both university researchers and consulting firms.

Current grants supporting NEIC are focused on exploring the feasibility of cross-correlation methods for improved relative relocations of earthquake sequences and swarms, applications of three-dimensional models and station corrections for improved absolute single-event locations, and improved implementation of regional and global moment tensor methods. In addition, the USGS is working with researchers on new algorithms and procedures for rapid modeling of finite fault parameters and on surface wave detection and imaging algorithms. As NEIC implements new and emerging technologies and modeling procedures, the external grants activity has become a critical component of NEIC development, which relies on innovative research to more effectively utilize the capabilities of the GSN, the ANSS backbone, and regional network stations.

An example of work currently under development is a global earthquake detector/locator using very long-period (>60 s), vertical-component surface waves. Using surface wave dispersion relations, waveform envelopes are continuously back-projected onto a global grid. A test system using a small subset (20) of available stations reliably located global earthquakes down to a magnitude 5.5. More importantly, the method can be used to provide reliable near real-time locations and magnitudes for very large earthquakes, such as those near Sumatra of December 2004 and March 2005.

Hazards Program places high priority on investigations in geographic areas where large populations are exposed to significant seismic risk.

Despite many years of near-flat funding and in the face of annual inflationary increases in fixed costs, USGS has purposefully maintained funding for external research activities despite mounting internal budget pressures. At the same time, under the developing Advanced National Seismic System, we have significantly expanded support for regional seismic monitoring, increasing funding to university-operated regional networks (all of which are IRIS member institutions) and states by over 80% between 2000 and 2006.

The Earthquake Hazards Program has also, on the advice of our external advisory committee and internal program council, made a commitment to continue support for competitively selected external research and monitoring. In the future, as resources increase to the Earthquake Hazards Program, additional funding will go to the external component of the program.

Scientific research is critical to helping build safer communities nationwide. The risks that earthquakes pose to society, including death, injury and economic loss, can be greatly reduced by better planning, construction and mitigation practices before earthquakes happen, and by providing critical and timely information to enable effective response after they occur. We can only hope to reduce earthquake risk through the combined efforts of our internal and external research and monitoring efforts. The external component is a great strength of the USGS Earthquake Hazards Program, and indeed vital to the success of NEHRP as a whole. We welcome feedback on how to make the most of these partnerships. ■

CEA-IRIS Joint Session in Beijing

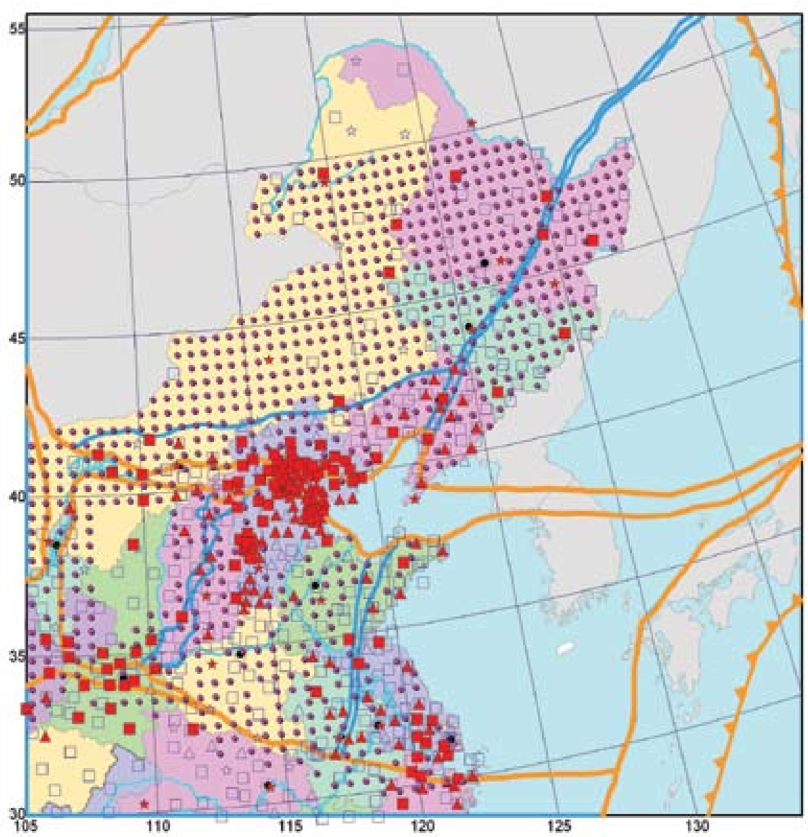
Ray Willemann • IRIS Consortium; Chen Qi-fu • China Earthquake Administration; Rob van der Hilst • Massachusetts Institute of Technology

