Sixteenth Annual IRIS Workshop

Celebrating
Twenty Years of IRIS and Earth Science from Crust to Core

IRIS
TWENTIETH ANNIVERSARY

June 10-12
Westward Look Resort
Tucson, AZ

IRIS 20th Anniversary Workshop

Thursday June 10, 2004	**Friday** June 11, 2004	**Saturday** June 12, 2004
Welcome and Introduction	Margaret Leinen, NSF/GEO	David Applegate, USGS
MULTI-BAND EXPERIMENTS A Levander and K Miller	FIRST BIGFOOT-PRINT Tectonics of Western North America T Pratt and F Waldhauser	CYBER-SEISMOLOGY: The Role of Seismologists in IT R Keller and T Owens
POSTERS	Lunch	POSTERS and SIG's USArray Siting & Outreach - R Aster, J Taber
Lunch	**SPECIAL MEETING** **IRIS BOARD OF DIRECTORS**	Lunch
IRIS: Then and Future PASSCAL Sacks - Levander E&O The Future of Seismology Aster - Velasco	POSTERS	EarthScope Update - K Shedlock, B Smith
POSTERS and SIG's PASSCAL: Next 20 Years - D James, C Zelt Data Access Tutorial - T Ahern	IRIS: Then and Future DMS S Alexander - S Bratt GSN R Engdahl - R Butler	WHITHER OR WITHER? THE FUTURE GSN R Butler and T Lay
Dinner	Dinner	POSTERS and SIGs Backbone Science - J Park Synthetic Exchange Standards - D Okaya
IRIS/SSA Distinguished Lecturer David James	POSTERS and SIG's Antarctic Seismology - R Butler, R Aster Active Source Seismology - J Hole	**20th ANNIVERSARY CELEBRATION** **"IRIS at 20"** T Owens - F Wu
POSTERS		

Thursday, June 10

8:15 – 9:00	Welcome and Introduction Workshop Convenors – Göran Ekström, Art Lerner Lam NSF/EAR/Instrumentation & Facilities – David Lambert	Sonoran Ballroom
9:00 – 11:15	Science Session I – Multi-Band Experiments Alan Levander,Rice University/Kate Miller, University of Texas, El Paso *Introduction – Kate Miller* *Reflection, Refraction and Teleseismic Imaging of the Lithospheric Mantle: A LITHOPROBE Perspective – Ronald Clowes, University of British Columbia* *Paleo-subduction and modern basalt extraction structures in the Southern Rocky Mountains: Multi-band images from the CD-ROM experiment – Alan Levander, Rice University*	
10:00 – 10:15	BREAK *Controlled and natural seismic source experiments in the Andes – Rainer Kind, GIF Potsdam* *A case for whole-band seismology: five orders of magnitude in the southwest U.S. – Michael West , New Mexico State University*	
11:15 – 12:30	Posters	Santa Catalina Ballroom
12:30 – 1:30	LUNCH	Sonoran Rooftop
1:30 – 3:30	IRIS Then and Future PASSCAL Selwyn Sacks, Alan Levander E&O The future of Seismology Rick Aster, Aaron Velasco	Sonoran Ballroom
3:30 – 5:30	Posters	Santa Catalina Ballroom
3:30 – 4:30	PASSCAL – Strategic Plan: The next 20 years David James, Colin Zelt	Palm Room
4:30 – 5:30	DMS – Tutorial Somethings Old and Somethings New: A Tutorial for using DMC systems and tools Timothy Ahern	Canyon Room
6:00 – 7:30	CASH BAR & DINNER	Sonoran Terrace and Rooftop
7:30	IRIS/SSA Distinguished Lecture *Revealing the Mysteries of the Earth's Deep Interior: Plates, Plumes, and the Birth of Modern Seismology* – David James, Carnegie Institution of Washington	Sonoran Ballroom
8:30	Posters	Santa Catalina Ballroom

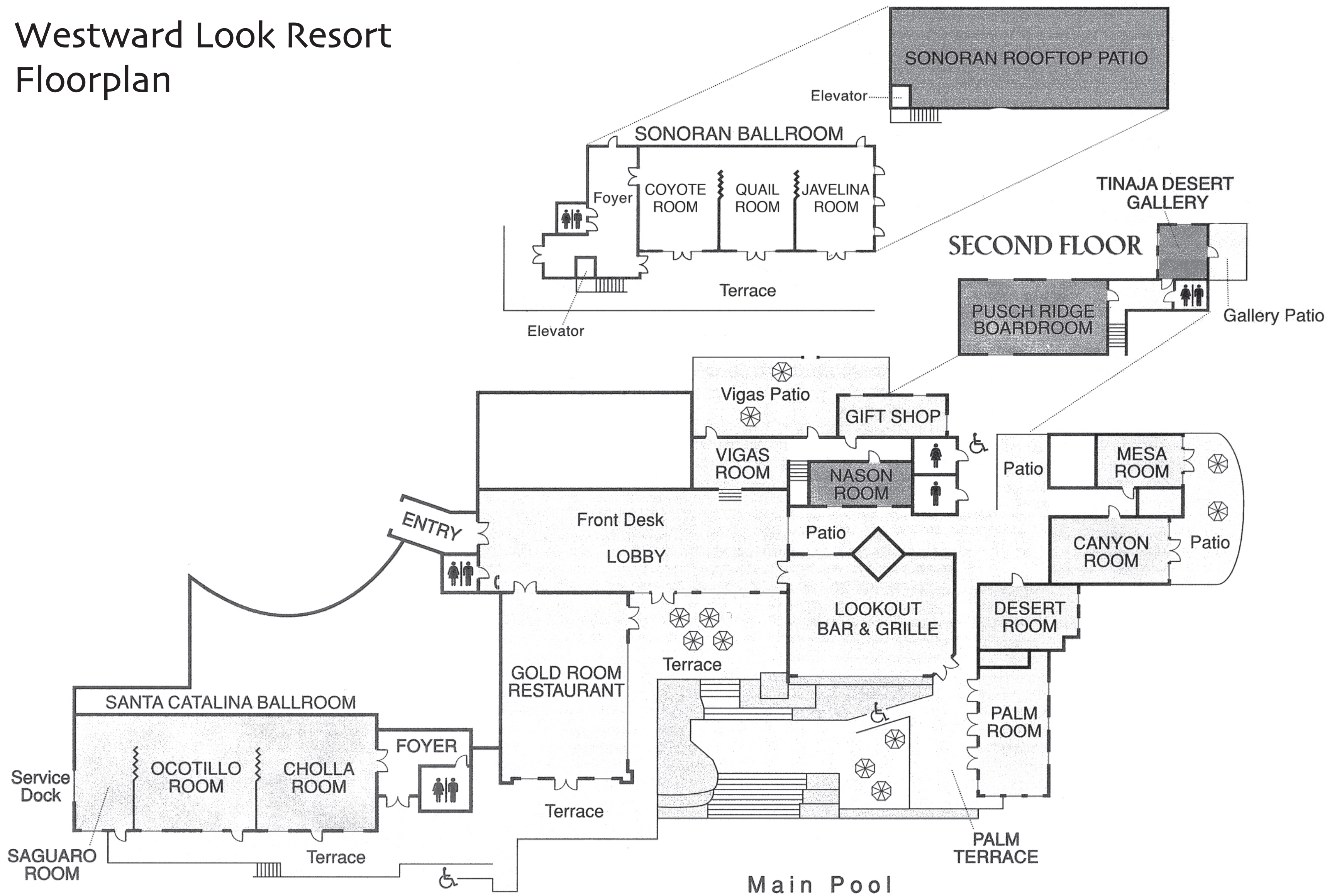
Friday, June 11

8:30 – 9:15	Margaret Leinen, Associate Director for Geosciences, NSF	Sonoran Ballroom
9:15 – 12:00	Science Session II – First Bigfoot-print Thomas Pratt, USGS, University of Washington/Felix Waldhauser, Columbia University	
	Introduction – Felix Waldhauser and Thomas Pratt	
	Mountain Building, Mantle Dynamics and Seismic Hazard in Southern California – Paul Davis, University of CA, Los Angeles	
	Western US GPS Observations & Crust/Mantle Interactions – Robert McCaffrey, Rensselaer Polytechnic Institute	
10:20	BREAK	
	Cascadia volcanism – volatiles, melt generation and volcanic eruptions – Katharine Cashman, University of Oregon	
	Cascadia, USArray and Teleseismic Mantle Imaging – Michael Bostock, University of British Columbia	
	First Bigfoot Print and Earthquake Hazards in the Pacific Northwest – Thomas Brocher, USGS, Menlo Park	
12:15 – 1:15	LUNCH BUFFET	Sonoran Rooftop
1:15 – 3:00	Special IRIS Board of Directors Meeting	Canyon Room
	IRIS Governance and By Law Changes	
	IRIS Future Directions	
1:15 – 3:00	Posters	Santa Catalina Ballroom
3:00 – 5:00	IRIS Then and Future	Sonoran Ballroom
	DMS	
	The formative years for DMS – from virtual reality to reality and more Shelton Alexander	
	Spinning Threads for the Next Generation of the Web Steven Bratt	
	GSN	
	Early Developments in Global Digital Data Acquisition and Data Distribution Robert Engdahl	
	Celebrating the Evolving GSN Rhett Butler	
5:00 – 6:00	HOSTED BAR	Sonoran Terrace
6:00	DINNER	Sonoran Rooftop
7:30	Posters	Santa Catalina Ballroom
7:30 – 8:30	Antarctic Seismology and 3-D Arrays Rhett Butler, Richard Aster	Palm Room
7:30 – 8:30	Active Source Seismology – Sources and Permits John Hole	Canyon Room

Saturday, June 12

8:30 – 9:15	David Applegate – The Future of Earthquake Science at USGS	Sonoran Ballroom
9:15 – 11:20	Science Session III – Cyber-seismology: the role of seismologists in IT Randy Keller, University of Texas, El Paso/Thomas Owens, University of South Carolina	
	Introduction – Randy Keller, University of Texas, El Paso	
	Weaving a Web for the Next Generation of Science – Steven Bratt, W3 Consortium	
	GEON: The Geosciences Network – Chaitan Baru, University of California, San Diego	
10:15	BREAK	
	Advances and opportunities in computational seismology *– Jeroen Tromp, California Institute of Technology*	
	Lessons from OpenSHA's effort to develop a community modeling environment for seismic hazard analysis *– Edward Field, USGS, Pasadena*	
11:20	Posters	Santa Catalina Ballroom
	USArray Siting and Outreach Richard Aster, John Taber	Palm Room
12:30 – 1:30	LUNCH	Sonoran Rooftop
1:30 – 1:45	EarthScope Update Kaye Shedlock, NSF/EAR Bob Smith, ESEC, University of Utah	Sonoran Ballroom
1:45 – 3:45	Science Session IV – The Future GSN-Whither or Wither Rhett Butler, IRIS/Thorne Lay, University of California, Santa Cruz	
	Introduction – Rhett Butler	
	Global Dense Arrays – Donald Helmberger, California Institute of Technology	
	New Horizons for Global Seismology: Polar Regions and Oceans *– Douglas Wiens, Washington University, St. Louis*	
	Infrasound and International – David McCormack, Geological Survey of Canada	
	Ionospheric and Planetary Seismology – Phillippe Lognonné, Institut de Physique du Globe de Paris	
3:45 – 5:30	Posters	Santa Catalina Ballroom
4:00 – 5:00	Strengthening the Scientific Backbone for ANSS Jeffrey Park	Palm Room
4:00 – 5:00	Synthetic Seismogram Exchange Standards: (Formats & Metadata) David Okaya	Canyon Room
6:00	CASH BAR	Picnic Grounds
6:30	IRIS at 20 Thomas Owens, Francis Wu	

Westward Look Resort
Floorplan



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Westward Look, Tucson, Arizona
June 9-13, 2004

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THE WHOLE IS GREATER THAN THE SUM OF THE PARTS: NEES+IRIS+USGS
NEES/IRIS/USGS Working Group

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STRUCTURE OF THE INNER CORE-OUTER CORE BOUNDARY INFERRED FROM PKPBC DIFFRACTED WAVES
Zuihong Zou and Keith D. Koper

THE FORMATIVE YEARS FOR DMS: FROM VIRTUAL REALITY TO REALITY AND MORE

Shelton Alexander

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When IRIS was formed initially the Data Management Center (DMC) was established to be on a par organizationally with the Global Seismic Network (GSN) and PASSCAL programs, though there were no IRIS data to manage at first. This element of IRIS was envisioned to be vital to the success of IRIS in facilitating frontier seismological studies by the broad seismological research community, using this new generation of high quality seismic data; that has proven to be the case. Early estimates of the future growth of data available through the IRIS DMC (later the DMS) seemed unrealistically large, but instead they were unrealistically low, both in terms of data volume and requests from users. Real-time data back then was just a passing thought and yet today the DMS fills requests by near-real-time electronic mechanisms for more than 16 terabytes per year from up to 800 stations around the world. Currently the volume of data available through the DMS has grown to exceed 50 terrabytes and the annual number of on-line data archive requests has grown to over 35,000 and customized data shipments to over 70,000. The sustained success of IRIS can be attributed in significant part to the role that DMS has played in providing easy and free access to a very large volume of state-of-the-art seismic data by the entire seismological community.

REGIONAL SEISMIC MOMENT TENSOR INVERSION FOR ANDEAN CRUSTAL EARTHQUAKES USING BROADBAND WAVEFORMS OF THE PASSIVE CHARGE ARRAY

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The fast convergence rate between the Nazca and South America tectonic plates generates a large number of earthquakes in the Andean back-arc region. North of 33S, the Wadati-Benioff zone defines a flat subduction geometry that extends 400km east of the high Andes before resuming its descent into the mantle. Seismicity levels are high in the upper continental plate and have been responsible for many destructive earthquakes in Argentina (1861, 1894, 1944, 1952, and 1977). Crustal earthquakes are related to the thin-skinned Precordillera fold and thrust belt and the thick-skinned metamorphic basement cored uplifts of the Pampean Ranges. Previous portable short-period seismic experiments around San Juan showed the crustal seismicity is deeper than 10 km. This observation, together with some P-wave first motion focal mechanisms, led to the interpretation of a complex blind fault structure for the region. Some focal mechanism solutions obtained by modeling teleseismic data are also known for earthquakes of magnitudes bigger than 5.0. However, crustal earthquakes of magnitudes between 4 and 5 are more abundant and important for constraining the tectonics of the region. In this work we present the regional seismic moment tensor inversions for 27 crustal earthquakes that occurred in the main cordillera and back-arc region between 29 and 36S. We used the broadband waveforms recorded by the Chile-Argentine Geophysical Experiment (CHARGE) during November 2000 to May 2002. The portable seismic network consisted of 22 broadband (IRIS-PASSCAL) seismographs deployed along two transects at 30S and 36S and some stations in between. We used a least-squares moment tensor inversion technique developed by Randall et al. (1995) that models full seismic displacement waveforms at regional distances. We used epicentral locations from a local network catalog and a seismic velocity structure previously determined from receiver function and Pn studies that also used the CHARGE data. In addition, we tested for the best hypocentral depth by performing the inversion for different trial depths for each earthquake and constructing a curve of the misfit errors versus focal depths to find a minimum around the best depth. We found the focal mechanisms do not change for a range of depths indicating the robustness of the focal solutions. Our results indicate the Andean back arc is in compression. No extensional focal mechanism solutions have been obtained. The earthquakes are concentrated at an average depth of 20 km in the back-arc region and at depths shallower than 5 km in the main cordillera south of 33S. Only two strike-slip solutions have been found and these have very shallow depths (< 7 km). Two Harvard-CMT solutions available for this region indicate similar focal mechanisms as ones we obtained from the regional moment tensor inversion. Overall, we observed that the western Pampean ranges are more active than the eastern Pampean ranges. We also obtained better fits using a 45-km thick crust with Vp/Vs ratios of 1.80 and 1.70 for the western and eastern Pampean ranges, respectively. In addition, an interesting concentration of seismic events is observed along a terrane suture within the western Pampean ranges. This suggests that old terranes and their boundaries are having some control on the present day deformation of the Andean back-arc region.

THE GEOSCIENCE DIVERSITY ENHANCEMENT PROGRAM (GDEP): AN NSF-OEDG PROGRAM EMPHASIZING INTEGRATED GEOSCIENCE RESEARCH IN URBAN AREAS

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The Geoscience Diversity Enhancement Program (GDEP) is a three-year, NSF-OEDG funded project centered at California State University, Long Beach (CSULB). Begun in fall 2001, GDEP involves faculty leadership within three CSULB departments; geological sciences, geography, and anthropology. Partners include five Long Beach area community colleges and Long Beach Unified School District, one of the largest K-12 school districts in California. At the core of GDEP is a summer research experience. More than nine separate research projects developed and led by CSULB faculty, involve faculty and staff from community colleges and high schools. Several of the projects have a strong seismology theme, including shallow seismic reflection imaging of the offshore Palos Verdes Hills Fault; seismic refraction investigations of the White Pine Fault in Nevada; and GPS measurements of coseismic deformation of the western coast of Mexico. The summer research experiences have been highly successful: during the summers of 2002-2003, more than 50 Long Beach area faculty and students participated in GDEP. Although our evaluation is still underway, formative assessment of the impact of the summer research experience indicates that research work combining field experiences, ready access to faculty mentors, and a team approach to investigations appeared most valuable to program participants. These research experiences also appear to figure in changes in pedagogy and content focus for some faculty participants, particularly at the high school level.

http://www.csulb.edu/geography/gdep

MANTLE FLOW IN THE CHILE-ARGENTINA FLAT SLAB SUBDUCTION ZONE FROM SEISMIC ANISOTROPY

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The purpose of this study is to characterize the seismic anisotropy of a part of the South American subduction zone. This particular subduction zone affords us the opportunity to try and characterize the effect of a change in subducting slab dip on mantle flow, a factor that has been hard to tease out of other studies where station coverage is sparse, or no change in dip of the slab exists. At 30 degrees S the subducting Nazca slab flattens at a depth of approximately 100 km under Argentina and extends at this depth almost 300 km eastward before continuing its descent into the mantle. South of 33 degrees S, the slab has a uniform dip of approximately 30 degrees. Earthquakes were recorded by 22 portable broadband seismic stations as a part of the CHile ARgentina Geophysical Experiment (CHARGE). We estimate anisotropic fast-axis orientation and magnitude from split teleseismic SKS and SKKS waves and from shear waves from local earthquakes in the subducting plate. The magnitude of the shear wave splitting (0.5-1 s) for teleseismic results is too large to be reasonable for a thin layer such as the crust or even for the mantle wedge. In addition, receiver function analysis from other studies in our working group show small magnitude to no anisotropy in the crust, while estimates for the mantle wedge from local events shows magnitudes of anisotropy only in the 0.1-0.3 second range. Therefore it is likely that the largest anisotropic source for the observed splitting is within or below the subducting slab. This conclusion gives us the advantage of simplifying our model for anisotropy to alignment of olivine fast seismic axes with mantle flow. Later we will consider above slab models as we flesh out the above slab component. Estimates of fast axis direction across our network show a dramatic change in anisotropic fast axis azimuth across this zone of change in dip of the slab. The fast axis rotates from N-S under the southern part of our network to E-W in the northeastern part of our network. We would like to use this observation to test dynamic models of subducting slab-mantle interaction. One possibility is that retrograde motion of the subducting Nazca plate is causing N-S strain of the mantle below the trench retreat point, an idea suggested by previous studies. In our area, the local slab geometry may create an accommodation zone under the flattened slab that allows mantle in that area to flow eastward, entrained by the Nazca plate.

COMPARISON OF BACKGROUND NOISE BETWEEN GLOBAL SEISMIC NETWORK (GSN) AND IRIS/PASSCAL TEMPORARY SEISMIC STATIONS

Eliana Arias

IRIS/PASSCAL Instrument Center

In order to compare the quality of seismic stations from IRIS/PASSCAL temporary experiments with seismic stations from the Global Seismic Network (GSN), an analysis of background seismic noise Power Spectra Density (PSD) was performed. Selection criteria for noise comparison of pairs of stations are: identical sensor type (STS-2, CMG-3T and KS-4000), similar geographical location (±8º), and continuous, simultaneously recorded time periods during two-month intervals surrounding the equinoxes. Selected station pairs are located in Antarctica, USA, Africa, South America and Alaska. GSN stations are of two types: about 100 m borehole (COLA, SSPA and TRQA) and well-constructed, near-surface vaults (SBA, LVC and FURI). In contrast, PASSCAL stations (MCK, MM05, LLAN, E004, HEDI and AAUS) are deployed in temporary vaults, typically hand dug to a depth of approximately 1 m (and not necessarily located on bedrock). Seismic events were both auto-detected by ANTELOPE and visually inspected to be removed obtaining a database of background noise. Hourly noise PSD estimates for each station and each component (Z, N, E) were calculated using Welch's Method (Welch, 1967) and compared with the USGS high and low noise models (Peterson, 1993) at the 0.05 to 20 Hz frequency range. Median PSD values were then calculated for daily and monthly estimates. In general, initial results show no significant variations in background noise between the GSN and PASSCAL stations for the frequency range and time period evaluated. GSN/FURI-PASSCAL/AUSS (Ethiopia), GSN/LVC-PASSCAL/HEDI (Chile-Argentina) and GSN/SBA-PASSCAL/E004 (Antarctica) are similar in the mean PSD estimates with variation limits of 95% (1.96 x standard deviation) that overlap. Stations in Central Pennsylvania, GSN/SSPA and PASSCAL/MM05 present similar behavior with variations in the range of 5 power decibel (pdb). Argentina GSN/TRQA appears slightly noisier (~6 pdb) than PASSCAL/LLAN for frequencies below 1 Hz, though at higher frequencies LLAN is noisier (~10 pdb). The most significant difference between a GSN and a PASSCAL station pair is in Alaska, where GSN/COLA is up to 20 pdb higher than PASSCAL/MCK at frequencies greater than 1 Hz. Current work extends the analysis of PSD values to longer periods (< 0.05 Hz) for each pair of stations. Further analysis will include characterization of noise at different frequency ranges and the evaluation of earthquake signals to compare the sensitivity at GSN and PASSCAL stations.

CRUSTAL STRUCTURE IN SOUTHERN CALIFORNIA – RESULTS FROM LOS ANGELES REGION SEISMIC EXPERIMENT (LARSE) LINES 1 AND 2

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U. S. Geological Survey US Geological Survey

We present P wave velocity models of the crust in southern California using active-source data collected during the LARSE Line 1 (1994) and Line 2 (1999). Both refraction/reflection lines extend from the vicinity of San Clemente Island to the Mojave Desert but have different azimuths and traverse extremely different geologic structures. In the offshore region we supplement LARSE data with USGS multichannel seismic (MCS) data collected from 1998–2000 AND oil-well data. Our models are based on forward modeling. For LINE 1, our model represents a refinement of the forward model of Godfrey et al. (2002), in that we re-model the offshore upper crust, incorporating MCS and oil-well data. For our model of LINE 2, we use the inverse model of Lutter et al. (2004) as a starting model and extend it downward by modeling wide-angle reflections. In the upper crust of LINE 1, maximum depths of sedimentary basins are modeled as follows: Los Angeles Basin, ~9.0 KM; Wilmington Graben, ~3.5? KM; San Pedro Basin, ~1.4 KM; Catalina Basin, ~0.8 KM. In the upper crust of LINE 2, maximum depths of sedimentary basins are modeled as follows: Mojave Desert (Antelope Valley), ~2.4 KM; Santa Clarita Valley, ~2.9 KM; San Fernando Valley, ~4.0 KM. On both lines 1 and 2, crustal blocks with similar characteristic mid-crustal (10-KM) velocities are observed as follows: Mojave Desert, 6.3 km/s; Central Transverse Ranges, 6.0 KM/S; Eastern Los Angeles Basin (LINE 1), 6.8 KM/S, and San Fernando Basin (LINE 2), 6.3 KM/S; Inner Borderland, 6.3 KM/S.