A session on “Continent Scale Seismic Arrays” was jointly convened by the China Earthquake Administration and IRIS at the AGU’s 2006 Western Pacific Geophysics Meeting in Beijing during July. As countries with two of the largest scale dense seismographic networks now being planned and deployed, ChinArray and USArray are becoming widely known. The first full deployment of the ChinArray instruments, “Deep Earth Lightening” was described in a news article in the August 4 issue of *Science*. This network is designed partly to better characterize seismic hazard in northeastern China and was the topic of the first presentation in this session.

Other presentations in the session highlighted rapid growth in the number and size of dense networks that extend across hundreds or even thousands of kilometers. Some of the networks are true arrays with stations close enough to each other to overcome spatial aliasing, at least at long periods, while others will vastly improve imaging in regions that are now not well monitored, such as Africa and the northern Philippine Sea. The importance of even denser deployments was addressed in presentations on the role of geographically focused passive and controlled-source experiments within the larger scale arrays and in summaries of accomplishments from recent experiments in Asia. Even applications to earthquake source processes were included among the presentations about the power of coherently processing data from very wide aperture arrays.

The presenters at the session included a balanced mix of seismologists from China, the U.S., and elsewhere. A complete list of titles and authors, with links to the abstracts, is posted on the AGU web site (*www.agu.org/meetings/wp06/*, sessions S41B and S42A) and selected presentations are posted on the IRIS web site (*www.iris.edu/wpgm2006*).

There were numerous attendees at this popular session, including William T. Chang, Director of the U.S. National Science Foundation office in Beijing. Perhaps as important as anything else, the session was an opportunity to begin working together toward the discoveries that will be possible with wide dissemination of data from a remarkable new generation of seismological facilities. ■



Proposed integrated deployment of ChinArray and NECESS Array. Magenta discs show 800 sites that could be occupied with ChinArray instrumentation. Other stations (filled for existing, open for under construction) are represented as stars for national stations with very-broadband, circles for regional broadband, and squares for regional short period.

2006 IRIS Workshop

Gene Humphreys • University of Oregon; Karen Fischer • Brown University; Susan Beck • University of Arizona

More than 250 participants attended the 18th IRIS Workshop held June 8-10, 2006, in Tucson, AZ. The 3-day event highlighted USArray science, international disaster mitigation and seismological research, and advances in interpreting seismic velocity and attenuation. The Workshop included

both oral and poster presentations as well as Special Interest Groups meetings to afford participants the opportunity to discuss research findings and exchange ideas. Abstracts for the Workshop are available at http://www.iris.edu/jmla/view/2006_abstracts.php. Opening remarks included presentations by Arthur Goldstein, Acting Division Director of the National Science Foundation Division of Earth Sciences, and David Lambert, NSF Program Director of the Instrumentation and Facilities Program within the Division of Earth Sciences. The second day featured a half-day field trip to the Santa Catalina metamorphic core complex led by John Spencer of Arizona Geological Survey and gave participants an introduction to the region's tectonic setting and local geology. Prior to the Workshop, Steve Park and Shane Ingate conducted a one-day symposium on magnetotellurics, while Tim Ahern and other IRIS staff members offered a tutorial on retrieving data from the DMC. The Workshop agenda with links to available PowerPoint presentations is online at *www.iris.edu/jmla/index.php?option=com_content&task=view&id=29*.