RECEIVER FUNCTION PRODUCTION WITH A SIMULTANEOUS ITERATIVE TIME DOMAIN DECONVOLUTION

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We have modified the iterative approach of receiver function production (Ligorria, J. and C. J. Ammon, 1999) to include benefits of simultaneous production of a single receiver function from a cluster of events. In this method normalized crosscorrelated seismograms are analyzed for largest peak which are used to construct a temporary receiver function. This temporary receiver function is used to generate a synthetic horizontal component of a seismogram which is subtracted from the original seismogram to produces a differential horizontal component seismogram. This differential seismogram is then used to select the next appropriate phase in a receiver function. This process is repeated until the differential horizontal component appears to be stripped of coherent signal. We modified this process by summing the crosscorelation functions for several events before selection of a largest peak. We found that the noisier events contaminated the averaged crosscorrelation functions sufficiently to cause the method to be less effective than producing individual receiver functions followed by stacking. By using the smaller number of higher quality events the simultaneous approach resulted in a bin averaged receiver function at 0.4 Hz that resembles a synthetic in clarity and signal strength. To improve the number of events summed into an individual receiver function we applied IASPI moveout corrections to depth convert the crosscorrelation functions which enables stacking of data from different ray parameters. For relatively data rich stations, this enables us to produce receiver functions with coherent well defined P410s and P660s phases for frequencies up to 2.5 Hz.

UPPER MANTLE SEISMIC VELOCITY STRUCTURE BENEATH ETHIOPIA

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The origin of Cenozoic tectonism in East Africa remains enigmatic. Previous studies suggest that slow seismic velocities may extend through the upper mantle beneath this region, consistent with a lower mantle origin for the Cenozoic tectonism. To further understand the origin of the tectonism in East Africa, we analyze data collected from the 2000-2002 Ethiopia Broadband Seismic Experiment. We employ body wave tomography to examine the upper mantle seismic velocity structure and receiver function analysis to constrain the depth and lateral extent of the thermal anomaly by mapping topography on the upper mantle discontinuities Results from our tomography study beneath Ethiopia reveal SW-NE trending low velocity anomaly in the upper mantle zone beneath the Afar triple junction and Western Ethiopia Plateau that appears to extend to depths greater than 400 km, at least beneath the Afar. The lowest mantle seismic velocities appear to correspond to rifted areas regions of highest elevation. Additionally, our receiver function results suggest that the 410 km olivine phase transformation is deeper beneath the Afar than beneath the rest of Ethiopia, thereby implying a hotter than average mantle at this depth.

ELECTRONIC ENCYCLOPEDIA OF EARTHQUAKES

Mark Benthien (1), Tom Jordan (1), John Marquis (1) , John Taber (2)

Southern California Earthquake Center 1: SCEC 2: IRIS

This digital library of educational resources and information is connected with the Digital Library for Earth System Education (DLESE) and the National Science Digital Library (NSDL). E3 is a collaborative project of the Southern California Earthquake Center (SCEC), the Consortia of Universities for Research in Earthquake Engineering (CUREE) and the Incorporated Research Institutions for Seismology (IRIS). When complete, information and resources for over 500 earth science and engineering topics will be included, with connections to curricular materials useful for teaching and learning about earth science, engineering, physics and mathematics. The purpose of the E3 collection is to support high-quality K-12 and undergraduate education by providing educators and students with a comprehensive library of tools and resources for instruction and research. E3 is also a valuable portal to anyone seeking up-to-date earthquake information and authoritative technical sources.
E3 is a unique collaboration among earthquake scientists and engineers to articulate and document a common knowledge base with a shared terminology and conceptual framework. It is a platform for cross-training scientists and engineers in these complementary fields and will provide a basis for sustained communication and resource-building between major education and outreach activities. For example, the E3 collaborating organizations have leadership roles in the two largest earthquake engineering and earth science projects ever sponsored by NSF: the George E. Brown Network for Earthquake Engineering Simulation (NEES) and the EarthScope Project. The E3 vocabulary and definitions are also being connected to a formal ontology under development by the SCEC/ITR project for knowledge management within the SCEC “Community Modeling Environment” Collaboratory.
A very sophisticated information system for building and displaying the E3 collection and web pages has been developed, now called the SCEC Community Organized Resource Environment (SCEC/CORE). This system is now fully operational, and several hundred entries are in development. Scientists, engineers, and educators who have suggestions for content can visit www.earthquake.info now to describe their resources via the “Contribute” page.

EARTH NOISE: A SURVEY OF THE GLOBAL SESIMOGRAPHIC NETWORK STATIONS

Jonathan Berger, Peter Davis, Harold Bolton, Goran Ekstrom, Charles Hutt

The IRIS Global Seismographic Network (GSN) consists of widely distributed, similarly equipped, and well-calibrated stations. Using data from the 118 GSN stations operating during the year July 2001 through June 2002, we have made over 738,000 hourly spectral estimates of the observed ground motion in seventh-decade (approximately half-octave) bands for periods between 1000 and 0.07 seconds. From these estimates we have developed a robust earth noise model and characterized the performance of the network. We note the differences in vertical and horizontal component of the noise and in the performance of the 4 models of seismometers used in the network. In addition to the well known microseismic noise peaks, at many stations there is an additional peak at about 125 seconds. At longer periods, the vertical component of earth noise is considerably quieter than previously reported. Indeed, these lowest noise levels can only be observed on one of the GSN sensors - the STS-1.

GETTING THE MOST OUT OF A “TEXAN” – UTILIZING RG RECORDED ON A “TEXAN” NETWORK

Jessie Bonner (1), Delaine Reiter (1), Heather Hooper (1), Mark Leidig (1), Steve Azevedo (2),Glen Gettemy (2), Brian Stump (3), and James Lewkowicz (1)

(1) Weston Geophysical Corporation (2) IRIS PASSCAL Instrument Center (3) Southern Methodist University

The IRIS RT125 recorder and associated geophone, nicknamed “Texans”, have traditionally been used for active crustal reflection experiments; however, our research team has recently used Texan data in a variety of additional applications. We deployed 140 Texan sensors near a series of 9 explosions at a coal mine in northern Arizona. The explosions ranged from 232 lbs to 33,000 lbs and were detonated in a variety of different confinement settings. The distance ranges for the Texan deployments varied from 1.5 km to 13.5 km and were designed to achieve complete azimuthal coverage of the blasts. The explosions were detonated on 6-7 September 2003, and we achieved 93% data recovery. Our research objective was to use the Texan data for short-period fundamental-mode Rayleigh-wave (Rg) studies. Since Rg typically exhibits periods below the corner frequency of the geophone, we first had to correct for the instrument response of the Texan. Given prior use of the Texan for velocity studies only, this was not a trivial exercise. The instrument response was obtained, and the data were corrected and spot-checked for accuracy using an approximately co-located broadband instrument. In addition to using the Texan data to develop multi-layer refraction models of the upper crust P-wave velocity, we also have used the Texan data to: a) Invert Rg phase- and group-velocity dispersion curves for upper crustal S-wave velocity structure, b) Develop attenuation relationships for 0.5 to 4 Hz Rg, c) Examine spectral ratio radiation patterns to determine if the explosions were pure monopole explosions (most were not!), d) Solve for the explosion moments by matching Rg amplitudes, and e) Estimate decoupling factors that quantify the differences between confined and unconfined explosions. This study, together with a similar study at a copper mine in southern Arizona, both show the multi-faceted capabilities of the Texan recorders.

CASCADIA, USARRAY AND TELESEISMIC MANTLE IMAGING

M.G. Bostock

The University of British Columbia The University of British Columbia

Over the past two decades, our understanding of the structure and dynamics of the Cascadia subduction zone has significantly improved. Both active (LITHOPROBE, SHIPS) and passive source (IRIS-PASSCAL, POLARIS) experiments have contributed to this effort. These studies collectively point to the importance of dehydration reactions in the subducting plate in controlling or influencing such factors as the downdip limit of megathrust earthquakes, the origin of shallow Wadati-Benioff seismicity, the mechanism of arc magmatism, and asthenospheric flow in the mantle wedge. In this talk, I will review recent results from broadband teleseismic experiments concerning these issues and discuss the role that USARRAY can play in furthering our understanding of subduction processes in Cascadia. I will conclude with a summary of technical challenges faced in fine-scale subduction zone imaging using teleseismic waves recorded on dense arrays of 3-C, broadband seismometers.

SPINNING THREADS FOR THE NEXT GENERATION OF THE WEB

Steve Bratt

World Wide Web Consortium

Founded in 1994 by Web inventor Tim Berners-Lee, the World Wide Web Consortium (W3C) [1] has spun the threads that enable today's Web (for example, the HTML standard) and is now spinning the threads that are rapidly becoming the foundation for tomorrow's Web. This talk provides an overview of standards that are defining the Web of the future, with a focus on Web Services and the Semantic Web.

The early Web was largely a Web of documents shared among people. It was not long before scientific (geophysicists among the leaders), commercial and government communities applied technologies like HTML forms as interfaces between people and the programs and data stores of interest. The advent of XML [2] as the atomic unit of data exchange standards makes it easier for systems in different environments to exchange data. The universality of XML makes it a very attractive way to communicate data and information between programs.

Web Services is a growing suite of XML-based standards to enable a Web of programs, supporting interoperable and extensible application-to-application interaction over a network. In its simplest terms, a Web Service has an interface described in a machine-processable format (i.e., Web Services Description Language). Other systems interact with a Web Service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP. Web Services can be combined in a loosely coupled way in order to achieve complex operations.

Semantic Web technologies enable a Web of data with machine-processable meaning. This extension of the original Web provides a common framework for data sharing and reuse across different applications (including Web Services), enterprises, and communities. The Semantic Web is based on the Resource Description Framework (RDF), which integrates a variety of applications using XML for syntax and URIs for naming. The Web Ontology language (OWL) provides a standard for defining structured, Web-based vocabularies to enable richer integration and interoperability of clearly-defined data among descriptive communities.

A companion presentation, "Weaving a Web for the Next Generation of Science", will provide examples of scientific communities starting to leverage Web Services and the Semantic Web.

[1] http://www.w3.org

[2] http://www.w3.org/XML/Activity

[3] http://www.w3.org/2002/ws/Activity

[4] http://www.w3.org/2001/sw/Activity

WEAVING A WEB FOR THE NEXT GENERATION OF SCIENCE

Steve Bratt

World Wide Web Consortium

The presentation entitled, “Spinning Threads for the Next Generation of the Web”, provided an overview of Web Services and Semantic Web technologies. The objective of this session is to motivate discussion on the integration of new technologies into research communities using the experience emerging from communities that are starting to employ Web Services and Semantic Web standards.

The seismological community realized, before most others, the value and necessity of developing well-defined format and protocol “standards” for collection, exchange and storage of large quantities of data. Though there was more than one set of these standards, exchange of seismic data between sub-communities was enabled through sharing of documentation and tools. Activities from research to large-scale systems development all benefited from common seismic data standards.

The emergence of global, interoperable standards for Web Services and Semantic Web is a sign that the rest of the world is catching up to seismology. What might be the benefits if the seismological community migrated toward the use of these Web standards? What if these standards allowed computer applications to read the data and as well as the meaning of the data (e.g., the definition, units, origin, relationships, etc., of each data attribute and value)? And what if many other communities in academia, industry and government employed the same standards to define and make available their data and vocabularies?

To begin to fathom the possibilities, one could extrapolate the global benefits that have arisen from the standardized HTML Web. There would be obvious benefits from improved computer-enabled networking with the broader geosciences, emergency management, arms control, cartography, funding, equipment, transportation, journals, etc. communities. Because the underlying data standards would be the same, there would be expanded opportunities for sharing tools within this Web of communities. Enhanced communication, collaboration, creativity, directed and serendipitous discovery, and new levels of efficiency would all be distinct possibilities.

However, paradigm shifts are not free. Are the potential benefits worth the re-direction of financial and human resources to make the shift? What about all the legacy applications and their user bases? There is also a cost to shifting cultural momentum (also a benefit?).

To further explore the opportunities and challenges, this discussion will draw upon examples from the integration of Semantic Web and Web Services technologies within an expanding Web of communities surrounding the life sciences, digital libraries, publications, geospatial imaging, and other domains.

FIRST BIGFOOT PRINT AND EARTHQUAKE HAZARDS IN THE PACIFIC NORTHWEST

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US Array's First Bigfoot Print is well-positioned to investigate important alternate models for upper mantle structure related to earthquake hazard issues in Cascadia (and southern Alaska). A significant outstanding issue in earthquake hazard assessment in Cascadia is whether large inslab earthquakes can occur near Portland and beneath the Willamette Valley. Whereas Puget Lowland has experienced large inslab earthquakes in 1949, 1965, and 2001, Oregon has not experienced any large historical inslab earthquakes. Recent experimental petrology work suggests that the inslab earthquakes beneath Washington and Vancouver Island occur at the depths where metabasalt of the downgoing slab is metamorphosed into eclogite. This transformation drives water out of the slab, which may promote inslab earthquakes, and into the overlying forearc upper mantle, where it should hydrate and serpentinize the mantle peridotites. As predicted for these petrologic models, as the depth of the subducted slab increases inslab earthquake hypocenters migrate updip from the upper mantle into the subducted oceanic crust. Widespread serpentinization of the Cascadia forearc upper mantle has been inferred from low upper mantle seismic velocities and weak PmP reflections from the top of the upper mantle. More recently, joint analysis of aeromagnetic and gravity data has provided a method of mapping the serpentinized upper mantle in plan view. So defined, the serpentinized forearc upper mantle extends nearly continuously along the forearc in a 75- to 100-km wide band from Vancouver Island to southern Oregon. The mapped location in Oregon is almost exactly coincident with the serpentinized mantle defined by the broadband inversion by Bostock et al. (this meeting). The correlation between the locations of serpentinized upper mantle and inslab seismicity is strong in Washington and weak in central Oregon. The paucity of in-slab earthquakes beneath Oregon suggests that dehydration reactions are not the sole cause of inslab earthquakes in Washington. Several hypotheses for the lack of inslab earthquakes in Oregon include: 1) the subducting slab is younger and hotter beneath Oregon than beneath Washington, making it less susceptible to brittle failure and pushing up the eclogite metamorphism to shallower depths, 2) the subducting slab is truncated below 150 km-depth beneath Oregon, causing less slab pull stress, and 3) the slab geometry is simpler beneath Oregon, causing less flexural stress in the slab. By mapping the slab geometry and distribution of serpentinite within the forearc upper mantle, Bigfoot can test these hypotheses, providing better characterization of the inslab seismic potential near Portland. The convergent margin of southern Alaska shows similar characteristics: Some places with a strong correlation between inslab earthquakes and serpentinized upper mantle, other places with a weak correlation, suggesting along-margin variations in the slab or forearc upper mantle similar to those postulated for central Oregon. South of the Mendocino triple junction, the cessation of subduction, which cools the forearc upper mantle, allowing the formation of serpentinite, should cause the upper mantle to heat up, to dehydrate the upper mantle, and to expel this released water upwards. Could this process be the source of deep water inferred to help drive strike-slip faulting in California? First Bigfoot Print should help us better observe this process in Northern California.

GROUND MOTION AMPLIFICATIONS AND LOCAL SITE EFFECTS USING AFTERSHOCKS OF TWO MAJOR 1999 TURKISH EARTHQUAKES IN THE EASTERN MARMARA REGION OF TURKEY

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As part of a broader investigation of earthquake hazard, aftershocks of the 17 August 1999 Izmit (Mw=7.4) and 12 November 1999 Duzce (Mw=7.2) earthquakes are analyzed to investigate local site effects in eastern Marmara (Turkey) region. Seismic data used in this study (including IRIS PASSCAL stations) were collected by various organizations and assembled and distributed by IRIS and/or the United States Geological Survey (USGS). Nearby stations were paired to calculate soft soil to rock (or stiff soil) spectral amplifications for various aftershocks. Selected aftershocks are also used to test a novel slowness-frequency imaging approach for determining spectral amplifications for different seismic phases to assess site effects on their ground motions. Soft-soil ground motions are observed to exceed those at nearby rock or stiff-soil sites by factors of three or more in some cases. When site-specific velocity structure information is available (e.g. from receiver-function estimates, geophysical surveys, borehole measurements) the site amplification effects can be modeled for comparison to the observed amplifications. By using a GIS mapping tool results showing how local site variations affect ground motions are illustrated as overlays on other geologic, topographic, tectonic or subsurface information.

CASCADIA VOLCANISM – VOLATILES, MELT GENERATION AND VOLCANIC ERUPTIONS

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Subduction zone magmas are characterized by both high volatile contents (particularly H2O, CO2, Cl and S) and considerable compositional diversity. These two characteristics are related, and together explain the characteristic explosivity of arc volcanoes. Subduction zone volatiles are derived from the subducting plate and recycled back to surface reservoir by transport of H2O-rich fluids or melts from the slab to the mantle wedge. The effects of volatiles on arc magmatism are numerous. The introduction of fluids to the mantle wedge causes depression of the solidus and melt generation. Resultant hydrous basaltic magmas probably pond at the base of the crust, where they may either solidify, releasing volatiles to the overlying crust, or, occasionally, rise rapidly through the crust to erupt. The crust thus acts as both a density filter and a source of melt production when fluxed by heat and volatiles from these deep mafic inputs. Time scales of these processes are poorly constrained. However, data emerging from experimental and isotopic studies suggest that time scales of melt transport and crystallization may be short (decades to centuries), and thus may be observable by geophysical methods. From this perspective we suggest that important questions that may be addressed by integrated petrological, volcanological and geophysical studies of the Cascadia subduction zone include (i) What are the spatial and temporal variations in the structure of the mantle wedge? (ii) What evidence exists of fluid transfer within both the wedge and forearc environments? (iii) What is the nature of the Moho in subvolcanic environments, in general, and is there any evidence of ‘hot zones’ of melt accumulation at the base of the crust, (iv) What are the temporal and spatial variations in magma input to upper crust, and, over the long term, how are they coupled with basaltic inputs to the lower crust, on the one hand, and volcanic activity at the surface, on the other hand? Finally, recent geochemical, geodetic and seismic data indicate that magma is currently intruding the upper crust west of South Sister volcano, OR. This event provides a unique opportunity to examine potential links between mantle and crustal processes in real time.

REFLECTION, REFRACTION AND TELESEISMIC IMAGING OF THE LITHOSPHERIC MANTLE: A LITHOPROBE VIEW OF UPPER MANTLE HETEROGENEITY

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Passive teleseismic studies and active-source seismic experiments provide complementary data that span a broad range of frequencies and incident angles. The mantle has traditionally been the domain of passive seismic experiments while studies of the crust are predominantly accomplished using multichannel (MCS) reflection and refraction/wide-angle reflection (R/WAR) techniques. Analysis of coincident active- and passive-source datasets has the potential for enhancing our investigations of the lithospheric mantle, the primary region of overlap between these seismic techniques.

Active-source experiments have contributed immensely to new LITHOPROBE results on the structure and tectonic history of the crust. However, by recording MCS travel times to as much as 100 s and R/WAR offsets to as great as 1350 km, LITHOPROBE also has targeted the structure and characteristics of the lithospheric mantle. The lithospheric mantle is much less reflective than the crust, but it has clear features that can be related to tectonic processes and/or mantle discontinuities. Explanations for the long-offset, wide-angle reflection data require more heterogeneous velocity variations than are usually considered within the lithospheric mantle. Teleseismic data have lower resolution but readily provide velocity and structural characteristics to depths many times greater than do the active source methods. Thus, all three imaging techniques are fully complementary and necessary to aid understanding of the complex evolution of the continents. In this presentation, I exemplify this statement with results from three transects in the Canadian LITHOPROBE program.

In the Archean western Superior Province, the cratonic core of North America, MCS data image complex structures within the crust but show little reflectivity below the Moho. However, in two locations shallowly dipping reflections extend into the uppermost mantle and are interpreted as collisional suture zones. Orthogonal R/WAR profiles with offsets up to 600 km show azimuthal Vp anisotropy of 6% in a 15-20 km thick layer that dips northward at ~10º from a minimum depth of 50 km to at least 75 km. The mantle layer is interpreted as relic oceanic lithosphere accreted at the base of the crust during the final stages of lithospheric assembly of the western Superior Province at ~2700 Ma. A N-S linear array of broadband stations has enabled SKS-splitting studies and travel time tomography. In the north, these show a large high-velocity block in the lithospheric mantle that may represent the proto-craton against which island arcs, oceanic plateaus, etc. may have accreted. In the south, dipping high velocity features correspond well with features inferred from the active source experiments along the same profile.

LITHOPROBE's most spectacular seismic image derives from a reflection profile that extends for 690 km across the Archean Slave craton and Paleoproterozoic Wopmay orogen in NW Canada. Prominent dipping reflections extending from the lower crust across the Moho to about 90 km depth and other sub-horizontal mantle reflections to depths of ~100 km are observed over a 400 km segment of the profile. The former are interpreted as evidence for crustal delamination and subduction of crustal material into the mantle resulting from the collision of two lithospheric blocks at about 1840 Ma. The latter may be associated with the collision of a Proterozoic block with the western Slave craton at about 1920 Ma. A R/WAR survey along the same Slave-Wopmay corridor with source-receiver offsets to 800 km recorded wide-angle reflections from depths identical to those at which the MCS reflectors were interpreted. Images of the impulse response from five broadband stations at Yellowknife reveal a well-developed mantle stratigraphy from the Moho to the transition zone. Features in the lithospheric mantle correlate well with those interpreted from the active source experiments.

Extensive MCS data and three R/WAR profiles with maximum offsets of 750 km were recorded across and along the Manitoba-Saskatchewan segment of the Trans-Hudson Orogen, a 450-km-wide Paleoproterozoic orogenic belt that formed as a result of collision between the Archean Hearne and Superior cratons. Short-period and broadband receiver function studies, mainly located on the Phanerozoic sediments of the Western Canada Sedimentary Basin, provided crustal and mantle velocity functions for the crust and upper mantle. The MCS data show extensive reflectivity within the crust and defined a new structural model for the crust, but only very limited reflectivity was observed below the Moho. On the WAR profiles, a high quality secondary mantle phase, Pn2P,was observed as a 6 s to 3 s long sequence of spatially semi-continuous arrivals with variable moveout at offsets >300 km. Arrivals within the coda can be traced spatially over distances from 5-20 km. A significant difference in the continuity and strength of the Pn2P phase between the one E-W profile and the two N-S profiles exists. The phase is generated within the depth range of 80-150 km. To determine the source of this unusual phase, finite-difference forward modeling was undertaken. Randomly distributed, thin, horizontal, elliptical, negative velocity anomalies replicate the observed phase characteristics. However, the scale dimensions and velocity values of the cigar-shaped anomalies are different for the E-W and N-S profiles, indicating a form of anisotropic heterogeneity. We suggest that the reflective zone generating Pn2P underwent ductile deformation of the lowermost part of the lithospheric mantle during or following thickening of the THO lithosphere as a result of the collisional tectonics that formed the orogen. Perhaps modern broadband teleseismic studies could corroborate the existence and extent of the anisotropic reflective zone.

EXTREME EARTH TIDES STRONGLY TIGGER SHALLOW THRUST EARTHQUAKES

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We observe tidal triggering of shallow, thrust events by strong tidal stresses. Our dataset consists of the 9350 global earthquakes of M 5.5 or greater from 1977 to 2000 in the Harvard CMT catalog. We examined the entire dataset and subsets of the data for correlations with Earth tides, taking into account the amplitude of tidal stress. Tidal stress calculations include both a direct solid-Earth term and an indirect ocean-loading term. Globally, tidal Coulomb stress magnitudes vary significantly, with larger stresses induced in regions of large ocean tides near coastlines, as expected. Most of the high-tidal-stress earthquakes are in subduction zones, where ocean-loading tends to be largest and low-angle thrust events are most common. Tidal stress amplitudes decrease with depth. We examine in detail the subset of 2027 shallow thrust events with depths of 0-40 km depth. Excellent tidal correlations are found for shallow-dipping thrust events, assuming Coulomb stress frictional coefficient u = 0.2, 0.4, or 0.6. We perform a binomial test of significance to estimate the probability of seeing at random the fraction of earthquakes we observed during the time of encouraging tidal phase. This simple binomial test gives a probability of greater than 99.99% that earthquakes correlate with times of medium to high tidal stress amplitudes (>0.01 MPa) We show a strong influence of tidal stress on the timing of shallow, thrust earthquakes when and where the tides are strongest, with earthquake rate varying with tidal stress by a factor of three. The highest correlation is found assuming a coefficient of friction of u=0.4, although we see very good correlation over a range of u. The level of triggering observed agrees with values predicted by both rate-and-state friction and stress corrosion theories.