USARRAY TODAY

The first day of the Workshop was devoted to USArray science. In the two opening talks, Gene Humphreys and Wayne Thatcher described the form and potential causes of deformation in the western US, where the Transportable Array is now located, and highlighted some of the outstanding questions on tectonic processes that can be addressed in this area, including both the forces that drive deformation and the nature of resistance to deformation. Several talks offered more global views of the potential for USArray. Keith Priestley offered thoughts on how seismology can be used to resolve lithospheric thermal structure. Ed Garnero followed, addressing the potential for USArray to resolve structure and the dynamics of the convecting Earth, including the termination of sinking slabs and the origin of ascending plumes near the core-mantle boundary. As an illustration of developing techniques to make broad use of the large amounts of data being recorded by USArray, Tom Owens showed examples of receiver functions and derived crustal information from automated receiver function analysis. George Zandt presented continuing research on lithospheric delamination in the western US driven by compositionally dense lower crust and mantle. Ken Creager then discussed Cascadia episodic tremor and slip events (ETS), arguing that the phenomena underlying the seismic and geodetic observations are distinct. USArray Today concluded with a presentation by Derek Lerch on the results from Stanford University's active source investigation across the northwest portion of the Basin and Range, which suggest a crust only 40 km thick at 90 Ma.

INTERPRETING VELOCITY AND ATTENUATION

Following the field trip, the Friday afternoon sessions explored cutting edge multidisciplinary perspectives on how to interpret seismic velocity and attenuation models in terms of temperature, composition, and physical state. In the plenary session, Greg Hirth discussed how joint interpretation of mantle seismic properties and conductivity better constrains the range of physical and chemical properties that distinguish the lithosphere from the asthenosphere. Cin-Ty Lee then described how different petrological models for the formation of the continental lithosphere yield distinct predictions for the distribution of mantle Mg#, buoyancy, and the abundance of eclogite. Colleen Dalton pointed out that there are still significant discrepancies among global attenuation models even at large scales, unlike global velocity models, and showed that results from an inversion of Rayleigh wave phase and amplitude data for attenuation, velocity, and source, and receiver correction factors that includes the effects of focusing correlates well with tectonic features, as well as models of phase velocity and S wave velocity. After the talks, Karen Fischer led a lively half-hour of discussion from which it emerged that hypothesis testing can be enhanced by joint interpretation of multiple geophysical observables and use of geodynamically-based, mineralogically correct models, even though relationships between observables and material properties are complex and not yet completely defined. ➔

Maria Teresa Casas of the Regional Disaster Center for Latin America and the Carribbean being introduced by Art Lerner-Lam of Lamont-Doherty Earth Observatory, Columbia University.

INTERNATIONAL ACTIVITIES

The final day of the Workshop was designated as International Day. IRIS already has numerous international activities – including operation of the GSN, numerous overseas PASSCAL deployments each year, and data and users from around the world at the DMC – so the goals were to highlight these activities, spur discussion and enhance interaction with other international communities.

Art Lerner-Lam opened the morning session, which focused on the interests of international development agencies, with an overview on geohazards and their economic impact. Domenico Giardini offered a candid assessment of how much more IRIS should do for the international community and developing countries with high seismic hazards. Gari Mayberry from the Office of Foreign Disaster Assistance of US A.I.D. and Maria Teresa Casas from the Regional Disaster Center for Latin America and Caribbean provided us with information about their agencies and aimed to make us think beyond our usual seismology research projects. In the afternoon plenary session, Andy Nyblade gave an update on AfricaArray, which is the first project to receive long-term loans of RefTek72-A data loggers retired from the PASSCAL pool. Randy Keller then summarized active source imaging in Europe on a scale of that could not have happened without cross-border collaboration. Roger Bilham gave an overview of disaster preparedness in Asia with a focus on the 2005 Pakistan earthquake and showed how much of the damage to structures could have been prevented with just better education. Susan Beck concluded the session with a talk about mountain and capacity building in the Andes and some of the challenges and opportunities that face investigators deploying PASSCAL instruments outside of the US.

By the end of International Day, it was apparent that investigators deploying PASSCAL instruments outside of the US have tremendous opportunities to improve seismology around the globe and to make a long-lasting impact in international capacity building. The IRIS Workshop adjourned on a positive note with discussions on what types of international meetings, educational materials, software and training would be useful for the international community, particularly in regions without well-developed seismology programs. ■

IRIS and UNAVCO Collaboration Put on Ice

Kent Anderson • IRIS Consortium; Bjorn Johns • UNAVCO

No, we are not putting our relationship on hold. To the contrary, IRIS and UNAVCO are combining their collective skills and experience to solve a difficult problem facing those scientists wishing to work in the coldest places on Earth. The two flagship facilities for the seismic (IRIS) and geodetic (UNAVCO) communities have been awarded a collaborative Major Research Initiative (MRI) grant from the NSF's Office of Polar Programs (OPP) to develop a power and communication systems infrastructure that will allow for remote, autonomous geophysical observations in the extreme environments of the polar regions.