AUTOMATED EARTHSCOPE RECEIVER SURVEYING (EARS): A PROTOTYPE FOR USARRAY DATA PRODUCT GENERATION

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Receiver functions are a well known, commonly used technique for estimating crustal and upper mantle structure. Because it is well known, relatively stable, and has been used frequently over the past 40 years, it is ripe for automated processing. We have developed an automated receiver function processing system that retrieves data from the IRIS DMC, preprocesses it, calculates receiver functions and saves the original data, the receiver functions and an estimate of the crustal thickness and Vp-Vs ratio. This system will form the basis of an ongoing, near real time, standard data product for the upcoming USArray component of Earthscope. We term this product the "Receiver Reference Model" (RRM). Generation of RRMs for all Earthscope stations provides for identification of anomalous regions for more detailed study as well as basic information about the subsurface for E&O applications. In preparation for the rollout of USArray, we have applied this system to historical earthquake data from the IRIS DMC to produce estimates of bulk crustal structure for all stations in the US for which there is usable data. We also apply it to GSN stations to form a global crustal survey. This process will continue for both USArray data as stations are deployed and for new earthquakes at existing stations. We present preliminary results of this receiver function survey including crustal thickness and Vp-Vs ratio estimates for the stations based on the iterative deconvolution technique of Ammon and the stacking technique of Zhu and Kanamori. The processing system is based on SOD (Standing Order for Data, http://www.seis.sc.edu/SOD), a Java-based Fissures/DHI client. SOD is a highly configurable automated processing system developed at South Carolina to aid in the analysis of large volumes of data and to ease the burden on the scientist by handling the routine tasks of selecting relevant seismograms, retrieving the data and applying preprocessing functions. In addition, we have assembled common seismological utilities into a basic analysis group, BAG, that SOD and other Java applications can use. Currently this framework includes mean removal, trend removal, tapering, filtering, cutting, travel time calculation, rotation and response gain. Other functions will be added over the course of time. The design of these tools are loosely based on the functions in the popular SAC seismic processing software package, which lowers the learning curve required to use and understand them. SOD and BAG are freely available from the University of South Carolina under the Gnu Public License, (http://www.seis.sc.edu/software).

UPPER-MANTLE ATTENUATION AND VELOCITY STRUCTURE AS REVEALED FROM SURFACE-WAVE AMPLITUDES

Colleen Dalton, Goran Ekstrom

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Seismic-wave attenuation is highly sensitive to temperature and should provide an independent set of constraints on the Earth's internal structure that is complementary to the results of elastic velocity tomography. Such constraints may aid in distinguishing between thermal and chemical heterogeneity. Additionally, lateral and radial variations in Q may cause significant dispersion of waves traveling at different periods and should be considered when constructing and comparing velocity models derived from seismic observations from different portions of the seismic frequency band (i.e., short-period body waves versus long-period free oscillations). However, attenuation studies have historically lagged behind velocity models because of difficulties associated with measuring and interpreting seismic-wave amplitudes. For surface waves, amplitudes can be affected by uncertainty related to the source and instrument in addition to focusing and defocusing effects due to elastic velocity structure. We study upper-mantle attenuation using amplitude measurements of fundamental-mode Rayleigh waves with periods spanning 75-250 seconds. The amplitudes are corrected for the effects of the three contaminating factors; we account for focusing using the linear approximation of Woodhouse and Wong (1986), which depends on the second transverse gradient of phase velocity. We present the maps of attenuation and phase velocity that result from this analysis. The phase-velocity maps are very similar to phase-velocity maps derived entirely from measurements of phase delay, and they demonstrate that amplitudes contain significant and retrievable information about velocity structure. The attenuation maps show a strong correlation with surface-tectonic features, such as high attenuation beneath mid-ocean ridges and low attenuation associated with stable continental interiors. The results emphasize the importance of correcting the amplitude data for effects due to source and instrument uncertainty and focusing in order to isolate the signal in the data that is due to attenuation. A full three-dimensional inversion of the amplitude data, which is a future objective of this research, will help to reveal more precisely how attenuation structure varies with depth.

SEISMOTECTONIC AND NEOTECTONIC FEATURES OF CHARLESTON EARTHQUAKES

Inmaculada Dura-Gomez; Pradeep Talwani

University of South Carolina

As the seismogenic faults of the Middleton Place Summerville Seismic Zone (MPSSZ) in Charleston, South Carolina, are overlain by extensive basalt flows, they lack shallow or surficial manifestations. Hence their delineation has to be based on accurate hypocentral locations. P and S phases of earthquakes that occurred between 1997 and 2004 have been repicked leading to a modification of the existing velocity model with introduction of new station delays. These new delays and velocity model have been used to relocate events that occurred from 1977 to 1996. Considering only A & B quality locations for the period 1977-2004, the hypocenter locations were used to identify and delineate seismogenic faults lying beneath the extensive basalt flows. Fault plane solutions wewe obtained for nearly 100 events, and were used to obtain the sense of motion on the faults. The results support the presence of ~N15E Woodstock fault, cut and offset ~5 km by N45W trending Ashley River fault. The seismicity data have been introduced in a Geographic Information System (GIS) for a comparison with the results of various geological and geophysical investigations to infer evidence of expected neotectonic manifestation. These consist of topography, results of releveling GPS surveys, mapped scarps, shallow stratigraphy and observations following the 1886 Charleston earthquake. Additional geophysical data include the results of seismic reflection and refraction surveys and potential field investigations. We anticipate that a comparison of these features will help to reconstruct a history of neotectonic activity in the area.

PROMPT ASSESSMENT OF GLOBAL EARTHQUAKES FOR RESPONSE (PAGER): AN AUTOMATED SYSTEM TO ESTIMATE HUMAN IMPACT FOLLOWING SIGNIFICANT WORLDWIDE EARTHQUAKES

Paul Earle, David Wald, Lynda Lastowka, and Jonathan Godt

USGS US Geological Survey, Geologic Hazards Team

The US Geological Survey's National Earthquake Information Center (USGS/NEIC) is developing a system to rapidly assess societal impact immediately following significant global earthquakes. NEIC's near realtime earthquake solutions will be monitored to automatically identify quakes that likely caused human suffering or damage to infrastructure or that will attract significant media attention. Our goal is to help the NEIC fulfill its mission to provide critical earthquake-related information to emergency response agencies, government agencies, the scientific community, the media, and the general public. The system, know as Prompt Assessment of Global Earthquakes for Response (PAGER), will fill the gap between the time the hypocenter and magnitude are determined (minutes to an hour) and the time that onsite information is available through the media and other organizations (typically several hours to days). When complete, PAGER will provide an assessment of the situation based on estimated and any observed ground motions, total population exposed to varying degrees of shaking, and fragility of the impacted region. We expect that an automatic summary impact statement and associated alarms can be made within seconds of computing the ground-motion estimates, well before onsite damage estimates arrive. We will present progress towards a prototype system and give examples from several recent earthquakes.

EAGLE-A MULTIBAND EXPERIMENT TARGETING THE ETHIOPIAN RIFT: A SUMMARY OF PRELIMINARY CONTROLLED SOURCE SEISMIC RESULTS

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The EAGLE (Ethiopia Afar Geoscientific Lithospheric Experiment) multidisciplinary international project has the goal of defining the anatomy of a rift immediately prior to break-up. This project involved a 3-phase seismic experiment that was preceded by a regional broadband experiment conducted by Penn State University and was followed by a subsequent magnetotelluric experiment. Phase I consisted of deployment of 30 SEIS-UK broadband seismometers for a period of 16 months over a 250x250 km2 area of the rift valley and its uplifted flanks. The primary aim of this effort is to help define the shape of the Moho and to improve images of the uppermost mantle across the area. Receiver functions and body-wave analysis are providing images of deep earth structure while S-wave polarization analysis is being used to assess the nature of seismic anisotropy and its interpretation in terms of mantle dynamics, tectonic fabric and stress regime. Phase II consisted of the deployment of a further 50 SEIS-UK 3-component broadband instruments for a period of 4 months over a 200x100 km2 area encompassing 4 magmatic segments. This array is being used to locate local earthquakes, analyze fault plane solutions, and conduct receiver function analyses. The aims of Phase II are to estimate strain partitioning and lithospheric strength variations in 3-D, and to identify the distribution of magma reservoirs beneath the narrow magmatic segments. Phase III consisted of the deployment of a further 1100, primarily IRIS/PASSCAL, seismic instruments during a controlled source seismic project involving 20 seismic charges being fired into one 450km cross-rift profile (Profile 1), one 450km axial profile (Profile 2), and a dense 2-D array of instruments in a 150km diameter circle around the profiles' intersection (Profile 3). All of these deployments were centered on the magmatically active Nazret region. The preliminary crust and upper mantle velocity models presented here be are being used to provide estimates of total crustal thinning across and long the rift, to assess the role pre-existing lithospheric structure plays in locating major faults and magmatic segments, and to determine whether significant underplating takes place during the syn-rift stage. The high-density array around the intersection of the two profiles was designed to image any magma bodies beneath the Boset magmatic segment. We have derived preliminary models for all three elements of the controlled source effort, and these results are summarized as follows: Line 1 crosses the rift and the velocity model derived for this line shows a thin low velocity (3 km/s) layer confined within the central part of the model underlain with a ~4 km thick layer with a velocity of ~4.0 km/s. This upper lower velocity layer corresponds with the Late Miocene – Early Pliocene Nazrat ignimbrite series and the Quaternary sediments and volcanics of the Bishoftu embayment and rift valley. The lower layer most likely represents a combination of the pre-rift Jurassic sediments and Oligocene flood basalts. Beneath this layer, crystalline basement is modeled with a velocity of ~6 km/s. This layer shows significant structural relief beneath the rift where a clear graben like feature is modeled. As is the case with the topography, this structural relief is more pronounced along the eastern of the rift valley in the vicinity of the large Arboye border fault. Typical crustal (6.0 – 6.8 km/s) velocities are modeled with the exception of beneath the rift where higher velocities of are modeled in the upper crust. These velocities are interpreted to be the result of mafic intrusions beneath the rift magmatic centers. Beneath the western portion of the model beneath the Ethiopian plateau, a 10 km thick high velocity (7.5 km/s) lower crustal body is modeled. This layer produces a strong reflected phase from both its top and base. This body appears to terminate beneath the rift axis and is absent from beneath the eastern plateau region. Several possible explanations can be proposed for this high velocity body: (1) relic pre-rift crust, (2) partial melt at the base of the crust and (3) igneous underplate. Line 2 follows the axis of the rift from the southern Afar region southward for over 400 km into the main Ethiopian rift south of Lake Shala. Along this line, recording stations were deployed at an interval of ~1 km, and sources were placed at an interval of ~50 km. We started our analysis by using forward modeling of refracted and reflected phases to obtain an initial understanding of the phase relationships and correlations. We continued this analysis using the ray-tracing program RAYINVR. We then began an integrated analysis in which we continued using this program while also modeling a gravity profile along the line and first arrivals by travel-time inversion. As our work has progressed, we have included reflected phases, in particular the reflection from the Moho (PmP), to refine our velocity model via inversion using RAYINV. Our modeling clearly shows the strong thinning of the crust in the Afar region that is in good agreement with the results from earlier work. The velocity of the lower crust increases northward and the velocity of the upper mantle decreases in the same direction. The low velocities (~7.5 km/s) interpreted under southern Afar are particularly preliminary. The decrease in upper mantle velocities to the north indicates that the thermal regime is hotter to the north, and the very low upper mantle velocity values in the Afar area suggest the presence of some partial melt. To complete our integrated interpretation, a 2-D gravity model was constructed along Line 2 and jointly satisfying the gravity and seismic constraints proved to be straightforward, which increases our confidence in the major features in our model. Our preliminary interpretation shows that the crust is about 30 km thick in southern Afar about 40 km thick in the main Ethiopian rift. The low-velocity layer (Vp < 4.0 km/s) of volcanics and sediments at the surface is surprisingly thick (~5 km) along most of the profile, but the velocity structure appears to be that of stretched continental crust that has been underplated to some degree otherwise. The overall configuration of the crust along the axis of the rift is very similar to that observed in the Kenya rift. In northern Kenya, the crust under Lake Turkana is <25 km thick, to the south under the Kenya dome, the crust thickens to ~35 km and has a thick high velocity layer at its base, which is probably underplated material (Mechie et al., 1994). In both places, the crustal thinning appears to correlate with an increase in extension. Line 3 actually was an array, and to analyze the data from this array, a subset of 15 shots in the rift valley and on the rift shoulders was used to generate 7450 first-arrival travel-time picks for tomographic inversion. The 3-D first-arrival travel-time tomography code of John Hole was employed with a voxel size of 2 km. The final smoothing operator size was 6x6 km horizontally x 2 km vertically, and the RMS error on the final iteration was 117 ms, approximately the picking uncertainty in the data. A depth slice from the survey area at 10 km below the rift floor shows that elongate, high-velocity bodies (Vp = 6.5-6.8 km/s) lie beneath the magmatic segments, with rift volcanoes at each end. These bodies are ~10% faster than the background velocity of 6.0 km/s. The offsets between the segments, which are observed at the surface, are visible in our model particularly between the Koka and Boseti segments. Synthetic tests demonstrate that the segmentation is real, not an artifact of poor data coverage. Northwest of the Koka segment, another high-velocity anomaly diverts from the general N-S trend and extends to the NW, including the off-axis volcanoes of Zikwala and Yerer. The Koka segment includes the geothermal prospects of Tullu Moje and Gademsa and has slightly slower velocities than the other segments (6.3-6.4 km/s). A vertical slice across one of the high-velocity bodies in the Boset magmatic shows that the anomalous body is 20-30 km wide with steep boundaries and rises up to only ~7 km below the rift floor. Also evident is a shallow, low-velocity section (3-5.5 km/s), which is apparently downthrown to the west at the location of the eastern border fault. Beneath this low-velocity layer and away from the high-velocity body, the average velocity in the mid-crust is near 6.0 km/s. Slices across the rift valley near offsets between magmatic segments show no distinct high-velocity body. Our new 3-D seismic velocity model from the Main Ethiopian rift clearly images mid-crustal magmatic intrusions in this active, transitional rift setting, supporting breakup models based on diking and magma supply. The most striking features of our velocity model are anomalously fast, elongate bodies (Vp >6.5 km/s) running along the rift axis, interpreted as cooled mafic dike structures. These 20-km-wide and 50-km-long bodies are separated and laterally offset from one another in a right-stepping en-echelon pattern, mimicking surface segmentation of Quaternary volcanic centers. Our crustal velocity model, combined with results from geologic studies, indicates that below a depth of ~7 km, extension is controlled by magmatic intrusion in a ductile mid- to lower crust, while normal faulting and diking in a narrow zone in the center of the rift valley control extension in the brittle upper crust. This zone is inferred to be the proto-ridge axis for future seafloor spreading. The analysis of these three lines has been done in an independent but coordinated fashion, and the results generally agree well where they overlap. Our challenge for the future is to fully integrate these results with those from the passive monitoring and non-seismic efforts and to evaluate the tectonic implications of the full spectrum of observations.

EARLY DEVELOPMENTS IN GLOBAL DIGITAL DATA ACQUISITION AND DISTRIBUTION

Bob Engdahl

The development of a comprehensive and accessible data base for seismological research is an essential pre-requisite to scientific advancement. Before the mid-1970s accelerated progress in our understanding of earthquakes and global tectonics was due largely to the deployment in the 1960s of a Worldwide Standardized Seismograph Network (WWSSN) that generated a heretofore seismic data base unprecedented in quality and scope. However, as in all observational sciences, continued progress in seismology depends most of all upon continued improvements and modernization of the data base available for research. In the 1970s one of the important innovations in seismic observations was the advent of digital data recording. In what seemed revolutionary at the time, digital data acquired from the fledgling Global Digital Seismograph Network (GDSN) provided much greater resolution and recording range. Moreover, the data were made generally available in a format suitable for computer processing and analysis. This presentation will track the history of the earlier efforts made by the scientific community, largely through workshops and reports sponsored by the NAS/NRC Committee on Seismology, to bring our discipline into the digital age. In the mid-1980s, these efforts were undoubtedly important forerunners to the establishment of the IRIS Consortium and to the development of the GSN concept.

TRANSITION ZONE THERMAL CONSTRAINTS BENEATH THE YELLOWSTONE HOTSPOT

David Fee and Ken Dueker

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The dynamic cause of the globe's hotspots continues to improve as transition zone velocity heterogeneity and mantle discontinuity topography upon the 410 and 660 km olivine-component phase transitions are mapped into thermal estimates. Subsequent, correlation of these independent thermal estimates, from velocity and topography, provides one of the best quantitative tests of transition zone thermal structure. Of course, robust assessment of this correlation requires an accurate knowledge of mantle attenuation physics to constrain the magnitude of the anelastic thermal derivatives. Furthermore, the strong regularization of our velocity inversions often renders our "best" velocity maps as non-unique. And lastly, we acknowledge that the accurate measurement of discontinuity topography remains a low signal-to-noise imaging endeavour primarily because of low and non-uniform seismic coverage. Teleseismic P-coda waveforms from the Continental Dynamics Yellowstone and Snake River Plain broadband PASSCAL Arrays, along with USNSN data provides reasonable coverage of the Yellowstone region. Common conversion point stacking of radial and tangential receiver functions reveals 38±6 km of 410 topography that is dominantly uncorrelated with the 25±5 km of 660 topography. The maximum depth of the 410 discontinuity is 432 km, 15 km greater than the median value, indicating at least relatively elevated temperatures. This depression is not beneath the conjectured current plume location beneath Yellowstone Park, but 120 km to the west-northwest. Stacking of the high fold receiver function dataset from the Billings array reveals a strong (6% Vs) negative arrival gradient at 700 km that displays direct Pds moveout from three different back-azimuths. Most surprising is the isolation of a radial/transverse amplitude ratio of 0.9 for this arrival. Synthetic modelling of this feature is fairly non-unique, but a simple model to fit the stacks would require a dipping anisotropic layer. The 660 shows a radial/transverse amplitude ratio of 0.5 that is also difficult to model. The 410 shows a less robust (as assessed by phasing analysis) negative arrival between 360-390 km that is apparent in only 2 out of the 4 spatially independent stacks.

PROJECT SLAM: A FLEXIBLE FIELD SEISMOLOGY AND EARTHQUAKE STUDIES TEACHING MODULE

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A current challenge in science education and outreach is to provide students the vital link between scientific information learned in the classroom and the process of acquiring and evaluating new scientific data. The Earth sciences are uniquely positioned to leverage the allure of fieldwork as a driving force behind discovery that can be translated to the classroom with relatively little effort. More specifically, the advent of portable broadband seismometers has led to significant advances in our understanding of Earth's interior, structure, and dynamics. The primary goal of our efforts is to provide students the link between field seismology studies and the classroom from grade 7 to the introductory college level. We have therefore constructed a series of field seismology and earthquake studies teaching exercises to provide a first step at bridging this gap. This teaching module, named Project SLAM (Seismology Learning and Analysis Module), is publicly available on a web site (http://slam.asu.edu), and includes interactive teaching component as well as downloadable documents for distribution in classes. These exercises combine exciting and educational aspects of three areas of Earth sciences research, including the development of field seismology arrays, exploring earthquake activity, and understanding Earth structure. We utilize a multitude of Internet resources to enable a flexible system that can be used for a broad range of grade levels. For example, students work through the process of evaluating various locations in the U.S. for a hypothetical portable seismometer installation. Students are asked evaluate site's power, noise, accessibility, and safety using several WWW resources including the U.S. Census Bureau, TerraServer, and MapQuest. As part of the evaluation of the effectiveness of these exercises, we have performed initial evaluation and assessment through pre- and post-testing questionnaires for over 100 7th grade science students. We are currently examining these responses and will modify our evaluation tools as necessary before providing them to the public as part of the SLAM system. Finally, the recently initiated EarthScope program will produce an enhanced level of public awareness and excitement regarding studies of Earth's interior. Some of the activities in Project SLAM are ideal for integration into a broader-scale Education and Outreach component that can enable students and classrooms to help discover appropriate locations for seismometers as USArray marches across the U.S. over the next 10 years.

REGIONAL BROADBAND NETWORKS: CASE STUDIES FOR THE IMAGING OF CRUSTAL STRUCTURE AND EARTHQUAKE SOURCE PROCESSES IN CENTRAL CHILE AND ARGENTINA

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Regional broadband networks have long been used to obtain detailed constraints of the seismotectonic environment of specific regions. Here, we report the successful use of the waveforms recorded at the 22 broadband instruments deployed as part of the Chile Argentina Geophysical Experiment (CHARGE) for 17 months (January 2001 to May 2002) in central Chile and western Argentina. The purpose of the project is to study the transition between where the Nazca slab changes its flat slab configuration north of 33°S and resumes a normal dip towards the south. Two east-west trending transects where deployed at 30°S and 36°S. We used regional waveforms to obtain a first order image of the crustal structure underneath the northern transect and to study the source mechanism of the largest outer-rise event in the past 20 years. The northern transect of the CHARGE deployment at 30°S consisted of 8 stations separated by an average distance of 80-100 km. Along the profile, the surface deformation is accommodated by a fold and thrust belt in the Pre- and High Cordillera in the west and is composed of uplifted basement-cored blocks forming the Sierras Pampeanas which dissect the foreland basin in the east. We used arrivals of 9 crustal off-shore earthquakes to obtain apparent interstation Pn phase velocities. A global inversion scheme was used to match the observed and synthetic apparent phase velocities for crustal models defined by 8 Moho depths along the profile. Our preferred model shows a crustal thickness of 65km beneath the High Cordillera and Precordillera and a gradual decrease of Moho depths from 55 to 45km beneath the Sierras Pampeanas. Isostatically compensated Moho depths were computed along the profile for a range of reasonable density models. These calculations yield Moho depths that are systematically shallower than our preferred model. This discrepancy is particularly large (up to 15-20km) beneath the western Sierras Pampeanas, where the inferred thick crust conflicts with low elevations and minor crustal shortening. Reasonable crustal and mantle density models are not able to explain this large isostatic anomaly. Lower crustal flow and possible dynamic forces associated to the flat slab might play a role in explaining this anomaly. On April 9, 2001 a Mw6.7 earthquake occurred offshore the Chilean coast close to the intersection of the subducting Juan Fernández Ridge and the trench near 33°S. The mainshock as well as an unprecedented number of aftershocks were recorded at the CHARGE stations as well as on locally operated permanent short-period networks. A regional moment tensor solution of the mainshock was obtained in conjunction with a detailed aftershock relocation. The results reveal a tensional mainshock focal mechanism with the aftershock activity extending in to the oceanic lithosphere along two characteristic planes that are well aligned with the mainshock's fault planes. This suggests an activation of a conjugate normal fault system that extends into the lithospheric mantle and correlates surprisingly well with ridge-parallel fractures observed on the seafloor. In conjunction with the historic regional distribution of outer-rise and large interplate seismicity, our results indicate that with the exception of anomalously large thrust events, preexisting fractures associated with large bathymetric features like ridges have to exist to allow the generation of outer-rise seismicity along the Chilean margin. Hence, flexural bend and time-dependent interplate earthquake can locally affect the nucleation of outer-rise events. The occurrence of the outer-rise seismicity in the oceanic mantle suggests the existence of lithospheric scale faults which might act as conduits to hydrate the subducting slab.

DEVELOPMENT OF A GPS/SEISMIC DISPLACEMENT METER

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The Southern California Integrated GPS Network (SCIGN) consists of 250+ continuous GPS stations established over the last decade to monitor crustal deformation, and associated seismic hazards, across the diffuse Pacific – North America plate boundary in southern California. Positional accuracy is about 1 mm horizontally and 3-4 mm vertically using 24-hours of GPS carrier phase and pseudorange measurements sampled at a 30-second rate, which is sufficient to compute site velocities with a precision of less than 1 mm/yr, as well as coseismic and postseismic deformation. In 1999, SCIGN data captured motions from the Hector Mine earthquake in the Mojave Desert. Researchers at SIO discovered that the GPS data could also detect the seismic waves emanating from this earthquake, including dynamic motions in the Los Angeles basin lasting several minutes due to basin resonance effects. An effort was initiated to increase the sampling rate of select SCIGN sites to 1 Hz and stream the data back to SIO in real-time. First efforts were in Orange County and the Parkfield region is central California. The Orange County Real Time Network (OCRTN) was performed in collaboration with Orange County's Public Resources and Facilities Division, since the same data that were useful for "GPS Seismology" could also be streamed in real-time to surveyors who could then position their GPS equipment with respect to the geodetic backbone provided by the upgraded SCIGN sites with centimeter-precision in real-time. On 3 November 2002, the OCRTN captured teleseismic waves from the Mw 7.9 Denali fault earthquake in Alaska, more than 3900 km away. The Parkfield network, in a densely monitored region, captured the 22 December 2003 Mw 6.5 San Simeon earthquake, about 35 km away. SCIGN high frequency, real-time upgrades are now occurring in San Diego and Riverside Counties in collaboration with the UCSD's HPWREN and ROADNet projects. HPWREN's Toro Peak facility is being used to transmit 1 Hz data from 6 sites near Palm Springs that span the San Andreas fault back to UCSD, and plans are underway to upgrade additional sites in these two counties by leveraging this and other HPWREN and County communications infrastructure. Our objective is to develop a GPS/seismic displacement meter at the software (not hardware) level, which would optimally combine real-time seismic and high-rate GPS network data, for the purposes of fault slip and fault/earthquake parameter detection, seismic early warning, and structural monitoring. We discuss the status of SCIGN GPS upgrades in San Diego, Orange, Riverside and Imperial Counties, GPS/seismic co-locations, and possible integrative efforts of EarthScope's PBO and USArray components.

THE WHOLE IS GREATER THAN THE SUM OF THE PARTS: NEES+IRIS+USGS

NEES/IRIS/USGS Working Group

U.S. Geological Survey, IRIS, NEES

Over the last decade significant investments have gone into developing focused research facilities such as the Network for Earthquake Engineering Simulation (NEES) consortium, the Incorporated Research Institutes for Seismology consortium (IRIS), and those of the USGS National Earthquake Hazards Reduction Program. Recognizing that the combined capabilities of NEES's large-scale shakers (and other NEES facilities), IRIS's diverse array of seismic recording systems, and USGS geophysical and seismic instrumentation should greatly exceed even the sum of their individual ones, IRIS sponsored a workshop on April 29-30, 2004 to begin building multi-facility collaborations. Thirty-four scientists and engineers gathered at the NEES facility in Austin, TX to 1) brainstorm about scientific and engineering questions that could be best addressed using the combined resources of multiple facilities, 2) have an instrumentation 'Show and Tell', 3) exchange information about how different groups acquire, analyze, archive and distribute data, and 4) present ideas for specific experiments best implemented using NEES, IRIS, and/or USGS facilities together. Coordination with Earthscope and the ANSS also was discussed. Workshop discussions resulted in preliminary plans for at least one USGS-sponsored demonstration field experiment to be conducted this summer or fall, additions to already-planned experiments, and ideas for other new innovative collaborative studies. For more information see http://www.ceri.memphis.edu/~gomberg/NEES/index.htm.

RECEIVER FUNCTION IMAGING OF THE SUBDUCTING SLABS AND MANTLE STRUCTURE BENEATH JAPAN.

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Subsurface water is believed to be involved in many processes in subduction zones like material recycling, melting processes, arc volcanism, continental crust formation, and the uneven distribution of subduction zone seismicity. Because strong P-to-S scattering is expected from fluid-filled structures, scattering intensity can be a good tracer for subsurface water. Thus receiver-function imaging of the P to S converted energy offers the promise of providing understanding of these processes. We first performed extensive numerical experiments on the reconstruction of subducting slabs with receiver-function imaging. Synthetic seismograms are generated using a two-dimensional elastic wave finite-difference code. Teleseismic wavefields are approximated by an input plane-wave. Wave fields generated from ocean-side events are generally more complicated than those from earthquakes on the back arc. We have applied diffraction migration to the receiver function generated from the synthetic data. A receiver spacing less than 10 km is required in order to obtain a unaliased image. Lateral extension of receivers along the subduction direction is also required for better imaging. We then chose Japan as our study region because of the availability of dense borehole short-period seismic networks (Hi-Net). We developed a technique to form receiver functions from short period seismograms with reasonably high quality. Migration images of receiver functions are constructed for several sections across Japan. Both the two 410-km and 660-km discontinuities are well imaged in all the sections, whereas a deeper discontinuity at ~900 km is also clearly shown in some of the images. Strong scattering associated with the subducting slabs are found for several sections. Locations of the scatterers are ~20-50 km below the Wadati-Benioff zone, roughly at the lower boundary of the slabs. Event locations in migration images, however, depend strongly on the reference velocity model. In fact, if the reference velocity model differs from the true structure by 3%, the subducting slab could be mistakenly located by about 20 km. So our results may indicate that the mantle wedge has a very lower seismic velocity.

PRELIMINARY RESULTS OF WAVEFORM CROSS-CORRELATION ANALYSIS FROM THE COSTA RICA SEISMOGENIC ZONE

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The mechanical behavior along the seismogenic zone in subduction environments is not well understood due to the limited constraint on the precise geometry (thickness of the planar interface as well as the up- and down-dip limits) and the degree of plate coupling in these regions. The 1999-2001 collaborative CRSEIZE (Costa Rica Seismogenic Zone Experiment) consisted of a joint seismic and geodetic investigation of the Costa Rica plate interface to investigate the processes occurring at subduction margins. As part of this study, two seismic transects were established across the Middle America Trench at the Nicoya and Osa Peninsulas in Costa Rica and velocities at 46 GPS sites throughout the country were determined. The seismic arrays consisted of both land and ocean bottom stations situated directly above the seismogenic zone, allowing for direct recording of local seismicity. Previous work in this area examined the effects of seafloor roughness and thermal history on the earthquake rupture process and on the loci of seismogenic zone seismicity (Newman et al., 2002, Bilek et al., 2003, DeShon et al., 2003). Local seismic tomography has also been applied to image the three-dimensional P- and S-wave velocity structure in the vicinity of the seismogenic zone in northern Costa Rica. Currently, waveform cross-correlation techniques to improve P- and S-wave arrival times are being conducted. The automated correlation and clustering method employed greatly reduces the picking inconsistencies compared to human analysis alone (Rowe et al., 2002). Improved arrival time data are being used to calculate more accurate earthquake locations to refine previous determinations of the up- and down-dip limits of the seismogenic zone as well as to improve the results of local tomography. Also, by examining the degree of waveform similarity, we can determine if there are any repeating events in the dataset and compare their locations with the strength of interplate coupling revealed in both the seismic and geodetic data sets. Finally, P-wave first-motion determinations for many events are significantly improved by waveform cross-correlation, resulting in more reliable focal mechanisms and the improved ability to differentiate between underthrusting interplate events and intraplate seismicity. Preliminary results using the cross-correlation technique will be presented.

THE EFFECT OF EXPLOSIVE PROPERTIES ON TWO LARGE CRUSTAL SEISMIC SHOTS

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Conventional wisdom claims that explosives with higher detonation velocities produce higher frequency seismograms, that is high velocity explosives produce pulses with very steep fronts (Telford, et al., 1976). To test this assumption we loaded two large crustal seismic shots with different types of explosives as part of the Portrillo Volcanic Field experiment in May of 2003. Our expectation was that the shot loaded with the higher velocity explosive would yield seismograms richer in high frequency energy. Also, because the detonation pressure of the higher velocity explosive is more than twice that of the lower velocity explosive, we expected that higher velocity shot might produce higher amplitude seismograms.

Methods and Results

Our shots were located 40 m apart and were drilled along strike of an alluvial basin to the same depths and loaded with different, but energy equivalent amounts of explosives, totaling 0.8 gigacalories each. Everything was done to keep the shots as identical as possible. The higher velocity explosive was a demilitarized artillery propellant (DAP) with an oxidizer added to increase its combustion rate. This blasting agent had a detonation velocity of 7.1 km/s, a detonation pressure of 188 kbars, and strength of 885 cal/g. The lower velocity explosive was an emulsion with a detonation velocity of 4.7 km/s, a detonation pressure of 71 kbars, and strength of 700 cal/g. The emulsion contained microballons, which allows for full detonation at greater water depths. The mix we used was rated to 100m of water. The DAP has no known depth dependent problems. 900 kg of DAP and 1150 kg of the emulsion were used. The emulsion slumped in the hole more than the DAP, so both explosives occupied about 37 m of their respective holes. Both shots were hand loaded with detonating cord attached to the first charge lowered and 0.45 kg boosters distributed at approximately 1.5 m intervals. Hence the time interval from the beginning of the detonation until the end was the same both shots. The emulsion was shot first, followed 15 minutes lately by the DAP.

Recording stations were located approximately every 500 m along a line extending to the east from the shots, which are located on a north-south line. All recorders were Reftek 125s (Texans) with 4.5 Hz vertical geophones. The raw data were processed into SEGY gathers for each shot and DC offsets were removed. No other processing was done so as to preserve original amplitudes and frequencies. Figures1 and 2 are the near source record sections from the individual shots, notice the high signal to noise ratio due to the strong signal at these short ranges. The amplitude of the DAP shot is about 70% greater than that of the emulsion shot on all of these near traces. To test the assumption that higher velocity explosives produces higher frequency content, we calculated the amplitude spectra of the traces in Figures 1 and 2. We see no significant enrichment of the high frequency part of the spectra for the DAP shot versus the emulsion shot (Fig. 3 and 4).

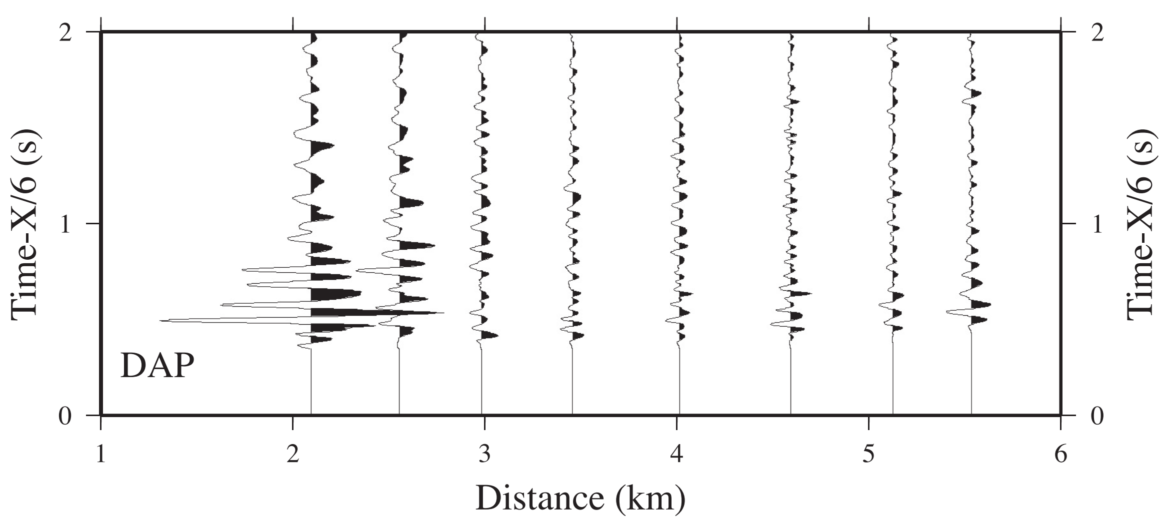

Fig. 1. The DAP shot traces from 1 to 6 km offset. Amplitude scales in the same for all traces in Figures 1 and 2.

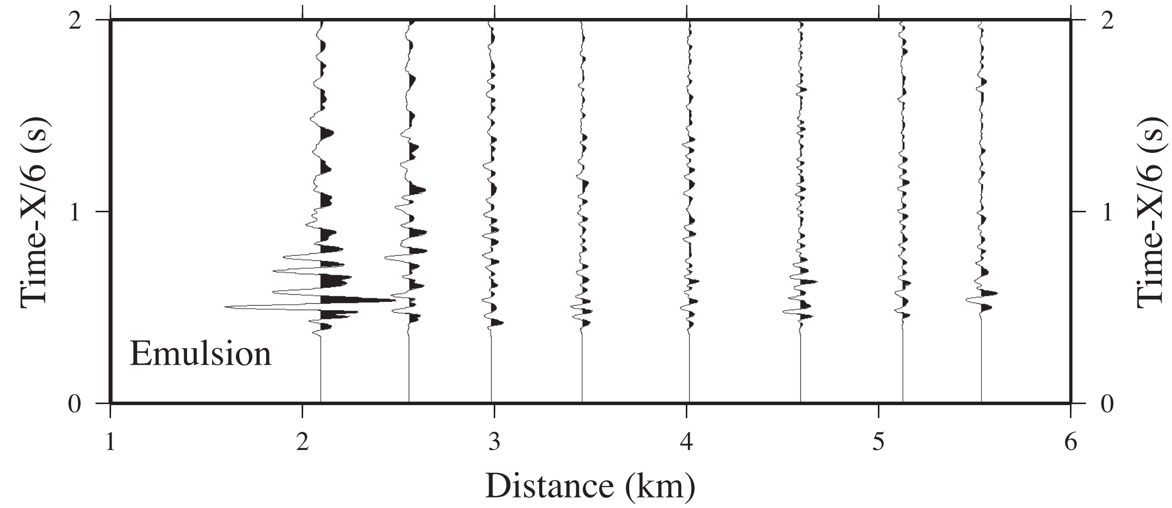

Fig. 2. The emulsion shot traces from 1 to 6 km offset.

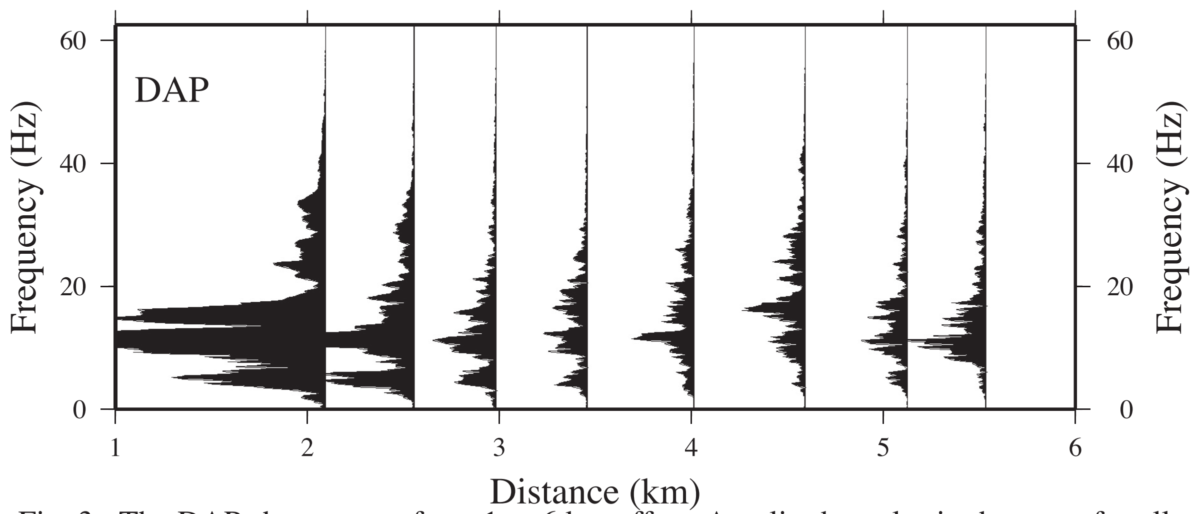

Fig. 3. The DAP shot spectra from 1 to 6 km offset. Amplitude scales in the same for all traces in Figures 3 and 4.

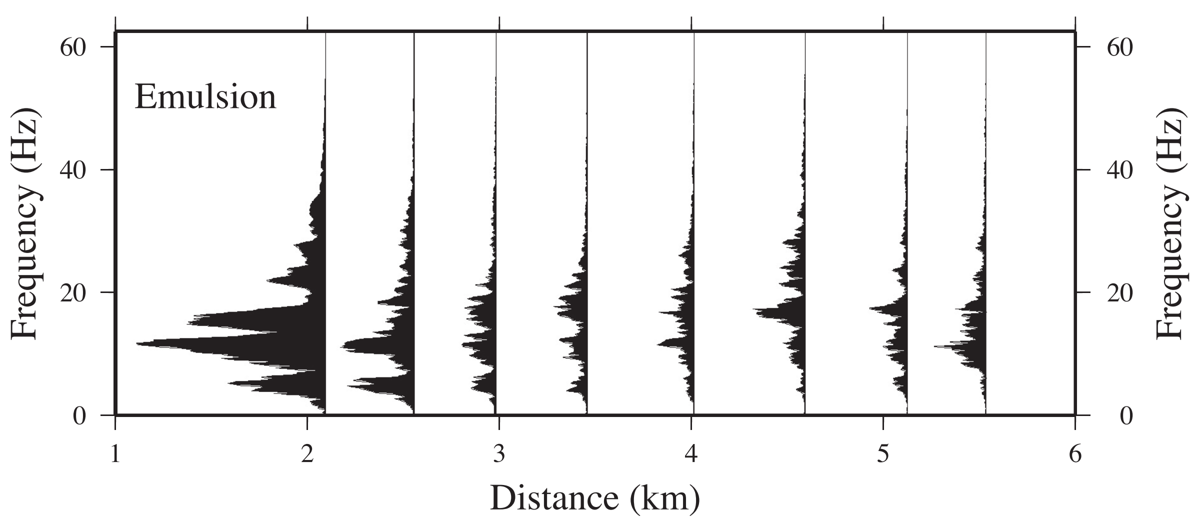

Fig. 4. The emulsion shot spectra from 1 to 6 km offset.

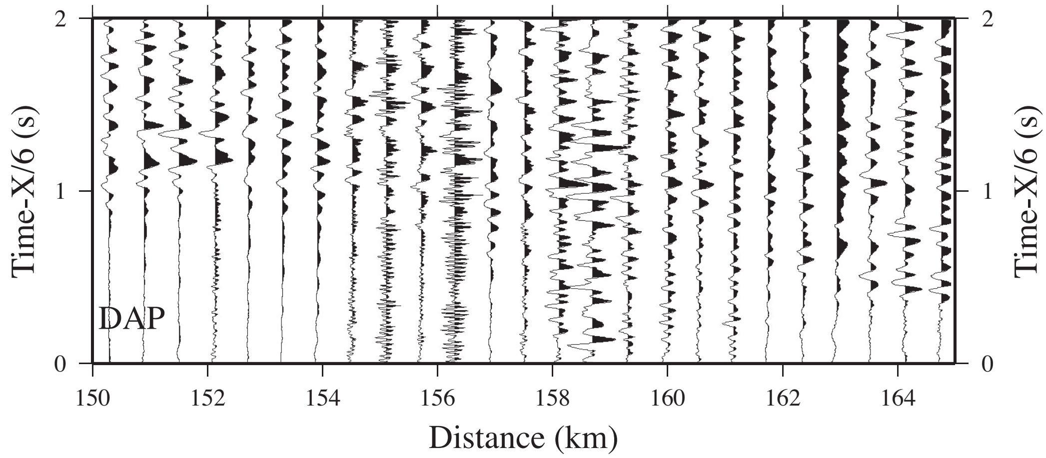

Fig. 5. The DAP shot traces from 150 to 165 km offset. Amplitude scales in the same for all traces in Figures 5 and 6.

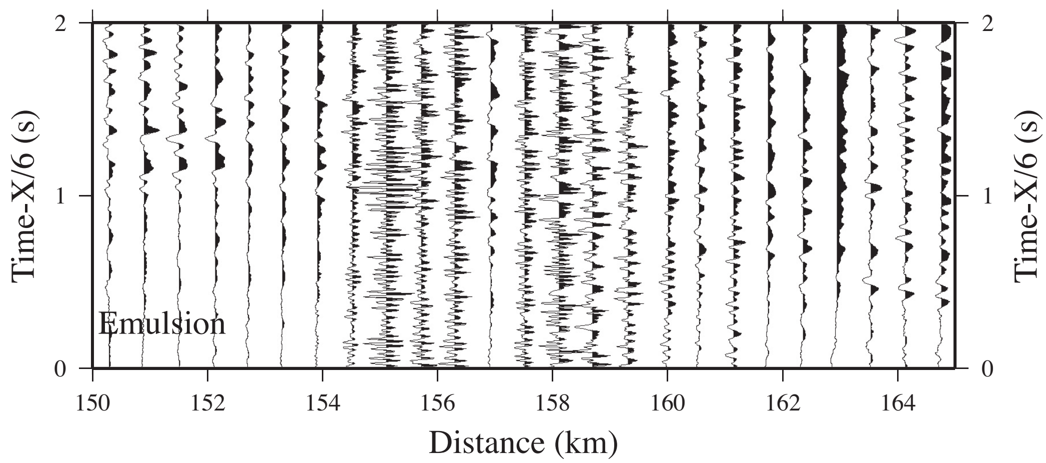

Fig. 6. The emulsion shot traces from 150 to 165 km offset.

At longer offsets, the amplitude of the DAP shot is still approximately 70% greater than the emulsion shot as seen in Figures 5 and 6.

Conclusions

In this test case, the detonation velocity of the explosive seems to have little effect on the spectral properties of seismograms. Detonation pressure however, seems have a large effect on the amplitudes of seismograms. With a factor of 2.65 increase in detonation pressure we observe a factor of 1.7 increase in amplitude, from a less expensive explosive.

One comparison is certainly not enough to draw sweeping conclusions about the effect of detonation pressure on seismograms. This experiment should be repeated under different conditions and geologic environments. Further, detonation velocity and detonation pressure are not independent variables when choosing explosives. Detonation pressure is proportional to the product of density and detonation velocity squared (ISEE, 1998). In physical terms the two shots detonated in this experiment had the same energy. However, the DAP delivered its energy to the borehole wall more quickly doing the same work in less time, thus developing more power. This is observed in the seismograms.

Acknowledgements

We would like to thank Cathy Snelson who detonated these shots. The Texas Higher Education Coordinating Board who provided funding to develop the Texans and for the Portrillo Volcanic Field experiment. The National Science Foundation, which also provided funding for the experiment and IRIS/PASSCAL who provide instruments and instrument support for this project.

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CRUSTAL THICKNESS VARIATIONS ACROSS THE SOUTHERN APPALACHIANS: AN ALTERNATIVE PROCEDURE FOR MIGRATING WIDE-ANGLE REFLECTION DATA

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Today, most crustal refraction/wide-angle reflection experiments are carried out with hundreds of instruments, large field crews, and specially drilled shots. Where resources are more limited, however, one can still obtain useful information about the crust by using quarry blasts and multiple deployments of much smaller arrays. We show results from a series of reconnaissance profiles across the southern Appalachians.

Extended source signatures generated by ripple firing were deconvolved using a combination of spectral whitening and least-squares inverse filtering based on source wavelets estimated by minimumentropy deconvolution. The data then were migrated using an extension of the method developed by Hawman and Phinney (1992) for migrating travel-time picks in common-source gathers. We have found it to be useful for migrating data recorded with isolated, short-aperture arrays. Like the methods described by Phinney and Jurdy (1979) and Milkereit (1987), it uses the localized slant stack of the source gather as an intermediate data set. Measurements of ray parameters fix the incidence angles, allowing separation and correct positioning of overlapping reflections. Unlike those methods, however, it assumes that all coherent energy in the slant stack consists of reflections from planar dipping interfaces; possible contributions of diffractions are ignored.

Briefly, the algorithm maps every sample in the coherency-filtered slant stack into a planar, dipping segment with a length that is a function of the length of the recording spread and the migrated dip. The method uses ray tracing to determine the position and dip of reflecting interfaces. Each sample in a given ray parameter trace (where the time axis corresponds to the travel time to the center of the recording spread) is downward continued until it intersects a ray traveling downward from the source which yields a combined two-way travel time that matches the observed time. The dip is determined from the ray parameters of the upgoing and downgoing rays. Once the subsurface position of the reflector midpoint is determined, a planar interface is generated by assigning the value of that slant-stack sample to all subsurface points along a linear segment with the appropriate dip. A separate subsurface section is generated for each ray parameter trace. Each trace in a given section is linearly interpolated over depth. The individual sections then are stacked to construct the final image of reflectors as recorded for that shot gather.

Although the method is not a true wavefield migration, it does incorporate some useful information from the input wavefield into the migrated image. The thickness and lateral extent of migration smiles are controlled by the degree of smearing in the slant stack, which in turn is controlled by the array aperture and signal bandwidth. The dimensions of these smiles thus serve as measures of the resolving power of the input gather.