To date, each OPP-funded experiment must construct its own support infrastructure to provide power, communications, and environmental controls for their particular transducers. There is currently no forum to exchange ideas on successful designs, nor means to avoid pitfalls discovered by others. While some groups have had good success in completing their experiments, those successes have not necessarily been shared with the broader community.

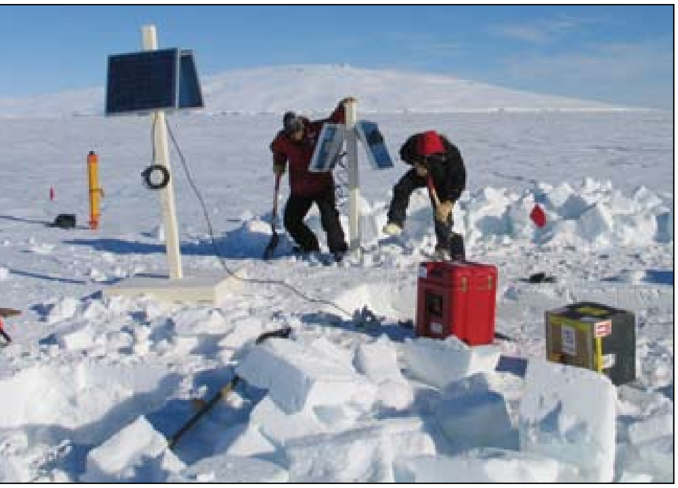
Seth White upgrading the power system at the Cape Roberts continuous GPS site.

IRIS, UNAVCO and scientists from the Antarctic seismological and geodetic research communities worked on this MRI proposal with the goal of making remote collection of scientific data in the polar regions more successful while minimizing long-term logistics support requirements. IRIS and UNAVCO are benchmark facilities for remote geophysical experiments throughout the world and have a tremendous amount of experience working in the polar regions as well as working with PI's. Collaborating to address common issues and resolve common problems →

will improve the data return on these very expensive experiments and help the greater community share in the successes of individual groups.

THE WORK TO BE DONE

Our goal is to develop a standardized approach to designing the infrastructure support for seismological and geodetic experiments. Through testing in each facility's cold chambers and in field trials at test beds located locally and in Antarctica, the MRI funds will be used to investigate optimal battery designs (both rechargeable and non-rechargeable), power systems (solar, wind), environmental conditioning, and telemetry systems for these extreme conditions.



Jonathan Thom and a field assistant deploying a PASSCAL seismometer on the giant tabular iceberg C16 in the Ross Sea, Antarctica, as part of a project to understand the sources and mechanisms of "iceberg tremor" detected as far away as Tahiti and the South Pole.

The field work on this project will begin this austral summer with the establishment of test beds at McMurdo Station and at the South Pole, as well as an operational GPS station near McMurdo Station. The basic station will be built using current "best practices" for near year-round operation and will be upgraded with advanced technologies as they are proven. These activities will allow for a variety of expected field conditions ranging from the relative warmth of sites near continental margins with their particular solar, wind and temperature characteristics to the harsh, cold, high, dry and nearly windless conditions expected on the polar plateau. The test beds will be close enough to the year-round operations of the two US Antarctic Program bases that winter-over science technicians will be able to perform status checks and corrections, as necessary. This will greatly reduce the turn-around time on winter-over projects because immediate feedback can be obtained on system problems as they arise rather than having to wait for the following season to visit a remote test site.

As the new systems are deployed in near-base test-beds and the designs stabilize we will prepare for the next step – building and distributing beta-test versions for field trials in OPP-funded experiments. Combining controlled testing scenarios with realistic, in-field applications will engage the scientific community as an able partner while providing valuable data on actual field deployments before the final designs are determined. Data from the experiments will be put into a final product of a scalable design for remote autonomous support.

LARGER AIMS

The aims of this collaboration include creating a means of incorporating advanced designs into experiments and exchanging ideas, designs and experiences with the researchers. IRIS and UNAVCO formed a new joint advisory committee with scientists working in the polar regions to facilitate the exchange of information on infrastructure design between the facilities and the research community. The startup of this advisory committee is tied to the MRI funding, but the committee can continue to function indefinitely to ensure the flow of information from scientists working in these extreme environments.