The method is being used to migrate a set of roughly 110 blasts recorded in several provinces of the southern Appalachians, including 44 blasts recorded in 2002-2003 in the Blue Ridge Mountains. Preliminary results show an increase in crustal thickness from 38 km for the Carolina Terrane (and associated regional gravity high) to about 50 km along a regional gravity low associated with the foothills of the southeastern Blue Ridge. Pg-PmP travel-time differences for blasts not yet migrated suggest even greater crustal thicknesses within the central Blue Ridge.

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GLOBAL DENSE NETWORKS

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While current Global tomographic models reveal many interesting features, they tend to be too weak. In particular, they fail to predict synthetics matching observed waveforms on the IRIS network for many paths. A common problem is the sharpness of tectonic boundaries where models predict about _ the relative timing jumps in multiple S phases observed when compared against SEM (20s–3D) synthetics, i.e., crossing the Rocky Mountain Front (WUS) and the Alpine Front in Europe.

At shorter scale-lengths (5s waves), the broadband arrays such as PASSCAL and permanent arrays (CISN) allow small reflected phases to be identified by conventional stacking from individual events. Moreover, we can identify multi-pathing by stacking along combinations of distance and azimuth searching for preferred alignment and organization (fan-shots). Modeling such features observed for a deep mantle structure beneath South Africa yields an enormous structure with nearly vertical relief. SKS paths crossing the structure at right angles show increases in timing by up to 8s while S paths sampling along the boundaries (parallel) display clear multi-pathing containing contributions from inside (slow) and outside (fast). Similar examples of upper-mantle triplication data for western U.S. indicate significant changes in relative timing between branches on the scale of 50 km, and the existence of deep transition low-velocity zones. Modeling such features require zones up to 90 km in thickness with velocity reductions of 5%, where the 410 discontinuity essentially disappears. These same features can be related to high-resolution receiver-function observations.

At still shorter scales (few Hz waves), the broadband arrays can detect the thickness of the crust-mantle transition from precursors to pP for deep events as well as the shallow structure beneath individual stations (top few km) by using the comparison of vertical to radial responses. Numerous data sections from TriNet with some modeling will be presented.

ANALYZING THE SEISMICITY OF THE BHUTAN HIMALAYA UTILIZING A TEMPORARY SEISMIC NETWORK

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We are processing data from a five station temporary seismic network set up from January 2002 until March 2003 within the Kingdom of Bhutan. Initial results confirm that the region is more active than previously identified. This is mostly due to the lack of local and regional stations in the region. We detected, associated, and located approximately 2000 teleseismic, regional, local events and discovered that approximately 900 were not in the global U.S.G.S. earthquake catalog. We further study these events by manually picking P- and S- wave phases for each event and performing event re-locations using a 1-D velocity model for the region. We developed our own 1-D velocity model from our event travel times to predict travel times throughout the region and created a velocity structure for the region. Initially, we find event clustering, which helps us to identify the location of active faults and the possible development of new faults. Future work includes processing the complete data, adding data from other seismic stations in the region, performing high-resolution earthquake locations, determining focal mechanisms and determining models of deformation for the Bhutan Himalaya.

SEISMIC VELOCITY STRUCTURE FROM A REFRACTION - REFLECTION SURVEY ACROSS THE SAN ANDREAS FAULT AT SAFOD

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(1) Virginia Tech; (2) GeoForschungsZentrum Potsdam

Detailed characterization of the subsurface geology surrounding SAFOD is required to plan drilling and to interpret down-hole results. A 46-km long seismic refraction and reflection line was acquired perpendicular to the San Andreas Fault centered on the SAFOD drill site. The line was deployed straight across country assisted by helicopters. A fixed array of 912 three-component stations at a 25-50 m spacing recorded 68 explosive 25-100 kg shots at a 0.5-1 km spacing. Piggyback deployments recorded the shots down the SAFOD pilot hole, on permanent and temporary earthquake arrays, and on a high-resolution survey near the drill site. First arrival travel times from the main line were inverted to obtain a 2-D seismic velocity model of the upper crust. The model contains strong variations from less than 2 km/s at the surface to greater than 6 km/s in granitic basement. Granitic rocks of the Salinian terrane west of the San Andreas Fault are substantially faster than adjacent sedimentary rock of the Franciscan terrane east of the fault. Salinian basement slopes westward from 0.7 km subsurface at SAFOD to ~2.5 km at the Salinas River, with indications of two faulted steps. A small velocity contrast and reflections indicate the position of the Coast Range fault, which thrusts Great Valley Sequence sedimentary rocks over the Franciscan terrane. A local sedimentary basin lies immediately west of the surface trace of the San Andreas Fault, between SAFOD and the fault. This basin is bounded to the west by (or near) the Buzzard Canyon Fault. The basin is substantially deeper than basement beneath the SAFOD site, extending very close to the shallowest earthquakes and explaining the previously observed zone of high electrical conductivity. Detailed structure of the San Andreas and Buzzard Canyon faults and the basin between them may affect the SAFOD drill hole and are critical to linking down-hole observations to surface geology.

INPUTS TO THE SEISMOLOGY STUDENT PIPELINE: THE IRIS UNDERGRADUATE INTERNSHIP PROGRAM

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Since 1998, the IRIS Education and Outreach Program, has facilitated opportunities for twenty-nine undergraduate students to work with leaders in seismological research, travel to exotic sites for fieldwork, and produce products worthy of presentation at large professional conferences. Designed as an 8-12 week program, the IRIS Undergraduate Internship Program provides undergraduate students with the opportunity to: • develop an understanding of scientific inquiry, including the ability to design and conduct scientific investigations and to defend scientific arguments, • gather, manage, and convey information, using a variety of skills, strategies, resources and technologies, • learn, use, and evaluate technologies for the collection and study of geophysical data, while working with a researcher at an IRIS institution. The goal of this program is to provide undergraduate students with research opportunities early in their educational careers, thus encouraging more students, representing a more diverse population to choose careers in Earth science and seismology. Of the twenty-nine students placed through the program's six-year history, one is currently employed in a geophysics career, fourteen are enrolled in either a MS or PhD level geophysics program, nine are completing undergraduate degrees, and five are unaccounted for. Thus, the program has demonstrated at least 75% success in its goal of encouraging students to pursue careers in geophysics.

43 YEARS OF GLOBAL OBSERVATIONAL SEISMOLOGY AT THE USGS ALBUQUERQUE SEISMOLOGICAL LABORATORY

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The USGS Albuquerque Seismological Laboratory (ASL) has been in existence since 1961. It was established as a quiet site for testing seismometers for the World Wide Standardized Seismograph Network (WWSSN), but quickly became the installation & maintenance depot and data collection center for the WWSSN. From "Then 'til Now", the ASL has been the installation, maintenance and data center for various improved versions of global seismic networks including the High Gain Long Period (HGLP) network, the Seismic Research Observatories (SRO), the Digital version of the WWSSN (DWWSSN), and the Modified High Gain Long Period network. During the 1980s and 1990s, ASL developed and deployed the 9 stations of the China Digital Seismic Network (CDSN) and the 9 stations of the Global Telemetered Seismograph Network (GTSN). In 1984, the USGS/ASL began working closely with IRIS in developing and installing the Global Seismograph Network (GSN), the first very broad band, digital recording, global, network designed specifically with research and earthquake monitoring needs in mind. ASL currently operates 84 GSN stations in 60 countries, and is in the process of installing 7 more. From the HGLP through the GSN, the ASL Data Collection Center has developed effective quality control, archiving, and distribution techniques that result in high quality data and data availability. ASL and the USGS National Earthquake Information Center in Golden, CO, are working together to develop quality control and data center capabilities that will serve both ANSS/Earthscope and the GSN. USGS/ASL will install, in cooperation with the USGS group in Golden, Colorado, 35 Backbone stations of the ANSS/Earthscope USArray project over the next three years.

SPICE: A EUROPEAN NETWORK IN COMPUTATIONAL SEISMOLOGY

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Recently, the European Union funded a Marie-Curie Research Training Network (MCRTN) in the field of computational seismology. The four-year project called SPICE (Seismic wave Propagation and Imaging in Complex media: a European network) started in January 2004, is coordinated by the seismology group of the Ludwig-Maximilians-University, Munich Germany, and links a total of 14 European institutions. While the overall goal of the MCRTNs is to train young scientists in the particular research area, the specific technical goal of the SPICE network is to develop infrastructure for an open digital library with (1) computational algorithms ready for use by the scientific community; (2) accessible simulation results (e.g. ground motions from earthquake scenarios, global seismograms, dynamic rupture modelling); and (3) training material. One of the most fundamental questions to address therefore is the specific format with which synthetic data should be stored in the long term. During the SPICE kick-off meeting in January 2004 it was decided that the development of such standards and programs to access and visualize synthetic data should be carried out in close collaboration with the national and international seismic data centres (e.g. ORFEUS, IRIS). In our poster we describe the SPICE project and present the concepts developed towards the goals mentioned above.

SITE AMPLIFICATION AND SCATTERING OF SH WAVES IN THE NEW MADRID SEISMIC ZONE AND INTERPRETATION OF INTRINSIC AND SCATTERING Q MEASUREMENTS FROM SH CODA.

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Three component seismograms are examined at different center frequencies to see if there is amplification by structures under stations with in the New Madrid seismic network. Intrinsic (Qi) and scattering (Qs) values are also measured from coda following the direct SH wave of the transverse component using the Energy Flux Model. At center frequency of 0.5 Hz, the envelopes of the SH coda, above the ambient noise level, of transverse seismograms recorded by stations located on sediments of the Mississippi embayment are amplified by at least a factor of eight compared to those of stations outside the embayment. At 1.0Hz the amplification factor is about six. The amplification factor becomes smaller at higher center frequencies. The radial component shows similar sediment site amplification, however the vertical component shows less amplification compared to the transverse and radial components. At 1.0 Hz center frequency, Qi and Qs are measured from two different lapse time bands: (1) between the SH-wave arrival time (ts) and twice this time (2ts), and (2) between 2ts and at a time where the coda is above the ambient noise level. For the first band, most stations within the embayment show relatively higher Qi values compared to those stations outside the embayment. The high Qi values for stations in the embayment may be caused by energy that is reverberating in the shallow sedimentary structure beneath stations (site response). However, Qs values seem to be higher for stations outside the embayment than those of stations in the embayment. For lapse times greater than twice the arrival time of SH waves (band 2), both Qi and Qs are consistently higher for stations outside the embayment compared to those for stations in the embayment. Energy from reverberations under stations is assumed to be absent for lapse times greater than 2ts (Spudich and Bostwick, 1987). Therefore, the low Qi and Qs values, for band 2, found for stations in the embayment are interpreted to be due to attenuation by the thick sediments (~500 to 900 m) beneath them.

THE YELLOWSTONE HOTSPOT

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The Yellowstone hotspot is outstanding in many respects. It features extensive volcanism, heatflow and large anomalies in geoid and gravity. A large number of studies were conducted and a variety of data sets and models have been compiled. However, the mechanism of the Yellowstone hotspot is still unclear. Therefore the aim of this work is to derive a comprehensive model of the Yellowstone volcanic system that is consistent with all the different observations and models. In the first step, we derive a high resolution 3D model of the seismic compressional wave velocities that will serve as a reference model for further geodynamical modeling. Since the teleseismic delaytime inversion tends to lack resolution in the lithosphere (depending on ray distribution) the model in this poorly resolved depth range is constrained by a priori information, including the upper crustal velocity structure and the known topography of the Moho and the major mantle discontinuities. Moreover, Bouguer gravity data is used as additional constraints which are incorporated into the inversion via a joint inversion approach. The resulting high resolution images show a low velocity zone beneath Yellowstone, reaching down into the transition zone, but not below.

INFRASOUND SIGNALS FROM THE TOKACHI-OKI EARTHQUAKE

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On September 25, 2003 a great earthquake (Mw=8.3) and an aftershock (Mw=7.4) occurred near the Hokkaido, Japan. This great earthquake and aftershock were sources of local and epicentral infrasound signals observed at two seismo-acoustic arrays in the Republic of Korea. Local infrasound results from ground motion at the receiver coupling into the atmosphere. The cross coupling from local ground motion to infrasound signal at two seismo-acoustic arrays enabled us to compute a transfer function at each array. The observed transfer function quantifies the microphone response when the seismometer response is known. When seismometers and infrasound gauges are collocated, this procedure can provide field calibration. Source generated infrasound, infrasound signals generated at the sources and propagating through the atmosphere to two seismo-acoustic arrays produced strong signals as well. Atmospheric ray tracing and phase velocity estimations indicate that these signals turned in the low thermosphere (~ 120 km altitude). Back azimuth estimates change systematically with time through the long duration signals (35 min for main shock). These changes may be a result of the source location changes. The amplitude and frequency of epicentral infrasound signal is found to scale with earthquake size for the main shock and aftershock.

SEISMOLOGICAL EVIDENCE FOR MOSAIC STRUCTURE OF THE INNER CORE BOUNDARY FROM PROPERTIES OF PKIKP WAVES OBSERVED AT DISTANCES FROM 6 TO 90 DEGREES

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Despite its simple character in standard models, inner core boundary is still admitted to have possible large/small-scale heterogeneities or thin transition layers. Fine structure of the inner core boundary may be complicated due to possible differential rotation of the inner core or its freezing. These complications might have, for instance, a form of global thin liquid layer, as a result of rotation, or local heterogeneities caused by the process of freezing at the inner core boundary. PKiKP waves may serve as an instrument to study this discontinuity due to their sensitivity to peculiarities at the reflection point, especially being observed at small distances. The assembled set of records of underground nuclear explosions carried out in USSR, China and USA, and registered at stations distributed worldwide enabled to measure parameters of more than 100 PKiKP waveforms observed at single digital vertical seismographic channels and cross-array in Borovoye (Kazakhstan). When processing, non-seismological information on source parameters (locations, origin times, depths etc.) was used for all of the dataset explosions, almost all of which are of the same magnitude about 5.9. Unlike other investigations, the current dataset makes the study free of errors resulted from different mechanisms and energies of sources, as well as uncertainties of origin times, locations and depths if earthquakes are used. To increase PKiKP signal-to-noise ratio, there were used frequency filtration, as well as polarization, correlation and f-k analyses. The main features of PKiKP waves include (i) stability of travel times agreeing with PREM with residuals less than 1 s, and (ii) high frequency content of waveforms with dominating period of 0.7 s. We specifically note registered dramatic changes in PKiKP amplitudes with shift of reflection point through the surface of the inner core at distances of just 10 km and strong PKiKP reflections at epicentral distances around 90 degrees, where standard models with sharp discontinuity predict almost zero PKiKP amplitudes. The analysis of measured parameters of PKiKP phases, their traces, along with distribution of reflection points corresponding to weak and strong PKiKP amplitudes on the surface of the inner core favors the former effect to determine properties of PKiKP (i.e. actual properties of PKiKP waves are highly predetermined by local conditions at the reflection point on the surface of the inner core). Modelling and comparison of PKiKP phases evidence strong variability of reflection coefficient along the inner core boundary. Regular global models either sharp or with liquid/solid transition are not capable of explaining such variability. We interpret these observations in terms of ‘mosaic’ structure of surface of the inner core. Such patchiness of properties may result from the Earth's inner core solidification process during which local plate-like liquid units with properties slightly different from properties of substance of the outer core are formed on the surface of the solid core. A single element of such mosaic structure may have characteristic dimensions of 10-100 km with thickness 2-3 km, density of the outer core, and 5 per cent P-wave velocity jump comparing to the inner core. The research described was made possible in part by Award No. RG2-2352-MO02 of the U.S. Civilian Research & Development Foundation for the Independent States of the Former Soviet Union (CRDF).

COMPARISON OF S-WAVE VELOCITY STRUCTURE BENEATH THE KAAPVAAL CRATON FROM SURFACE WAVE INVERSION WITH PREDICTIONS FROM MANTLE XENOLITHS

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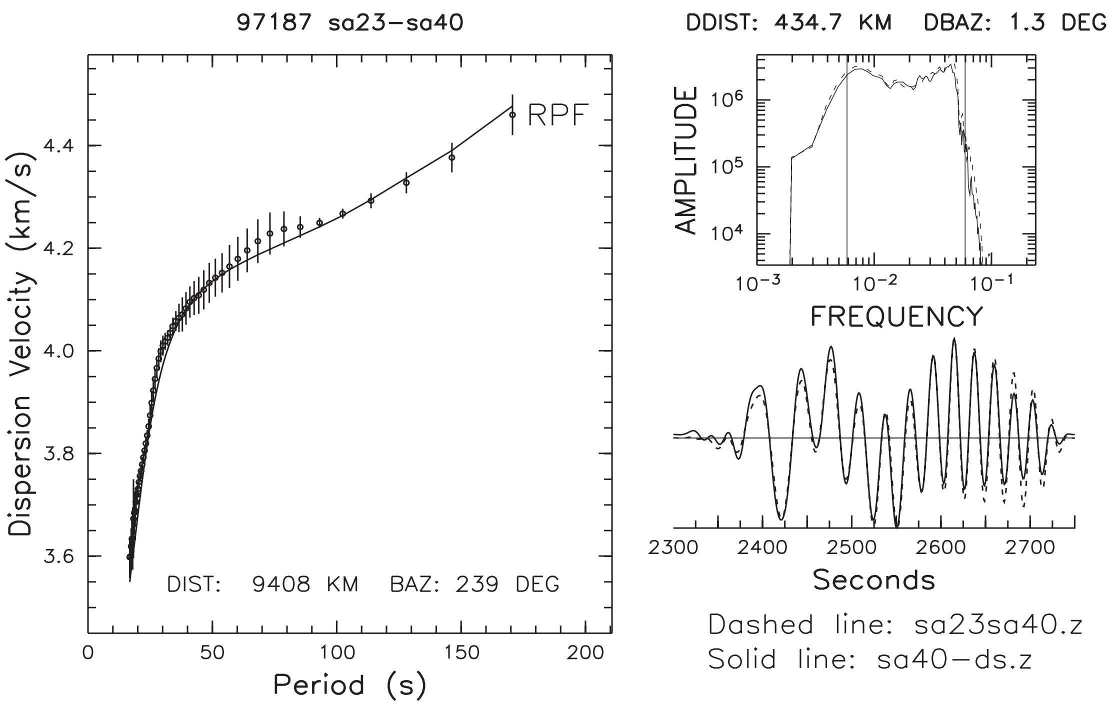
Results from two-station surface-wave inversions across the Kaapvaal craton of southern Africa are compared with seismic velocities estimated from approximately 100 mantle xenoliths brought to the surface in kimberlite pipes. These cratonic xenoliths from the southern Kaapvaal, all less than 100 Ma in age, have been analyzed thermobarometrically to obtain the equilibrium P-T conditions of the cratonic mantle to about 180 km depth. Seismic velocity-depth and density-depth profiles calculated on the basis of these P-T data and the mineral modes of the xenoliths (James et al., G-cubed, Jan 2004) are used to produce theoretical surface-wave dispersion curves and to generate starting models for inverting the observed surface-wave dispersion. The seismic velocity and density curves from the xenolith data are used to 180 km depth with deeper values taken from the PREM global model for depths of 220 km and greater. A smooth interpolation is used to bridge the gap between 180 km and 220 km. Surface-wave inversion using fundamental-mode Rayleigh waves for 16 paths from five events produce velocity structures consistent with those derived from the xenolith data. Hence the velocity structure (i.e., thermal structure) of the mantle to a depth of 180 km beneath the Kaapvaal craton has not changed significantly over the past 100 million years.



Shown above are pre-inversion fundamental-mode Rayleigh phase velocity determinations (labeled RPF) for one two-station path. The left-hand panel is the interstation phase velocity vs. period plot for the path between sa23 and sa40 for event 97187 located in southern Chile. DIST and BAZ are the epicentral distance and backazimuth respectively at sa40. The error bars are based on the coherence of the two waveforms. The solid line is the predicted phase velocity curve based on the model generated from the xenolith data. The dotted lines in the plots to the right are for spectral amplitudes and the time series from sa23 (near station) projected to the sa40 (far station) epicentral distance using the phase velocities in the left-hand panel. The solid lines are for the (unaltered) sa40 waveform.

ANALYSIS OF HIGH-RATE GPS DATA FROM THE TOKACHI-OKI (HOKKAIDO) EARTHQUAKE

Kristine Larson, Shinichi Miyazaki, Kazuki Koketsu , Atsushi Yamagiwa, Kevin Choi,John Clinton, Jennifer Haase, Paul Bodin, and Joan Gomberg

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The 2003 September 25 M8.3 Tokachi-Oki earthquake produced static displacements of nearly a meter on the island of Hokkaido, as measured by the GPS network, GEONET, which is operated by GSI (Geographical Survey Institute). The GSI network records observations at 30-second sampling rates, but a large subset of the network also recorded at 1-Hz during the Tokachi-Oki earthquake. Thus, we are able to use GPS to measure both the static and dynamic displacements from this earthquake. We discuss the precision and accuracy of these measurements by comparison with strong motion instruments. We also discuss the implications of these measurements for slip determinations and models of the rupture.

DATA REQUIREMENTS FOR USARRAY BACKBONE FROM LOW-FREQUENCY SEISMOLOGY (0.3 – 20MHZ)

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The first component of USArray that will ''go out in the field'' will be the permanent backbone array of about 100 stations most of which are intended to meet the GSN design goals. This poster lists a few reminders about what it is that low-frequency seismologists need from a GSN observatory quality station, and what we usually actually get. The issues raised are particularly timely in light of the current ''sensor crisis'' as we search for a new broad-band seismic sensor to replace the aging STS-1s. The observation of the Earth's free oscillations probably sets the most stringent data requirements of all seismic applications. Since the analysis of some modes requires very large deep earthquakes, seismologists may have to wait for 10 years to acquire the necessary seismic records. In addition to this, requirements regarding the quality of seismic records are exceptionally high. These include a high signal-to-noise ratio at frequencies between 0.5 and 10mHz and continuous data streams of several days or sometimes up to more than a month, depending on the mode to analyze. All of this can currently be met only by observatory quality installations (GSN and equivalent permanent installations) of very broadband seismic sensors (e.g. STS-1). The rate of seismic records available at the IRIS-DMC that are fit for analysis is typically 75% but this rate is expected to become smaller since sensors are now nearing the end of their lifetime. The imminent ''sensor crisis'' and the surprisingly clear observation of very low frequency modes on STS-2 sensors, which are typically not chosen as primary sensor at an observatory-quality site, prompted my research for this poster. The quality of a station is usually determined through its noise characteristics, and average noise statistics and seasonal variations are published in the FDSN station book. In this presentation I concentrate on the quality of the actual signal that is analyzed. For example, free oscillation spectra on vertical components of the GSN and comparable networks are compared for the 20 largest earthquakes in the last 10 years. A little less than 50% of the records of Wielandt-Streckeisen STS-1 vault sensors (132) meet the highest quality requirements, while the 46 Teledyne-Geotech KS5400 borehole installations (and its predecessor KS36000) yield less than 10% high-quality records. Surprisingly, the fraction of such records at 85 STS-2 and Guralp CMG3 (CMG-3t and CMG-3b) installations is almost as large. Overall, I find that 70% STS-1 records are ''acceptable'' for analysis, 50% KS54000 records, but less than 30% STS-2/CMG3 records which clearly stresses the importance of observatory-quality very-broadband installations. It is often argued that KS54000s are typically deployed in noisy environments so that my comparison should not be used directly to judge the value of a KS54000. The recently installed GSN station at the South Pole, QSPA, gives us the rare opportunity to compare all four co-located sensors more directly. Inspection of the three largest earthquakes in 2003 reveals that the STS-1 usually gives the best spectra. However, the noise level for the large September 25 Hokkaido earthquake is high below 1.5mHz. This inhibits the observation of 0S8 that is clearly visible in the STS-2 and CMG-3B records. On the other hand, the noise level below 6mHz is higher in the KS54000 records than in those of the STS-2 and CMG-3B for all three earthquakes. The three 2003 earthquakes were records by several other GSN stations that have primary (STS-1/KS54000) and secondary (STS-2/CMG3) sensors and hence allow a similar comparison. At 12 of these sites, the IRIS-DMC provides 10s or 1s data streams that allow a quick comparison. In 92% of the cases when an STS-1 is involved, it provides the best records. The same is true for only 46% of the KS54000 records, which implies that in more than half of the cases the secondary sensor (STS-2 or CMG3) provides the better record. The question now arises whether STS-2s would be fit for deployment as primary sensors at future GSN stations. It appears that this is indeed the case as the 10% STS-2 sites mentioned in the first comparison consistently produce good records. However, caution is in order. Even at the best installation, modes below 0S4 (lower than 0.5mHz) can not be observed for the June 23, 2001 Peru earthquake which is considered the largest earthquake that has been recorded since digital seismograms became widely available about 20 years ago. The comparison shown here includes only vertical component seismic records. Inspection of the horizontal components is pending but interesting food for thought for this workshop is whether gravimeters should be revived and co-located at future GSN sites, together with a separate set of newly developed sensors to record horizontal ground motion. Finally, I would like to add a few comments on so called ''broad-band'' sensors in temporary deployments such as PASSCAL experiments. Quite often, such experiments are carried out with one or two major scientific objectives in mind that usually involves the analysis of relatively short-period signals (periods shorter than 20s). Open data access provided at the IRIS-DMC a few years later to colleagues not involved in the original experiment ensures that the maximum amount of science can to done with such data. The set of chosen ''broad-band'' sensors in PASSCAL experiments typically includes STS-2 and CMG3 but recently also CMG-40Ts. These sensors typically have unfavorable noise characteristics at periods 40s and longer, which greatly inhibits the observation of surface waves beyond 50s. In many experiments such surface waves carry important information, if not the only one, on the deeper lithosphere and asthenosphere. An increasing group of principle investigators realizes the caveats of deploying 40T equivalent sensors and would rather invest the extra cost for deploying true broad-band sensors. This becomes particularly important as the OBS (ocean bottom seismometer) community is planning PASSCAL experiments on the ocean floor and is searching for an adequate low-power sensor for the new OBS instrument pool.

PALEO-SUBDUCTION AND MODERN BASALT EXTRACTION STRUCTURES IN THE SOUTHERN ROCKY MOUNTAINS: MULTI-BAND IMAGES FROM THE CD-ROM EXPERIMENT

A. Levander and the CD-ROM Working Group

The CD-ROM seismic projects targeted two Paleoproterozoic suture zones in the western U.S. in a north-south study corridor that extends from central New Mexico to central Wyoming. Seismic reflection, refraction, and teleseismic measurements were made across the Cheyenne Belt in southern Wyoming, and across the Jemez Lineament in northern New Mexico. The Cheyenne Belt is a profound geologic boundary separating the Archean Wyoming craton from island arcs accreted to the proto-continent in the Paleoproterozoic. The Jemez Lineament is a linear trend of modern volcanics extending SW from southern Colorado to Arizona, and also marks the southern edge of the suture between Yavapai and Mazatzal Paleoproterozoic island arc terranes. Karlstrom and Humphreys (1998) have speculated that the ancient accretion boundaries influence Cenozoic tectonism in the western U.S., noting the correlation of NE-SW low velocity upper mantle tomography anomalies with geochemical boundaries and mapped suture zones in the Southern Rocky Mountains.

At the Cheyenne Belt, the combined reflection-refraction-teleseismic datasets show crust and upper mantle subduction structures inferred to date to continental accretion and stabilization of the southwestern U.S. Of particular note are a north dipping high velocity slab structure and a fragment of subducted crust imaged in both the P and S tomography and prestack depth migrated receiver function images (Yuan and Dueker, 2004; Zurek and Dueker, 2004; Levander and Niu, 2004). At the Jemez Lineament the reflection data image a bivergenet orogen marking the Yavapai-Mazatzal suture in the crust (Magnani et al., 2004). Refraction velocities in the upper mantle under the suture zone suggest that the upper mantle contains 1% partial melt (Levander et al., 2004). In the same upper mantle region P and S tomography show low velocities that correspond to a series of moderately bright but complicated upper mantle events in the pre-stack depth migrated receiver function images (Yuan and Dueker, 2004; Zurek and Dueker, 2004). We have modeled this complex series of events in the upper mantle as the source zone of the recently erupted basaltic magmas found along the Jemez Lineament portion of the CD-ROM profile. We speculate that the paleo-suture zone acted as a conduit for the basaltic magmas to pass through the crust.

EDUCATIONAL SEISMOLOGY OUTREACH AT GEORGIA TECH SUPPORTED BY IRIS E&O

Tim Long, Tatiana Toteva

Georgia Institute of Technology

Educational Seismology Outreach at Georgia Tech Supported by IRIS E&O L.T. Long and T. Toteva, Georgia Institute of Technology. School of Earth and Atmospheric Sciences, Atlanta, GA 30332-0340 Students at Georgia Tech have helped develop teaching exercises using seismometers or seismic data. These exercises have included: storm tracking using microseisms, earthquake statistics and prediction using a sliding block. We have also developed exercises using the Palm Pilot with a digital voltmeter interface as a recording seismometer. The palm pilot may be used to record long period data on a conventional demonstration swinging-gate seismometer. With an exploration geophone it was used to illustrate amplitude and time relations as a function of distance. These exercises along with others were featured in a SummerScape workshop titled “Listening to the Earth”. During the first week the teachers learned and modified the exercises, and in two succeeding sessions used them to teach students. We are also developing a web site and resource disk to feature regionally significant earthquakes of historical significance. Many of these are pre-digital records that might otherwise be lost. By highlighting local earthquakes, many of which are quickly forgotten, we can help increase awareness of the likelihood of major earthquakes striking areas with lower levels of seismic activity.

EARTH SCIENCE PIPELINE: ENHANCING DIVERSITY IN THE GEOSCIENCES

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Our efforts to recruit and retain students from under-represented ethnic groups were guided by results from a survey of 145 students in our introductory geology courses during winter 2001. Among students from ethnic groups that are under-represented in the Geosciences, the most common reasons for NOT majoring in geology were (1) lack of exposure to geosciences and (2) lack of knowledge about careers in geology. To address these issues, we made presentations about the geosciences and careers in geosciences at local schools, and we invited school groups to visit our campus for hands-on activities related to Earth Science. Between October 2001 and April 2004, we conducted a total of 159 presentations, field trips or other activities, resulting in over 10,000 contact hours with more than 5400 students (mostly middle and high school students). The majority (74%) of the students participating in our outreach events were from ethnic groups that are under-represented in the Geosciences (African American (13%), Hispanic (52%), Native American (5%) and Pacific Islander (4%)). During the first year, responses on evaluation forms indicated that presentations that provided hands-on experiences for students were more likely to influence students to consider majoring in the geosciences than were more traditional presentations, such as slide shows. For this reason, most of our presentations are primarily focused around hands-on activities. We have also engaged in high school science teacher development. Each summer since 2002, we have conducted a weeklong field trip for high school teachers. Past field trips have been to Owens Valley, California (2002), Nevada (2003) and the Caribbean Island of Dominica (planned for 2004). The trips conducted to date have had very positive responses from participating teachers: “An excellent week of geology”; “the course was very instructive and useful to me as a high school Earth Science teacher”. We have also invited high school teachers to participate in research projects, as described below, in order to give them experiences with Earth Science that they can use to help get their students excited about the Geosciences. Our initial survey indicated that the third most common reason for NOT majoring in geology was a student’s perception that he or she is not a “science-type” person. In an effort to challenge these students’ perceptions, we have recruited undergraduate students from under-represented groups to participate in various research projects. High school teachers have also participated in these projects. One of these projects uses the Global Positioning System to monitor elastic strain accumulation across the San Andreas and San Jacinto faults along a 70-km-long transect that crosses the faults near our campus. To date, 20 students from under-represented ethnic groups and 10 teachers have participated in the GPS project. Several of the students from under-represented groups have taken additional geology courses since participating the in project and some have become geology majors or minors. Several students from under-represented groups have also participated in a research project on active volcanoes on the island of Dominica, in the Lesser Antilles.

A SOFTWARE TOOL TO EVALUATE AMBIENT SEISMIC NOISE LEVELS

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We present new software that will allow users to evaluate the seismic noise levels, for a selected time period, against a longer term baseline for any station streaming through the IRIS BUD system. The new software uses a probability density function (PDF) to display the distribution of seismic power spectral density (PSD). The algorithm and initial software were first developed by the USGS as a part of the ANSS data and network QC system. Further development, supported by IRIS, allowed us to port the codes to work within the IRIS QUACK framework and the BUD system.

The program runs continuously, estimating power spectral density (PSD), in 1 hour time segments, at broadband seismic stations in the BUD for frequencies ranging from ~0.01 to 16 Hz. For each 1 hour segment of continuous data, PSD is estimated and smoothed in full octave averages at 1/8 octave intervals. Powers for each interval were then accumulated in one dB power bins. A statistical analysis of power bins yields probability density functions as a function of noise power for each of the octave bands at each station and component. There is no need to screen for system transients, earthquakes or general data artifacts since they map into a background probability level. In fact, examination of artifacts related to station operation and episodic cultural noise allow us to estimate both the overall station quality and a baseline level of earth noise at each site. The output of this noise analysis tool is useful for characterizing the current and past performance of existing broadband sensors, for detecting operational problems within the recording system, and for evaluating the overall quality of data for a particular station.

THE PATHWAYS PROGRAM: A ROLE FOR SEISMOLOGY IN ADVANCING DIVERSITY IN THE GEOSCIENCES

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The University of Texas at El Paso serves a geographically isolated but fast growing bi-national metroplex of greater than 2 million people. With an enrollment of 17,000 students, UTEP is one of the largest Hispanic Serving Institutes in the country as its student body is comprised of 70% Hispanic and 10% Mexican National students. Pathways is a two-tiered program, funded by NSF's Opportunity for Enhancing Diversity in the Geosciences (OEDG) Program, focused on diversifying the geosciences through a research experience for undergraduates and a significant outreach program. The research experience for undergraduates (REU) is a program where students are funded to work with a faculty member on a research project. Students have presented their work at national conferences, and several are now actively pursuing graduate degrees. The centerpiece of the outreach program is a two-week summer camp for high school juniors and seniors that expose students and teachers to a variety of topics in geosciences and demonstrate how the biology, chemistry, and physics covered in high school courses integrates with the geosciences. Each of the two-week programs includes three teachers and 15 students between the junior and senior year of high school. In addition to exercises in geology and environmental science, the summer camp curriculum includes exercises in geophysics/seismology, which demonstrate wave propagation, followed by an active source field experiment where the students determine the depth to the water table. The success of the outreach program in inspiring students to pursue the geosciences as a possible career is still being assessed

ADVANCES IN GLOBAL AND REGIONAL TOMOGRAPHY USING IRIS DATA

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The development of the Global Seismographic Network (GSN) has been critical for advances in seismic tomographic imaging of the Earth's interior. Tomographic models need no longer rely on travel-time data alone nor on hand-digitized records from a few large earthquakes. The high-quality digital data recorded by the GSN allow information to be extracted from the whole waveforms of thousands of seismograms, making waveform tomography of the entire mantle possible. Similarly, measurements of surface-wave phase delays can now be obtained in a routine fashion, allowing for dramatic increases in the resolution of upper-mantle velocity structure. Recently, the high quality and abundance of GSN data have begun to make robust global analyses of anisotropic structure possible as well.

We determine a three-dimensional, radially anisotropic, shear-wave velocity model of the upper mantle under North America that constrains velocity variations on a length scale of a few hundred kilometers. Our dataset consists of approximately two million surface-wave phase-delay measurements (T = 35-150 s) from stations of the GSN, combined with a supplementary dataset from stations of the United States and Canadian national seismographic networks and selected IRIS PASSCAL stations. We also include a smaller dataset of long-period phase-velocity measurements (T = 200-350 s) made at GSN stations. The global nature of our GSN dataset allows us to determine a hybrid, global-regional velocity model, eliminating some of the artifacts that resulted from reduced ray coverage in and around North America in previous models. The correspondence between major geological features and those imaged in our mantle model is generally good, with a rapid transition from fast to slow velocities at the western edge of the North American craton and a distinct thinning of the fast-velocity region under the Appalachian mountains. We also image intriguing variations in anisotropy, with amplitudes of radial anisotropy reaching 4-6% at a depth of about 170 km under the Basin and Range province. The importance of the GSN dataset to our results highlights the potential benefits of the increase in GSN-quality seismic stations within North America that is planned as a part of the Earthscope/USArray project.

GENII: A DEVELOPING CONSORTIUM TO ARCHIVE AND USE INDUSTRY DATA TO EVALUATE PLATE BOUNDARY STRUCTURE, DEFORMATION, AND EVOLUTION

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Both onshore and offshore of southern California, and extending up to Oregon, Washington and Alaska, extensive grids of high-quality multichannel seismic (MCS) data were collected by industry for hydrocarbon exploration. These existing MCS data sets include both 2D and 3D surveys, and represent an incredibly valuable community research tool to evaluate important characteristics of subsurface structure, deformation and plate boundary strain. Many of these data were collected in areas where such data acquisition is now precluded by law. As such, the archiving and use of these industry data were specifically identified by the EarthScope community as a particularly urgent resource and science need. To do this though, funds are needed to transcribe the data from old 9-track tapes on to useable modern media. This amounts to about 1% of the original data acquisition cost. We are currently developing a coordinated program to transcribe these once-proprietary high-quality MCS data into an accessible online digital database. Ultimately, we hope this collaborative effort will include the U.S Geological Survey, EarthScope-NSF, Industry and IRIS (GENII). Currently, we have commitments from industry (WesternGeCo, Chevron-Texaco, Venoco, etc.) to release their data, from the USGS and industry for initial funding to start the process, and from the USGS and IRIS to archive the digital data once transcribed. However, additional support is needed to extend the process and make GENII really work. The Southern California Imaging Project (SCIP) is a proposed multi-phased EarthScope program to conduct integrated, multidisciplinary investigations of lithospheric structure and deformation in southern California. As a component of SCIP, we are requesting matching funds to support the USGS collaborative effort with industry and IRIS to transcribe and archive the onshore and offshore MCS data. Once transcribed, these extensive grids of MCS data would then be used to investigate, at least initially, plate boundary deformation in the offshore Continental Borderland. The offshore Borderland was the locus of Pacific-North American plate motion for about 70% of its tectonic history, and recent GPS data suggest that up to 20% of current plate boundary motion is still located offshore. The Borderland is also generally an area of deposition rather than erosion. This suggests that certain types of studies of fault processes, crustal structure, and plate boundary evolution are best performed offshore where the record of deformation is more complete, and can be better imaged in three dimensions. Results from this collaborative effort would thus complement EarthScope land studies and provide a more synoptic view of the active plate boundary, including how, within such a diffuse plate boundary system, two distinct tectonic regimes (the generally E-W-trending, rotating western Transverse Ranges province and the NW-trending, non-rotating northern Borderland) interact to absorb the same overall plate motion.

SIG: SYNTHETIC SEISMOGRAM EXCHANGE STANDARDS (FORMATS & METADATA)

David Okaya (Univ. Southern California)

Tim Ahern (IRIS)

A major contribution which IRIS has provided to the U.S. seismological community is a standardized format for seismogram observational data. This standard has allowed for easier archive and data exchange, as well as providing a framework for the development of many data handling and analysis tools. Synthetic seismograms do not have a community-accepted common format but are often exchanged in SAC, AH, SEGY, ascii, or raw binary formats along with associated readme files. Synthetics are not limited to single station one- to three- component seismograms. Numerical finite difference, finite element, or spectral codes can produce results of higher dimensionality including 2D surface-array seismograms, 3D snapshot volumes, and 4D time histories. These formats and associated descriptive and provenance metadata have storage requirements which are often not met by the observational data formats.

The purpose of this SIG is to initiate discussion as to if one or more standards are needed for synthetics and if so, what next steps are needed to define and implement them. During the SIG we will present information as to extra requirements needed for synthetics, pros & cons of using SEED or mini-SEED, the growing importance of metadata as seismology interacts with Information Technologies (digital libraries, search capabilities, visualization), and current international efforts on this topic. An open discussion will follow with a goal of community-based action items to be defined if applicable.

RECEIVER FUNCTIONS IN CENTRAL TIBET, IMPLICATIONS FOR DEFORMATIONAL STYLE AND SEISMIC ANISOTROPY IN THE CRUST

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The Tibetan plateau is composed of terranes amalgamated along roughly E-W trending sutures that was subsequently thickened to its present day crustal thickness of ~65 km and uplifted to a mean elevation of ~5 km. Particularly, the Late Jurassic age Bangong-Nujiang suture (BNS) between the Qiangtang and Lhasa terranes in central Tibet, marks the location of south-to-north variation between fast rigid Indian lithosphere and slow weak Asian lithospheric mantle. In this study, we used seismic data recorded by INDEPTH III array running NNW-SSE across BNS, and analyzed receiver functions for over 4000 teleseismic P waveforms by using an iterative time-domain deconvolution algorithm. For the radial component, we performed a common conversion point stacking for overlapping bins along the profile and then migrated resultant stacks using a constant P-wave velocity and laterally changing Poisson's ratio estimated from multiples. The resulting image exhibits crustal thicknesses that range between 65 and 70 km with low Moho relief. Several isolated low velocity zones are observed through the upper and middle crust with a semi-continuous mid-crustal interface in the Qiangtang terrane. For higher frequencies, amplitude of P to S conversions at the Moho diminishes along a 100 km wide zone across the BNS, and implies a gradual crust-mantle transition probably induced by seismically slow uppermost mantle. The sharp onset of strong SKS splitting near BNS was also argued as evidence of significant crustal anisotropy that formed due to strain localization along a lithosphere-penetrating transcurrent shear zone between India and Asia. In the receiver function method, presence of dipping layers and/or seismic anisotropy results in rotation of energy out of the source receiver plane and creates back azimuth dependent amplitude patterns. In this data set, the large azimuthally varying polarized phases occur only within the first 5 s and restrict the potential concentration of anisotropy and/or dipping layer to the upper and middle crust. In order to characterize these diagnostic features, receiver functions are stacked into back azimuth bins and modeled by using a global minimization technique that performs directed searches of model parameter space. During the inversion, crustal anisotropy is modeled for hexagonal symmetry with unique slow axis and synthetic seismograms are computed with a ray-based approach. Inversion results indicate strong anisotropy (>10%) near the surface and in the middle crust separated by a south-dipping (~25º) layer, possibly related to the earlier phase of crustal shortening. Near-surface anisotropy has a fabric dipping steeply southward and trending WNW-ESE that correlates with the suture and younger strike-slip faults. In contrast, mid-crustal anisotropy occurs in a low-velocity zone and has a fabric dipping gently (~18º) northward that might be related to a well-developed near-horizontal rock fabric induced by crustal flow. Synthetic calculations for SKS-wave splitting through the anisotropic crustal model produces a maximum of 0.5s split time, indicating the observed splitting measurements in excess of 2 s in this region are most likely due to mantle structure.

COMPARISON OF SEISMIC AND GEODETIC SCALAR MOMENT RATES ACROSS THE BASIN AND RANGE PROVINCE

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Scalar moment rates estimated from a 146-year seismicity catalog agree, within uncertainties, with the deformation rate of the Basin and Range province determined using space geodesy. Seismic moment rates have been estimated from a new catalog of earthquakes intended to be complete for $M \geq 5$. The catalog was compiled from 15 preexisting catalogs, supplemented by the review of 42 published journal articles. Throughout the catalog compilation, care was taken to obtain the moment magnitude or a reasonable, and not inflated, equivalent. 80% of the moment release occurred during 10 earthquakes of magnitude $M_W \geq 6.79$. The spatial pattern of earthquakes matches the geodetic pattern of deformation. About 75% of the seismic moment release, and 70% of the geodetic deformation, takes place in a 200 km zone along the western edge of the province, matching the pattern of the cumulative earthquake numbers. Several techniques, ultimately traceable to Kostrov and Brune, are used to translate the geodetic strain rates into rates of seismic moment release. Rates determined from seismicity, of 4.5×10^{25} to 10.8×10^{25} dyne-cm/year, substantially overlap the range determined from the geodetic data, 5.87×10^{25} to 13.0×10^{25} dyne-cm/year. This agreement suggests that within uncertainties, the rate of historic earthquakes within the Basin and Range province, taken as a whole, provides a reasonable estimate for the future rate of seismicity. These results support the hypothesis that even a few years of detailed geodetic monitoring can provide a good constraint on seismic hazard estimates.

THE PLATE BOUNDARY OBSERVATORY COMPONENT OF THE EARTHSCOPE PROJECT: THE TODDLER YEAR

The PBO Team

UNAVCO, Inc.

The Plate Boundary Observatory, the geodetic component of the NSF-funded EarthScope project, will give an unprecedented four-dimensional view of active plate boundary deformation across the western United States and Alaska, using a network of 891 continuous GPS stations, 174 borehole strainmeter stations, and five long-baseline laser strainmeters, all installed over the next five years. This network is carefully designed and integrated to capture short-term transient deformation, from minutes to a month, and longer-term steady state and transient deformation on time scales greater than a month. In addition, similar to the USArray Flexible Array, PBO will manage a pool of 100 portable GPS receivers for temporary deployment and rapid response for volcanic and tectonic crises. The PBO will also direct Geo-EarthScope activities which include the establishment of a national center for the storage and retrieval of digital imagery and funding for geochronology to support geologic investigations EarthScope wide. In this poster we will discuss the overall operations and data management aspects of the PBO project. In particular we will discuss our progress to date against our year one goals and how our plan is evolving based on lessons learned. We will discuss startup and staffing activities, facility construction activities including siting of stations, reconnaissance activities, installations, and data flow. In addition, we will present the highlights of our V1.0 Data Management Plan and discuss in detail our data flow, archiving, and data products strategy.

SPATIO-TEMPORAL VARIATIONS OF CRUSTAL ANISOTROPY ALONG THE KARADERE-DÜZCE BRANCH OF THE NORTH ANATOLIAN FAULT IN THE 6 MONTH AFTER THE 1999 MW7.4 IZMIT EARTHQUAKE

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We analyze spatio-temporal variations of crustal anisotropy along and around the Karadere-Düzce branch of the north Anatolian fault that ruptured during the 1999 Mw7.4 Izmit and Mw7.1 Düzce earthquake sequences. A method consisting of an iterative grid search for the best shear wave splitting parameters (Silver & Chan 1991) in sliding time windows is applied to ~22000 measurements that are within the shear wave window. Based on objective criteria, ~6600 measurements are assigned “high” quality and used for further detailed analysis. Most stations near the rupture zone have fast polarization directions that are parallel to, and change with, the nearby fault strike. The average delay times for ray paths that propagate along the rupture zone are larger than for the other paths. These results suggest the existence of an approximately 1-km broad zone around the Karadere-Düzce branch with fault-parallel cracks or shear fabric. The average fast polarization directions from ray paths that propagate inside the Almacik block, south of the Karadere-Düzce branch, are neither parallel to the local fault strike nor to the expected regional maximum compressive stress direction. The large overall spatial variations of the results imply that multiple structures and mechanisms contribute to the observed crustal anisotropy in our study area. Most stations do not exhibit a clear dependency of shear wave splitting delay time with increasing depth and hypocentral distance, indicating that the anisotropy is confined primarily to the top 3-4 km of the crust. Using the observed average delay time at fault zone stations and assumed propagation distance of 3.5 km, we estimate the apparent crack density in the damaged shallow fault zone rock to be about 7%. In an effort to detect temporal changes associated with the Düzce mainshock, we analyze spatio-temporal variations of crustal anisotropy in this area from similar earthquakes identified using a waveform cross-correlation technique (Aster & Scott 1993). Depending on the applied similarity criteria, about 5-55% of over 18,000 aftershocks belong to similar event clusters. Splitting parameters averaged within each cluster show significant variations for slightly different ray paths, indicating strong spatial variations of the anisotropic structures in this area. Apparent temporal changes of up to 30% shear wave splitting delay times are observed at stations near the epicentral regions before and after the Düzce earthquake. However, such changes can be mostly explained by the spatial variations of ray paths due to the changing seismicity, instead of temporal changes of the anisotropic medium. Splitting parameters measured within several similar earthquake clusters indicate at most 2% co-seismic changes of delay times associated with the occurrence of the Düzce earthquake. In addition, we use a sliding window cross-correlation technique (Niu et al. 2003) to measure relative travel times and evolving decorrelation of the P- and S-coda waves of similar earthquake clusters. At fault zone station VO that recorded ~0.9g peak acceleration during the Düzce earthquake, the analysis shows clear change of travel time of the coda waves following the Düzce mainshock. At other nearby stations, the temporal changes are considerably smaller. Updated results will be presented in the meeting.