The project also features an education and outreach component that will fund an upper-level undergraduate student to participate in this polar technology project. This important component is associated with "Research Experiences in Solid Earth Science for Students" (RESESS), a program of multiple research experiences and mentoring and community building to increase the number of Masters and PhD earned degrees in solid Earth geosciences in underrepresented populations.

The relationship between IRIS and UNAVCO is certainly on ice, but it is far from thin ice – up to 2 miles thick! Working towards a standardized approach to support infrastructure will utilize the best that these two facilities and the research communities have to offer. The engineers from both groups are hot to work on this literally cool project! ■

Staff News

Gayle Levy, IRIS Outreach Specialist since 2004, left IRIS in August after accepting a position at Revolution Health as a producer. Gayle left her mark on products such as this year's "Great Earthquakes" poster and she was the friendly face of the E&O program for numerous activities that included the IRIS/SSA Distinguished Lectureship, Seismographs in Schools, and the IRIS/USGS museum program. Her new position is an exciting and challenging opportunity to become part of a rapidly growing Internet company, but Gayle helped make the IRIS DC office a friendlier place to work and she will be greatly missed. We thank her for everything she has done for IRIS and wish her all the best in her new career.

After eight busy years at the IRIS Data Management Center, Stacy Fournier will be leaving to become a high school teacher. She will be pursing her Master's degree in Education at Gonzaga University in Spokane, Washington. As a Data Control Technician in the DMC's "Engine Room", Stacy focused primarily on data archiving. She shepherded the DMC through a major transitional phase of data archiving beginning in 2002, from the time when nearly all waveform data was transferred on tape media, to the current real-time transfer mechanisms. She provided great service to data users by streamlining access to waveform data. We will all miss Stacy, but our loss is certainly the gain of Washington State's high school students.

The IRIS Data Management Center was pleased to welcome MaryAnn Wood to the position of Data Control Technician on August 14. Prior to joining the staff of the DMC, MaryAnn worked for Seattle local icons Amazon.com and Boeing in the areas of software configuration management and deployment. She grew up on a farm near Corvallis, OR and attended Oregon State University. She moved to Seattle in 1987 and now lives in the Wallingford area with her six year old daughter, Suzanne.

Lindsay Wood joined the IRIS President's office as Meeting Planning Coordinator in early October. Lindsay is a graduate of Missouri State University and has extensive meeting planning experience, most recently at the Coalition for Juvenile Justice in Washington, DC. In addition to being responsible for all meeting planning functions, Lindsay will support IRIS International Activities and the Education and Outreach Program.

This Issue's Bannergram

M_W 8.2 Earthquake in Valparaiso, Chile on August 17, 1906

Various earthquakes and years have been said, at one time or another, to mark the beginning of modern seismology. With as many as five M ≥ 8 earthquakes over a period of less than nine months, the year 1906 stands second to no other in this pantheon of events and dates. No objective magnitude scale had yet been invented, of course, but the earthquakes of 1906 were notorious at the time for their destructive effects. In January, an earthquake off the coast of Ecuador generated a tsunami that probably killed over more than 1000 people in South America and caused extensive damage in Hawaii. April was the month of the San Francisco earthquake, which may still be the most infamous earthquake among the American public. August saw similar devastation in Valparaiso, Chile, with near total ruin in the central city.

One of the reasons that these earthquakes were so widely noted may have been wide dissemination of photographs of urban destruction. It takes requires at least a modest effort to read and empathize with the accounts of the 1811-1812 earthquakes in New Madrid, Missouri, for example, whereas images of razed city neighborhoods in San Francisco or Valparaiso have a visceral impact even today.

The earthquakes of 1906 influenced seismology as a science partly because society demanded a response, but also because seismologists had developed the capabilities for a more analytical investigation. Instrumental recording of large earthquakes anywhere was just becoming possible. Milne-Shaw seismometers, such as the one that made the seismogram shown here and on the cover, lacked damping. Nevertheless, and despite a possibly larger event in the Aleutians preceding just 30 minutes earlier, records from that time have been used recently to estimate the Valparaiso earthquake's scalar seismic moment. Static offsets observed after the San Francisco earthquake were the basis of H. F. Reid's "elastic rebound" hypothesis, and the geologic origin of earthquakes was supported by observations of widespread elevation changes after the Valparaiso thrust earthquake.