RETREAT SEISMIC DEPLOYMENT IN THE NORTHERN APENNINES, PRELIMINARY RESULTS

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The paradox of how horizontal contraction and extension can occur simultaneously in convergent mountain belts remains a fundamental and largely unresolved problem in continental dynamics. The Apennines represent one of the most accessible “type locality” areas of syn-convergent extension. Rollback - which describes the tendency of a subducting plate to retreat from the orogenic front - is commonly invoked as an explanation for syn-convergent extension, but this idea does not address how the retrograde motion of the subducting plate, which is a mantle-based process, causes horizontal extension in the overlying zone of crustal convergence, especially in light of the large accretionary fluxes typically associated with continental subduction. The goal of the multidisciplinary project RETREAT is to develop a self-consistent dynamic model of syn-convergent extension, using the Northern Apennines as a natural laboratory. In the context of this larger study, a passive seismological experiment got underway in the fall of 2003. At present the project is a collaboration between the Istituto Nazionale di Geofisica e Vulcanologia (INGV), the Geophysical Institute in Prague (GIP) and US universities (Rutgers and Yale). The project aims at developing a comprehensive understanding of the deep structure beneath the Northern Apennines, with particular attention on inferring likely patterns of mantle flow. Specific objectives of the project are the crustal and lithospheric thicknesses, the location and geometry of the Adriatic slab, and the distribution of seismic anisotropy laterally and in depth. The project will collect teleseismic and regional earthquake data for 3 years. The first phase of the project, successfully deployed in October of 2003, utilizes 10 broad-band stations from GIP, together with permanent installations operated in the region by INGV. This year a 25-node array of seismographs from the US PASSCAL pool will be deployed, densifying an already existing 2D grid, and also forming two tightly spaced linear transects across the Apennines. In addition, installing of several French stations is envisaged. This contribution reports on the goals, analytic tools and some initial results of the deployment.

ESTIMATING CRUSTAL AND MANTLE HETEROGENEITY FROM SEISMIC CODA

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Accumulating evidence strongly suggests that crustal and/or mantle heterogeneities are responsible for seismic coda. Observations of outcrops of crystalline crustal rocks have lead to statistical models of heterogeneity, and recent published observations of exposed ophiolites suggest that a similar approach to statistical modeling of mantle heterogeneity is appropriate. The upshot is that synthetic data generated through statistical models of Earth heterogeneity qualitatively and quantitatively resembles real field data. By using the statistical models of heterogeneity, we can produce forward models of seismic coda. Therefore, we are given an avenue by which to formulate formal inversion procedures to estimate stochastic parameters that quantitatively describe seismic heterogeneities in the Earth. This poster summarizes our work on developing stochastic models of seismic heterogeneities, as well as inversion tools to estimate stochastic parameters from seismic coda. Although these tools are tested with synthetic data, the models are based on observable field evidence, and real seismic data corroborates our findings. Teleseismic data collected as part of the IRIS-PASSCAL program further tests our methods. That is, by imaging teleseismic array data collected on IRIS-PASSCAL arrays and then applying our inversions, we are able to make progress on quantifying mantle seismic heterogeneity. This approach has implications in terms of mantle structure, composition, and evolution.

ADDING PROBABILITY AND CHOICE TO CRUSTAL STRENGTH MODELS

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The familiar crustal strength model is a compilation of several different calculations into one result, a crustal strength profile. Commonly referred to as “Christmas Tree” diagrams, crustal strength profiles are deterministic outlines of the estimated yield strength versus depth over a range where many deformation mechanisms may operate. In reality, the boundaries between lithologies with depth are not always certain and neither are the bulk properties of that rock type. In the past, modeling a crustal strength profile meant choosing a particular surface temperature, heat flow, strain rate and rheologic flow law, etc., based often on guesses, which then create a single crustal strength profile of uncertain accuracy. It is difficult to have a “feel” for how uncertainties in the input parameters affect not only the strength profile but also the deformation mechanism (brittle or ductile) that might dominate at any particular depth. I adopt a probabilistic approach to investigate these issues. The Fortran 90 program “strength” is designed to take a basic lithologic structure and thickness range from the user. In conjunction with a user defined library of lithologic properties consisting of the full appropriate ranges for a given rock type, the program then cycles in a Monte Carlo fashion, randomly choosing values from the given range to calculate many crustal strength profiles. These crustal strength profiles are then used to create a mean strength profile representative of that region with rounded and less abrupt boundaries and a corresponding probability of brittle and ductile failure, to compare to local seismicity. I intend to demonstrate the effectiveness of this method of calculating crustal strength by remodeling Liu and Zoback’s (1997) model of strength for the New Madrid seismic zone and the central United States.

EXCITATIONS OF EARTH'S INCESSANT FREE OSCILLATIONS BY ATMOSPHERE-OCEAN-SEAFLOOR COUPLING

Junkee Rhie and Barbara Romanowicz

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The physical mechanism responsible for Earth's continuous background free oscillations is as yet not fully understood, with competing models invoking atmospheric turbulence or processes in the oceans. We have developed an array based method to detect and locate sources of the excitation of this "hum" during time intervals uncontaminated by earthquakes, taking advantage of the dispersive properties of long period Rayleigh waves. Here we show that, during northern hemispheric winter, the Rayleigh wave energy originates primarily in the northern Pacific Ocean, while in the summer, it arrives primarily from the southern oceans. These locations correlates with those of maxima in significant wave height associated with winter storms in the northern and southern hemispheres, respectively. We infer that the mechanism of generation of the "hum" involves an atmospheric-ocean-seafloor coupling process, most likely through the conversion of storm energy to ocean infragravity waves interacting with the deep seafloor topography.

2-D LITHOSPHERIC DENSITY MODELING IN SOUTHERN CALIFORNIA

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We report results from density modeling of the crust and uppermost mantle along the LARSE I and II transects across southern California. A linear gravity inversion technique was used to calculate crustal and mantle densities along a two-dimensional profile. We used borehole measurements, seismic velocities, and petrologic information to constrain the model where possible. We further assumed that the lithosphere is close to isostatic equilibrium in the deep ocean and east of the Mojave Desert. We used the linear equation r=a+bVp (where r is density, Vp is seismic P-wave velocity) to approximate the mantle density-velocity ratio. A value of b=0-0.2 corresponds to a purely thermal effect on density in the mantle, whereas a coefficient of b > 0.3 implies that petrological or metamorphic changes play an important role in determining density. Solutions with b=0.2-0.4 are considered optimal. It was noted that solutions without mantle density variations require an abnormally dense lower crust (3.1 g/ccm) beneath the Los Angeles basin, however, analysis of the isostatic balance of the models and the average density of the consolidated crust did not allow us to clearly define a preferred density model. We therefore cannot distinguish if thermal or petrological and/or metamorphic processes cause density variations in the study area.

A SURVEY OF SOUTH AMERICAN CRUSTAL STRUCTURE BASED ON RECEIVER FUNCTIONS

Koichi Sakaguchi, Hersh Gilbert, George Zandt, Susan Beck, and the CHARGE working group

University of Arizona

The diverse geology of South America results largely from the amalgamation of several cratons followed by accretion of additional terrains as well as the deformation associated with the subduction of the Nazca plate. Regional geologic research in the last few decades has revealed some unique geologic features of the South American continent such as flat subduction zones and the abnormally thick crust of the cordillera, however, the large-scale sub-surface structure of the continent is still sparsely known. We have estimated the Moho depth and the ratio of seismic P- and S-wave in the crust from 16 global (GSN, GTSN, and Geoscope) broadband seismic stations located in the South American continent. We obtained a total of 1245 teleseismic traces with the number of events at each station ranging from a maximum of 189 to a minimum of 10 from earthquakes occurring between 1996 and 2002. Five stations are located near the subduction zone in the forearc region west of the high cordillera of the Andes. Seven stations are located in the cratonic part of the South American continent. Three stations are located in the actively deforming region of the Andes, and the remaining stations are offshore island stations. The seismic waveforms were deconvolved to isolate P to S conversion phases to be stacked both as a function of backazimuth and rayparameter to distiniguish between primary P to S conversions and their two major multiples. A clear Moho was not observed under the stations in the forearc region, and the receiver functions appear more complex, but a strong conversion was observed that we interpret as the top of the subducting slab in the depth range of 60-80km. The Vp/Vs values obtained in the forearc region ranges from 1.86 to 1.92, representing high, integrated Vp/Vs though the upper mantle and the crust that, in conjunction with the absent Moho, suggests a high degree of mantle hydration. Slab arrivals present at stations within the forearc vary azimuthally in a manner consistent with expectations based on a layer dipping to the east, as radial arrivals from western azimuths exhibit lower amplitudes. Additionally, tangential receiver functions for forearc stations contain significantly more energy than those recorded at cratonic stations, which display low amplitudes, just as would be expected in regions devoid of dipping layers or anisotropy. The Moho under the cratonic crust was clearly seen in the depth range of 34-50 km, within the global range for cratons. The cratonic Vp/Vs values are consistently lower than those from the forearc stations, in the range of 1.63 to 1.84. The variable crustal thickness and Vp/Vs values are probably related to compositional and age differences between the cratons.

SOURCE PARAMETER STUDY OF OCEANIC TRANSFORM EARTHQUAKES

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Previous work by Stein and Pelayo (1991) found differences in energy release versus frequency among earthquakes at different oceanic plate boundary types. Compared to ridge earthquakes, transform earthquakes often have large Ms relative to mb and large Mw relative to Ms, suggesting that seismic wave energy is relatively greater at longer periods. These differences may reflect differences in stress drop, either due to intrinsic differences in the strength of transform zones relative to ridges and intraplate settings, or a bias due to strike-slip mechanisms. We have begun expanding the earthquake data set in order to test these results using events from the Harvard CMT catalog.

FUNDAMENTAL MODE RAYLEIGH WAVE TOMOGRAPHY OF THE YELLOWSTONE HOTSPOT

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Over the last 17 Ma, the Yellowstone Hotspot has progressed from the Oregon-Nevada-Idaho region (also the source of flood basalts and the beginning of the Newberry hotspot), to its current location within the Laramide-deformed Archean Wyoming Craton, forming the dramatic eastern Snake River Plain depression. Using fundamental mode Rayleigh wave tomography, we have reliably imaged the crust and upper mantle to a depth of 250 km, in a 150 km radius region centered on Yellowstone National Park, the current surface manifestation of the Hotspot.

Rayleigh wave real and imaginary components have been measured for wave periods between 15 – 150 s and inverted for wavefront geometry (approximated by two interfering plane waves) and phase velocities at 17 periods. For each period, ~95% of the data variance can be explained by two constant velocity regions: a low phase velocity Hotspot track, and the higher velocity surroundings. Only small phase velocity variations are imaged within the two regions, although this may be because lateral variations in structure occur on smaller scales than the horizontal Fresnel zone of the Rayleigh waves (about 40-200 km, depending on wave period).

Phase velocities along the Hotspot track are significantly lower than observed along the Hawaii hotspot track. Outside the Hotspot track, in the Wyoming Craton, phase velocities are much slower than other cratons, and consistent with IASPEI91 VS and the observations of Godey and van der Lee..

Phase velocities for each wave period are inverted for S-wave velocity, as a function of depth, using the assumption dVP/dVS = 1.2, close to that predicted for near solidus conditions. Our linearized inversions are dependant upon the starting model, especially the depth of the moho; however, several robust features are observed. Along the Hotspot track, the mantle lithospheric thickness, as estimated by the depth of the top of the negative velocity gradient (z positive downward), is nearly constant, at ~20 km.

Beneath this, extremely low S-wave velocities are found, 3.6 +/- 0.1 km/s at 75 km depth, as low as the lowest published VSV found in the upper mantle. This low velocity channel, as bounded by sharp negative and positive velocity gradients, extends from 60 – 150 km depth. This is also where the majority of our lateral P and S-body wave velocity heterogeneity is imaged.

Mantle lithospheric thickness in the Wyoming Craton is about 20-40 km, which depends somewhat on the initial velocity model, but is resolvably greater than the Hotspot track thickness. The low velocity channel is also deeper, at 80-150 km depth.

In comparison, the Hawaiian hotspot has a minimum Vs of ~4.0 km/s, and a lithospheric thickness ranging from 108 km under Hawaii to 54 km under Kauai. That the Yellowstone mantle is 0.4 km/s slower than Hawaii is curious. If the velocity difference is not due to variations in data coverage or inversion technique, this may imply Yellowstone has a greater equilibrium melt porosity; or alternatively, if the amount of mantle melt is the same (due to the same percolation threshold), then the Vs of mantle at the solidus is lower in Yellowstone, perhaps because the mantle here is more refractory. The nearly constant lithospheric thickness along the Yellowstone Hotspot track, in contrast to Hawaii, may indicate Yellowstone lithosphere is more resistant to thermal erosion than Hawaiian lithosphere. We will soon look for S-P conversions off the lithosphere to improve our horizontal resolution in this matter. Finally, the low velocities under Wyoming confirm that little or no tectosphere remains under this craton.

THE NATURE AND PROMISE OF BROAD-BAND SURFACE-WAVE MEASUREMENTS FROM THE RANDOM WAVEFIELD

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We demonstrate that coherent information about earth structure can be extracted from background seismic noise and that this information has characteristics that in some circumstances may make it preferable to traditionalinformation obtained on ballistic waves (with approximately known source and trajectory). We compute cross-correlations between vertical component records for several days of seismic noise observed at various station-pairs separated by distances from about 100 km to more than 2000 km. Coherent broadband waveforms emerge with dispersion characteristics similar to predictions from traditional Rayleigh-wave tomography maps constructed using ballistic surface waves. Background seismic noise, therefore, contains a significant component of Rayleigh wave energy that is the basis for the measurement. This energy is probably excited by oceanic microseisms and atmospheric forcing. These signals form a wavefield in which phase is randomized by a multiplicity of sources. This random wavefield provides a new source of broad-band surface-wave information. Such measurements may be particularly useful in the context of dense arrays of seismometers, such as PASSCAL, USArray, or other national deployments, that will produce numerous inter-station paths that are not sampled with ballistic waves. We show that the measurements obtained on this random wavefield can be made reliably to shorter periods than those made on the ballistic wavefield and, therefore, promise to provide better constraints on crustal structure. In addition, the spatial sensitivity kernels for the random wavefield will be narrower than those for the traditional measurements and, therefore, promise improved spatial resolution in the context of dense arrays. Finally, the measurements will be relatively unaffected by source location and phase and will, therefore, be free from potential sources of bias that affect traditional tomographic methods.

THE SAN FERNANDO VALLEY HIGH SCHOOL SEISMOGRAPH PROJECT

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Following the 1994 Northridge earthquake, the Los Angeles Physics Teachers Alliance Group (LAPTAG) began recording aftershock data using the Geosense PS-1 (now the Kinemetrics Earthscope) PC-based seismograph. Data were utilized by students from the schools in lesson plans and mini-research projects. Over the past year, several new geology and physical science teachers are now using the AS-1 seismograph to record local and teleseismic earthquakes. This project is also coordinating with the Los Angeles Unified School District (LAUSD) high school teachers involved in the American Geological Institute's EARTHCOMM curriculum. The seismograph data are being incorporated with the course materials and are emphasizing the California Science Content Standards (CSCS). The network schools and seismograms from earthquakes in southern California region (e.g. San Simeon 2003) and worldwide events (e.g. Alaska 2002) are presented with associated lesson plans.

HOTBED FOR INTEGRATION: DEEP PROBE AND CD-ROM SEISMIC REFRACTION/ WIDE-ANGLE REFLECTION WITH TELESEISMIC RESULTS

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The Deep Probe ’95 and CD-ROM ‘99 experiments were designed to illuminate the lithospheric structure of the Rocky Mountains. Both projects focused on Precambrian features and their effects on Phanerozoic deformation. The Deep Probe profile crossed such geologic features as the Yavapai-Mazatzal transition zone, the Cheyenne belt, the Great Falls Tectonic zone, the Medicine Hat block, the Vulcan structure, and several Archean blocks within the Hearne and Slave Provinces. The CD-ROM profile crossed such geologic features as the Jemez lineament, the Colorado mineral belt, and the Cheyenne belt. Major results from Deep Probe velocity model were the observation of the Cheyenne belt suture zone at depth, a relict rift that formed prior to inception of subduction, and a thick high-velocity lower-crust (HVLC) layer under northern Wyoming and Montana. The suture zone showed a thickening of the crust at the Cheyenne belt to about 50 km whereby the crust thins to about 40 km north of the Cheyenne belt indicating a relict rift. In northern Wyoming, the crust thickens dramatically and the HVLC layer is about 20 km thick and continues to the north over 100 km. Final results from the CD-ROM velocity model show a small step in the Moho in northern New Mexico, which could indicate the location of the Jemez lineament. The northern end of the model shows similar thickening and thinning of the crust as seen in association with the Cheyenne belt and relict rift, which were first identified in the Deep Probe model. The southern end of the model shows a HVLC layer, which ranges in thickness from 5-10 km and is most evident under the Great Plains. Comparisons between the refraction and teleseismic results have been made visually and the results are consistent, but are not fully integrated. A goal of many of these large multi-disciplinary projects is complete integration of the various datasets, which is always a challenge. Using techniques that have been developed by the Las Vegas Valley Seismic Response project as well as the GEON project may allow for the future integration of these various datasets.

TOMOGRAPHIC INVERSION OF PN TRAVEL TIMES IN CHINA

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The arrival times of Pn from Chinese and ISC earthquake bulletins are used to invert for uppermost mantle Pn velocity and anisotropy and crustal thickness in China. We obtained 57740 Pn arrival-time picks from 5433 earthquakes and 307 stations from the Annual Bulletins of Chinese Earthquakes (ABCE), earthquake bulletins compiled by provincial seismological bureaus of China, and the ISC bulletins. The ray coverage for most of China is excellent because of the station distribution and the diffused seismicity. Our inversion reveals significant features that correlate well with surface geology. The major basins in the west are characterized by high Pn velocities and relatively small anisotropy, suggesting they are strong and cold with weak deformation. Low Pn velocities are found in areas of active volcanoes (Myanmar and western Yunnan) and Quaternary volcanisms in northern Tibet, in seismically active areas in North China and western Tien Shan, and in the south China (the Hainan plume). The southern Tibet generally has higher velocity than the northern Tibet, but significant low velocity anomalies are also observed along 82 and 90 degrees longitude in the southern Tibet. Complex station delays in the eastern and southeastern margin of the plateau suggest the whole crust may be highly deformed. The anisotropy pattern there suggests a mantle lithospheric deformation similar to the clockwise rotation of material observed at the surface. Strong anisotropy is also found beneath other high deformation regions (the Tibetan plateau, western Tien Shan, and part of North China), suggesting the anisotropy is mostly related to recent large-scale tectonic activities. A large area of North China shows prominent low Pn velocity beneath Archean basement with thin crust. The observations are consistent with rifting, lithospheric thinning, and mantle upwelling in the region. The locations of gold ore and oil deposits in North China correlate remarkably well with the low Pn velocities, suggesting the metallogenesis and oil formation of the region may closely related to magma and thermal activity in lithospheric mantle and crust-mantle interaction since Mesozoic and Cenozoic.

TIME-DOMAIN FINITE-DIFFERENCE MODELING OF ABYSSAL T-PHASES

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Ocean seismic networks that exploit T-phase arrivals provide a popular, convenient and inexpensive approach to monitoring earthquake activity in the ocean basins. The characteristics of earthquakes, as revealed by T-phase observations, have the potential to provide important constraints on physical models of crustal processes under the oceans. We do not know, however, how to infer earthquake source mechanisms, magnitudes, or depth from T-phase observations because we do not know the physical mechanisms responsible for getting T-phase energy from the earthquake epicenter into the ocean sound channel. The “T-phase problem” can be described as a disconnect between i) the steep grazing angles of sound propagation in the ocean from a source in the crust or upper mantle and ii) the shallow grazing angles required for sound traveling in the ocean sound channel. It has been postulated that some form of scattering at or near the seafloor is necessary to convert the compressional and shear body waves from earthquakes into the low grazing angle paths necessary for propagation in the ocean sound channel. Other mechanisms include “wave tunneling”, interface waves (Stoneley, Scholte and Rayleigh waves), and shear wave resonances (modes) in the sediments. We use the time domain finite difference method to demonstrate how these mechanisms work. We also discuss the advantages and disadvantages of each mechanism in solving the T-phase problem.

REGIONAL VARIATIONS IN THE UPPERMOST LAYER OF THE EARTH'S INNER CORE

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The structure of the uppermost layer of the inner core was examined by using PKIKP and PKiKP waveforms recorded at a distance range of 118º -140º. We found evidence of a low-velocity layer in the uppermost inner core confined to the middle part of Eastern hemisphere underneath the Indian Ocean and eastern Asia. The maximum thickness of the layer inferred from waveform modeling is 40 km with velocity jump of about 3%. We speculate that this layer may represent newly solidified core in the area where the vigorous convection facilitates crystal growth.

SEISMOGENIC PERMEABILITY

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Induced seismicity associated with reservoirs and well injection is usually confined in space and time and thus offers an excellent opportunity to study the hydromechanical properties of fractures associated with earthquakes. We have studied the temporal pattern of seismicity associated with reservoir impoundment, lake level fluctuations and the injection of fluids in wells. In all cases, the diffusion of pore pressure in fractured rocks is the primary cause of the observed seismicity. The diffusing fluid pressures reduce the effective stress in rocks, leading them to failure. We have examined available worldwide data for fluid induced earthquakes, and from their temporal pattern, estimated the hydraulic diffusivity, c, of the seismogenic fractures. For 66/68 cases where c could be calculated, it was found to lie between 0.1 sq.m/s to 10 sq.m/s. The intrinsic permeability, k, calculated from c, was found to lie between about 0.5x10**-15 sq.m to 50x10**-15 sq.m (0.5 to 50 mDarcy). We call this range, seismogenic permeability, ks. Simple 1-D analysis of the diffusion equation applied to different filling histories suggests that for fractures with k<ks, the rocks tend to respond elastically to loading and for those with k>ks, the increased fluid pressure changes are not associated with the delayed response of the reservoir. They are very rapid and not discernable from an instant response of the reservoir to filling. Thus, the seismogenic permeability, ks, is a characteristic property of rocks where fluid pressure changes are associated with seismicity.

CONSTRAINING THE FOCAL MECHANISMS OF SMALL EARTHQUAKES USING HIGH FREQUENCY P WAVES

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California Institute of Technology California Institution of Technology

Retrieving source parameters of small earthquakes (Mw < 5) relies on regional data. While the source mechanisms of events with Mw ~ 4.0 or larger are well routinely determined using the full waveform data over a relatively long-period frequency band (usually 5+ sec for Pnls and 10+ sec for surface waves), where imperfections of the Green's functions are tolerated. Retrieving the mechanisms for a much larger population of smaller events still has to rely on the short-period polarity data; therefore the mechanisms of the smaller events remain poorly constrained, since their waveform data are devastatingly dominated by noise over the long-period frequency band. Better constrained source mechanisms of these smaller events could greatly contribute to a bunch of interests, such as the fine fault structure, earthquake triggering. In this study, we aim at lowering the magnitude threshold for using waveform data to resolve an event's source mechanism. We notice that the first few seconds of records from a magnitude 3 event (mainly Pnls) well survive noise over a higher frequency band (< 1 sec). The direct use of these higher frequency records is forbidden since the complications imposed by the path and site effects are far beyond the current model prediction. Simultaneously analyzing waveforms of nearby small (Mw ~ 3.0) and large events (Mw ~ 4.0) confirms that the embedded path and site effects are similar and less sensitive to differences in their focal mechanisms. Under this circumstance, we propose to use the well determined bigger events to calibrate the path and site effects for nearby smaller events, so that the mechanisms of the smaller events could be resolved with both the polarity and amplitude information. We present two approaches to fulfill the task: the direct empirical amplitude amplification calibration and the transfer function analysis. We will use the 2003 Big Bear sequence to test our algorithm.