The earthquakes of 1906 prompted growth in numerous seismographic networks, including creation of the Chilean National Seismological Service. Much as the US marked the centennial of the San Francisco earthquake with a major scientific conference in April, the University of Chile hosted an international conference in Santiago looking back on 100 years of earthquake seismology and ahead to how advances can reduce earthquake risk in the future. ■

Photos: Rodolfo Saragoni and Diana Comte, University of Chile and Chilean Association of Seismology and Earthquake Engineering

IRIS Newsletter

Published by the IRIS Consortium.
Please address your letters or inquiries to:

IRIS NEWSLETTER
1200 NEW YORK AVENUE, NW, SUITE 800
WASHINGTON, DC 20005
PHONE: 202-682-2220 • FAX: 202-682-2444 • WWW.IRIS.EDU

The Incorporated Research Institutions for Seismology (IRIS) is a university consortium of more than 100 research institutions dedicated to facilitating investigation of seismic sources and Earth properties, promoting exchange of geophysical data and knowledge, and fostering cooperation. IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and monitoring underground nuclear explosions. IRIS core programs are operated through a Cooperative Agreement with the National Science Foundation under the Division of Earth Science's Instrumentation and Facilities Program. IRIS also manages the USArray component of the EarthScope project. Funding is provided by the National Science Foundation, the Department of Energy, other federal agencies, universities, and private foundations. All IRIS programs are carried out in close coordination with the U.S. Geological Survey and many international partners.

The IRIS Newsletter welcomes contributed articles. Please contact one of the editors.

Editor-in-Chief: David Simpson (simpson@iris.edu)
Executive Editor: Raymond Willemann (ray@iris.edu)
Production Editor: Jason Mallett (jason@iris.edu)

Annual Meeting of IRIS Members

The Annual Meeting of IRIS Members will be held at the Yank Sing Restaurant in San Francisco at 7 PM on Monday December 11, following a reception at 6PM. At the Annual Meeting, the IRIS President and Program Managers report on activities of during the year and a quorum of representatives of the voting Members elect new members to the IRIS Board of Directors.

The Directors completing their service on the Board this year are Greg Beroza, David Okaya, and Brian Stump. All three of them helped to guide IRIS through significant advance over the past three years, including introduction of the new governance structure for the Consortium two years ago when the Executive Committee was replaced by a Board of Directors, which is elected from among the primary representatives of the voting Members.

A nominating committee of Greg Beroza, Kate Miller, and Barbara Romanowicz convinced six already busy faculty members to commit themselves to significant, uncompensated service to the Consortium. Generously agreeing to serve from 2007 through the end of 2009, the nominees are Ken Creager of the University of Washington, Doug Dreger of the University of California, Berkeley, Jim Gaherty of Columbia University, Chuck Langston of the University of Memphis, John Louie of the University of Nevada, Reno, and Suzan van der Lee of Northwestern University.

IRIS welcomes representatives from two new voting Members at this year's meeting – Aibing Li, representing the University of Houston, and DelWayne Bohnenstiehl, representing North Carolina State University. The ranks of IRIS's Educational Affiliates grew significantly, including the addition of the State University of New York at Potsdam, represented by Frank Revetta. Representatives are expected at the meeting from several of IRIS's thirteen new Foreign Affiliates from Europe, Asia, the Middle East, the Americas and Africa.

DECEMBER 11 - 15, 2006

AGU Fall Meeting
San Francisco, California
www.agu.org/meetings/fm06

MARCH 27 - 30, 2007

EarthScope National Meeting
Monterey, California
www.earthscope.org/meetings

APRIL 11 - 13, 2007

SSA Annual Meeting
Kona, Hawaii
www.seismosoc.org/meetings/2007

MAY 14 - 16, 2007

International Conference on Seismology & Earthquake Engineering
Tehran, Iran
www.iiees.ac.ir/SEE5

MAY 22 - 25, 2007

AGU Joint Assembly
Acapulco, Mexico
www.agu.org/meetings/ja07/

IRIS
Incorporated Research Institutions for Seismology
1200 New York Avenue, NW
Suite 800
Washington, DC 20005

ADDRESS SERVICE REQUESTED

Non Profit Org.
U.S. Postage
PAID
Washington, DC
Permit No. 1227