DETAILED STRUCTURE OF UPPER MANTLE DISCONTINUITIES IN THE TONGA SUBDUCTION ZONE FROM HIGH FREQUENCY LOCAL REFLECTIONS AND CONVERSIONS

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Recordings of deep Tonga earthquakes from two arrays of 12 broadband seismographs each in the Fiji and Tonga islands were stacked and searched for reflections and conversions from upper mantle discontinuities near the Tonga slab. The arrays operated as part of the SAFT (Seismic Arrays in Fiji and Tonga) experiment from July 2001 to August 2002. In comparison with the commonly used teleseismic approaches, the short path lengths for the local data provide smaller Fresnel zones and high frequency content for precise mapping of discontinuity topography and sharpness. This is particularly important for a subduction zone, where variations in temperature and water content may be expected which should cause changes in the elevation and sharpness of the discontinuities. We study the phases s410p, P660p and S660p where they arrive at least 10 seconds after the direct P wave and prior to the S wave across the arrays. To anhance low-amplitude reflections/conversions, deconvolved seismograms from each event/array pair are aligned on the maximum amplitude of the direct P wave and subsequently slant-stacked. For the 410-km discontinuity, the results show no systematic variations in depth with distance to the cold slab. The 660-km discontinity varies between about 655 and 715 km in depth. For the southern and central parts of the sudduction zone, the largest depths for the 660-km discontinuity occur in the core of the actively subducting slab. For the northern part, two separate areas of depression for the 660-km discontinuity are detected. These depressions are induced by the actively subducting plate and a remnant of subducted lithosphere from the fossil Vityaz trench, respectively. Waveform modeling of the converted/reflected phases, susggests that both the 410 and 660 discontinuities are sharp. The thickness for the 410 discontinuity varies between 2 and 10 km, and that of the 660 discontinuity between 2 and 5 km.

ADVANCES AND OPPORTUNITIES IN COMPUTATIONAL SEISMOLOGY

Jeroen Tromp & Seiji Tsuboi

Modern parallel computers and numerical algorithms have facilitated the routine calculation of synthetic seismograms in fully 3D Earth models. On a modest 12-node PC cluster one can now calculate global synthetics at periods of 20~s and longer that account for lateral variations in the crust and mantle, ellipticity, topography, full 21-parameter anisotropy, 3D variations in attenuation, fluid-solid interactions, self-gravitation, rotation, and the oceans. On the world's largest and fastest supercomputer, the Earth~Simulator at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), one can reach a shortest period of 3.5~s. To put these numbers in perspective: typical normal-mode summation codes that calculate broadband synthetic seismograms for 1D Earth models are accurate down to 6~s. In other words, the Earth~Simulator allows us to simulate global seismic wave propagation in fully 3D Earth models at periods shorter than current seismological practice for 1D spherically symmetric models.

The challenge now lies in harnessing these new found capabilities to enhance the quality of tomographic images of the Earth's interior, in conjunction with improving models of the rupture process during an earthquake. On the face of it, this seems like a herculean task because hundreds or even thousands of model parameters are involved in such inversions. In principle, the Fréchet derivatives that represent the sensitivity of a seismograms with respect to the model parameters may be calculated numerically, but this would require a number of forward calculations equal to the number of model parameters. By drawing connections between waveform tomography, adjoint methods popular in climate and ocean dynamics, time-reversal imaging, and finite-frequency `banana-donut' kernels, we demonstrate that Fr\'{e}chet derivatives for tomographic and (finite) source inversions may be obtained based upon just two calculations for each earthquake: one calculation for the current model and a second, `adjoint', calculation that uses time-reversed signals at the receivers as simultaneous, fictitious sources.

What are the opportunities associated with these advances in computational seismology? 3D synthetics for all events above a certain magnitude could be calculated routinely and made available through the web to the seismological community. Machine time-permitting, past events could be simulated and incorporated in the synthetic seismogram database. Centroid-Moment Tensor inversions based upon fully 3D Green's functions could be routinely performed and cataloged. Not every seismologist will want to purchase and manage his/her own PC cluster. Therefore, one can imagine an on-demand, web-based synthetic seismogram service through which one requests synthetic seismograms for a specific earthquake recorded at specific stations based upon user-specified numerical methods and (finite) source, crustal and mantle models.

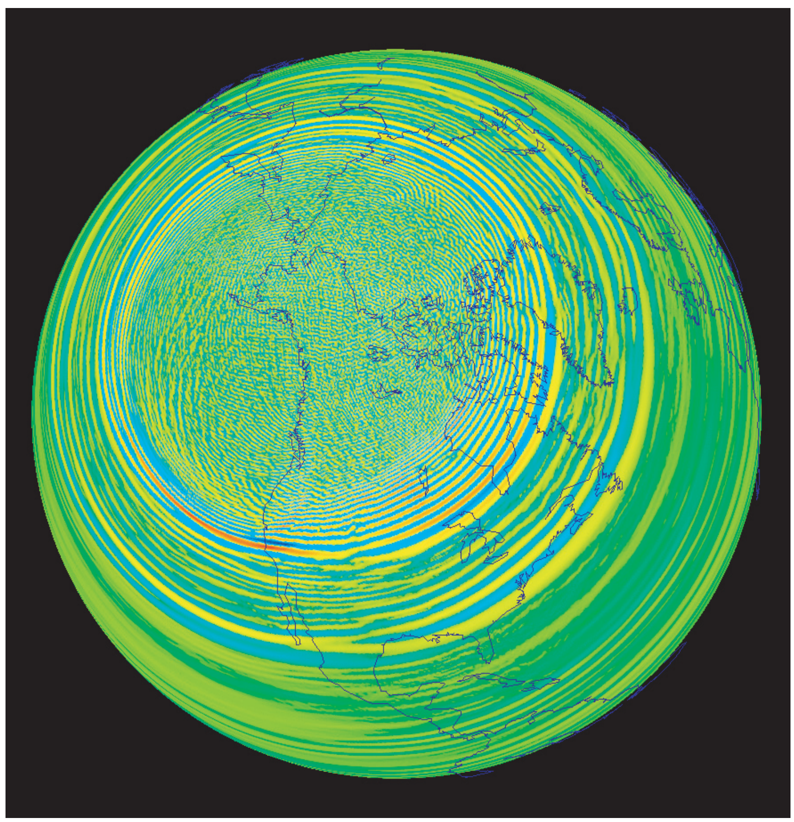

Figure 1: Snapshot of verticle component seismic waves generated by the November 3, 2002, Denali, Alaska, earthquake. Note the large amplification of the waves along the West coast of the United States.

What role can IRIS play in taking advantage of these opportunities? The routine calculation of 3D synthetics, and complementary 1D synthetics, requires a standard with regards to the choice of source parameters as well as new 1D and 3D Reference Earth Models (REMs). IRIS could help set this standard and help finalize the construction of the REMs. On-demand 3D simulations require management of a web server and direct access to a number of distributed compute platforms, e.g., the GRID, to accommodate the request for simulations. This could involve IRIS partnerships with national supercomputing centers.

CONVERSION OF SEED FORMAT TO XML REPRESENTATION FOR A NEW STANDARD OF SEISMIC WAVEFORM EXCHANGE

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The Standard for the Exchange of Earthquake Data (SEED) has been designed as an international standard format for the exchange of digital seismological data. It is now widely used among the community which maintains the broadband seismograph network and recognized as a standard format for data exchange. SEED volume consists of headers and data records and blockettes are stored in headers. The format for data records is called mini-SEED and it is closely related to the format recorded in data loggers. Since SEED blockettes are defined as a collection of named fields with fixed length data, this introduces difficulties of extension of data structures. However, because there already exist huge amount of waveform data saved in mini-SEED format, it is a formidable task to fully revise the current SEED format to allow future flexible extensions. Although it has been recognized that the revision of SEED format is necessary, there has been no attempt for revision since its latest release of Ver. 2.3 in February, 1993 because of this difficulty. Here, we represent SEED header structure in XML (eXtensible Markup Language) and show that this representation allows extension of header content without introducing any modification to existed mini-SEED waveform data structure. To represent SEED header structure in XML, we have paid attention to (1) entities described in the current SEED headers should be identical to those described in XML representation; (2) changes in structures of SEED headers should be as small as possible; (3) XML document should have structures that allow validation with XML-Schema language. The first requirement is essential to keep compatibility with XML-based SEED description with the current SEED volumes. The second one is to avoid complexity of conversion. The third one is for more robust data validation. Although we do not modify the current structure of mini-SEED formatted waveform data in our XML-based full-SEED format, our representation of SEED header in XML may allow a distribution of waveform data through header only XML-based SEED volume. Then, to get seismic wave data, one can access data server or look for data files according to data location described in this header file. We distribute seismic waveforms recorded by broadband seismograph network of Ocean Hemisphere Project through Pacific Region Geophysical Network Data Center of IFREE in our prototype XML representation of SEED format. We also distribute software to read our prototype XML-based SEED volume for users to review our XML representation of SEED format.

EARTHSCOPE UNDERWAY: PROGRESS, GOALS, AND EMERGING OPPORTUNITIES

Gregory E. van der Vink (1), Robert B. Smith (2), Christel B. Hennet (1), Charna E. Meth (1)

(1) EarthScope; (2) University of Utah

With instruments already in the ground, collecting geodetic and seismic data, and the borehole into the San Andreas Fault breaking ground, EarthScope is now underway. EarthScope is taking a comprehensive "systems" approach to understanding the tectonics of the North American continent at all scales – from the active nucleation zone of earthquakes, to individual faults and volcanoes, to the deformation along the plate boundary, and to the structure of the continent. The project is unprecedented, both in its interdisciplinary approach to Geoscience and in its scope. With approximately $200 million in funding from the National Science Foundation's (NSF's) Major Research and Facility Construction account, EarthScope will be developed over the next five years. Once complete, EarthScope is anticipated by NSF to be operating for an additional 15 years. The North American continent is an ideal location for EarthScope, as no place else on Earth offers such a rich set of active geological processes so accessible for study. Available for observation is the full spectrum of plate boundary processes, ranging from plate convergence in the subduction zones of Cascadia and the Aleutians, to transform faulting along the San Andreas Fault, and intraplate extension of the Basin and Range. EarthScope has begun collecting multiple data sets that will allow us to study the transition from plate-scale tectonic interactions to small-scale system level processes such as individual faults and volcanoes, and how they interact. EarthScope is being implemented through the parallel construction of multiple observational systems. A four-kilometer deep observatory (SAFOD) bored directly into the San Andreas fault at Parkfield has broken ground and is providing the first opportunity to observe directly the conditions under which earthquakes occur, to collect fault rocks and fluids for laboratory study, and to monitor continuously with seismic stations and strainmeters an active fault from within the earthquake zone. A network of continuously recording Global Positioning System receivers, borehole strain meters, borehole seismic stations, and meteorological instrument packages (PBO) is being installed along the western US plate boundary. A network of seismographic stations, GPS reference marks, microbarographs, and magneto-telluric instruments (USArray) is being deployed to migrate slowly across the United States, eventually occupying 2,000 sites over the next ten years. Additional seismic and geodetic instrumentation will soon be available to individual PIs for high-resolution imaging in areas of special geologic interest. EarthScope data is freely and openly available to maximize participation from the scientific community and to provide on-going educational opportunities at all grade levels.

ORFEUS AND THE VIRTUAL EUROPEAN SEISMOGRAPH NETWORK

Torild van Eck, Bernard Dost, ORFEUS and the MEREDIAN consortium

Royal Netherlands Meteorological Institute ORFEUS, c/o Seismology Division, Royal Netherlands Meteorological Institute, De Bilt, The Netherlands

European seismological observatories are currently undergoing an impressive evolution and modernisation. The result is a very dense, but patch like coverage with seismic instruments operated by a multitude of different observatories funded through an even larger multitude of independent sources. Consequently, providing the research community with free, easy and rapid access to all of this waveform data poses a significant challenge. An on-going 4½ year EC-funded project, MEREDIAN, involving 18 European national observatories, aims at shaping these national efforts into a European-Mediterranean infrastructure for broadband waveform data exchange and archiving. This major extension to the ORFEUS data collection and archiving infrastructure includes the Virtual European Broadband Seismograph Network (VEBSN). The VEBSN gathers (near) real-time data at the Orfeus Data Center from all over Europe and is one of the most visible components of the MEREDIAN project. The implemented data exchange infrastructure realised within MEREDIAN has facilitated rapid earthquake information throughout Europe and has opened up many new challenging opportunities for earthquake monitoring and research in the European-Mediteranean region.

RESOLUTION OF VP, VS, AND VP/VS IN REGIONAL BODY WAVE TOMOGRAPHIES: A STUDY OF ‘BLEED-OVER’ EFFECTS

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One of the long-standing debates in seismic tomography centers on the best way to determine Vp, Vs, and the Vp/Vs ratio. Each of these three quantities gives us important information on the composition and state of the volume being studied, yet they are each obviously not entirely independent from one another. We can determine Vp and Vs relatively independently (assuming fixed event locations), as they are each tied to the absolute travel times of a particular phase. Errors in P-wave picks map directly to errors in the P-wave velocity structure but not necessarily to errors in the S-wave velocity structure, and vice versa. The Vp/Vs ratio, on the other hand, is derived from the difference in travel times between the P and S wave arrivals, and as such the accuracy of a given Vp/Vs measurement is sensitive to errors in both P- and S-picks and velocity structures. Further complicating the determination of Vp/Vs is the generally uneven distribution and quality of P- and S-wave picks. Even if all picks were made with total accuracy, an under-resolved S-wave anomaly that is related to a well resolved P-wave anomaly would produce a spurious Vp/Vs ratio. A number of authors have addressed this issue by inverting directly for Vp and Vp/Vs, deriving Vs from the previous two quantities. This should guarantee that deviations in Vp/Vs are mandated by the data and are not merely artifacts of uneven resolution. Unfortunately, Vs deviations determined from this method suffer from many of the same problems associated with determining Vp/Vs by inverting for Vp and Vs. In particular, large P-wave anomalies in areas with better P-wave coverage than S-wave coverage tend to “bleed over” into the S-wave anomalies via an under-resolved Vp/Vs anomaly. We investigate this problem by inverting simultaneously first for Vp and Vs, and then for Vp and Vp/Vs, using a modified version of the method proposed by Zhao et al. (1992). We use data collected during the Chile Argentina Geophysical Experiment (CHARGE) to investigate the upper mantle structure above the flat slab in central Chile and Argentina. We find a layer overlying the flat slab characterized by low Vp, high Vs, and low Vp/Vs, regardless of which tomography method is used. However, smaller second order features are sometimes produced by “bleed over” as can be demonstrated using synthetic data in a “recovery” test following the method described by Husen et al. (2003). We conclude that in order to avoid interpreting spurious results, it is best to always invert directly for the quantity being analyzed.

UPSEIS - PUTTING TEMPORARY SEISMOGRAPHS IN K-12 SCHOOLS

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Upper Peninsula Seismic Experiments in Schools (UPSeis) is an educational program that has been developed over the past several years to engage K-12 students in hands on activities learning about earthquakes and Earth science. The UPSeis program brings a working seismograph system into the classroom and includes computer software, several lesson plans and activities, and a supporting informational web page. The hardware components consist of a S-102 seismometer with an amplifier/A-D converter that is directed into the computer through the serial port. The UPSeis system software, created using LabView (a graphical programming language), is easy to install and runs on any PC. The system comes with a manual and overall is easy to setup and use. We have recently completed an accompanying set of lesson plans and activities designed for students of all levels, correlated to Michigan's Curriculum Content Standards, and likely to be readily transferable to national standards and those of other states. The supporting website contains basic information on earthquakes and will serve as a reference for students, teachers, and volunteer UPSeis instructors. Ongoing work will lead to a collection of earthquake seismograms that have been recorded on this system and interpreted, with easy-to-follow references to travel-time curves. Classes will be able to use the website to compare their interpretation with ours. The UPSeis recording system itself requires no connection to networks and does not require timing to be more accurate than a couple of seconds, obtained by setting the PC clock to radio-controlled clocks. Our intention is for the UPSeis systems to be in any given classroom for three to four months at a time, usually sufficient for 2 or 3 large teleseismic events to be recorded. Teachers that find this program exciting and want to keep a permanent system in their classroom can be referred to a more involved system such as MichSeis or PEPP. Recently, the UPSeis program has been operating successfully in two local area schools, providing us with experience in actual school settings. The next step is to get the program into more schools. Seed funding from the SEG Foundation (Society of Exploration Geophysicists) has enabled the program to be created. In the future, it is our hope to train groups of interested individuals to use the UPSeis system and curriculum at large conferences of earth science professionals, such as SEG and AAPG. After training, individuals will be expected to find financial backing to acquire a system, and to go back to their respective communities with a seismograph system in order to educate students about earthquakes and earth science through fun hands-on activities using the UPSeis system.

EVOLUTION OF THE USGS EARTHQUAKE HAZARDS PROGRAM WEBSITE

Lisa Wald & EHP Web Team

USGS

The U.S. Geological Survey (USGS) Earthquake Hazards Program (EHP) website (http://earthquake.usgs.gov/) focuses on 1) earthquake reporting for informed decisions after an earthquake, 2) hazards information for informed decisions and planning before an earthquake, and 3) the basics of earthquake science to help the users of the information understand what is presented. The majority of website visitors are looking for information about current earthquakes in the U.S. and around the world, and the second most visited portion of the website are the education-related pages. People are eager for information, and they are most interested in “what’s in my backyard?” Recent and future web developments are aimed at answering this question, making the information more relevant to users, and enabling users to more quickly and easily find the information they are looking for. Recent and/or current web developments include the new enhanced Recent Global Earthquakes and U.S. Earthquakes webpages, the Earthquake in the News system, the Rapid Accurate Tectonic Summaries (RATS), online Significant Earthquake Summary Posters (ESP’s), and the U.S. Quaternary Fault & Fold Database, the details of which are covered individually in greater detail in this or other sessions. Future planned developments include a consistent look across all EHP webpages, an integrated one-stop-shopping earthquake notification (EQMail) subscription webpage, new navigation tabs, and a backend database allowing the user to search for earthquake information across all the various EHP websites (on different webservers) based on a topic or region. Another goal is to eventually allow a user to input their address (Zip Code?) and in return receive all the relevant EHP information (and links to more detailed information) such as closest fault, the last significant nearby earthquake, a local seismicity map, and a local hazard map, for example. This would essentially be a dynamic report based on the entered location. This type of “what’s in my backyard?” information would be of great benefit to both various organizations, such as insurance agencies and building contractors, and the general public.

SEISMOLOGY IN THE GREAT BASIN: SOLVING THE ELEVATION PROBLEM

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The Great Basin has an average elevation of ~2 km, with the highest elevations in eastern Nevada between the Lahontan and Bonneville depressions. The average crustal thickness of ~32 km does not explain that high elevation, hence the mantle appears to be anomalously buoyant, which could be due to thermal or compositional buoyancy. Around 16-17 Ma, an outpouring of flood basalts erupted throughout the northern Basin and Range. A linear progression of felsic volcanism began at McDermitt volcano in northern Nevada and progressed toward the northeast and northwest, to the current locations of Yellowstone and Newberry (Oregon), respectively. Published tomographic images show a low-velocity zone beneath Nevada at ~350 km depth, although the images are quite smooth and do not reveal fine structure. Receiver functions suggest a low-velocity zone atop the 410-km discontinuity in northern Nevada that pinches out beneath eastern Nevada. Waveform modeling of turning waves near the 410-km discontinuity beneath the northern Basin and Range suggests that this low-velocity zone varies in thickness from 20 km to a maximum thickness of 90 km in central Nevada. We present new teleseismic shear-wave splitting data from six broadband seismic stations deployed along the axis of the SRP from June 2000 to September 2001, and show the simplest interpretation required by the data is that splitting is due to a single layer of anisotropy with a horizontal fast axis. Our station fast directions, as well as shear-wave splitting data from numerous other stations throughout the Basin and Range, are best explained by a lattice preferred orientation of olivine due to horizontal shear along the base of the plate associated with the gravitational spreading of buoyant plume-like upwelling material beneath eastern Nevada into a southwestward flowing asthenosphere (with respect to a fixed hotspot reference frame). This parabolic asthenospheric flow (PAF) model for the Great Basin is attractive because it explains the observed high elevations, high mantle buoyancy, low-velocity anomaly beneath eastern Nevada, high heat flow, and depleted geochemistry of some erupted basalts. An upwelling model may also be consistent with the results of turning-ray waveform and receiver-function modeling, which suggests the low-velocity zone atop the 410-km discontinuity beneath the northern Basin and Range does not exist beneath eastern Nevada. The lack of Pliocene-Recent major volcanism in eastern Nevada suggests that a significant amount of the buoyancy flux is due to compositional buoyancy. If this active-upwelling model is correct, it could explain the observed elevation beneath the Great Basin as due to an unusually high compositional buoyancy in the upper mantle. It also implies that if a ~17 Ma-old upwelling exists beneath Yellowstone and/or Newberry, they are not necessarily directly responsible for the high elevations we observe in the Basin and Range today. In addition, the splitting data vary over lateral distances that require the deformation due to plate-motion to be relatively shallow, much shallower than the transition zone. When used to drive a rigorous data-analysis and geodynamic-modeling effort, the U.S. Array should be the perfect seismological tool (using both passive and active sources) to investigate the detailed mantle structure beneath the Great Basin, and solve the question "why is the Basin and Range so high". In addition, it could answer the question "is a plume from the lower mantle responsible for this upwelling, or is this feature a result of upper-mantle small-scale convection".

SH WAVE VELOCITY STRUCTURE NEAR THE 660 KM DISCONTINUITY BENEATH SOUTH AMERICA

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The Earth's transition zone plays an important role in mantle dynamics. For example, the endothermic phase transformation from ringwoodite to perovskite occurring at the 660 km discontinuity is recognized to have significant influence on mantle convection. In reality, the stable phase assemblages in the transition zone region are sensitive to mantle composition, temperature and chemical interactions between the olivine- and pyroxene-normative components. With the accumulation of in-situ measurements of elastic properties and accurate determination of phase equilibria data, we can now explore various chemical interactions and quantitatively calculate seismic velocity profiles for various mineralogical models. Mantle composition and thermal models can thus be quantitatively constrained by jointly modeling seismic and mineral physics data. In this study, we constrain fine seismic structures near the 660 km discontinuity beneath South America using the seismic data recorded at the distance range of 10-30 degree for an event occurring in the South American subduction zone at a depth of 597 km. We then iteratively search compositional and thermal models that predict seismic properties that are most consistent with the seismic data. The event exhibits a simple source time function and is selected from the seismic data recorded in three PASSCAL seismic arrays in South America for events occurring in the South American zone from January, 1994 to September, 1995. The observed direct SH phases, the reflections from the 660 km discontinuity and the waves traveling below the 660 km discontinuity are used to place constraints on several important seismic features near the 600 km discontinuity, such as, the depth of the discontinuity, the velocity jump across the discontinuity, and the velocity gradient above the discontinuity. Our modeling results indicate that the SH velocity gradient above the 660 km discontinuity is larger than PREM, the 660 seismic discontinuity appears to be 15 km deeper than PREM, and the shear velocity jump across the discontinuity is similar to PREM. The large shear velocity gradient above the 660 km discontinuity and the velocity jump across the discontinuity are well constrained by the seismic data. The exact depth of the discontinuity however requires accurate determination of event depth. In joint modeling of the mineral physics and seismic data, we calculate seismic velocity profiles for a variety of compositional and thermal models using the Tr660 program developed by Weidner and Wang (1998). We then obtain the most appropriate compositional and thermal models based on the criterion that their predicted seismic profiles best match those inferred from the seismic data and the synthetics of those predicted seismic profiles best fit the seismic data.

OBSERVATIONS OF SOURCE FINITENESS IN DEEP TONGA EARTHQUAKES

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One of the basic issues regarding the physical mechanism for deep earthquakes is the extent to which they occur on pre-existing faults: Do deep earthquakes reactivate faults that formed in the oceanic plate prior to subduction? A previous study of the Tonga subduction zone (Jiao et al., 2000) compared nodal plane distributions between outer-rise events to events as deep as 450 km depth, and found them to be very similar. While this comparison provides some support for the pre-existing fault hypothesis, a more stringent test of the hypothesis is available by identifying the actual rupture planes of these events. We are developing the methodology to perform such a test based on the detection of source finiteness. Between 1990 and 2002, the IRIS FARM database contains approximately 200 earthquakes with m_b >= 5.5 in the region studied by Jiao et al. For these earthquakes, we use the Harvard CMT focal mechanism to identify the two possible fault planes and then search over potential rupture directions on these planes for evidence of source finiteness. The finiteness of the source is visible in variations in the relative timing of subevents and as increases in pulse width with increasing angular separation between the rupture and takeoff vectors. Thus, for each potential rupture direction, we plot broadband P waveforms as a function of the angle between the rupture direction and the takeoff angle to the station. For many earthquakes, we are able to identify a rupture direction that highlights the effects of source finiteness and estimate the directivity of the rupture from it. Augmenting these observations with aftershock locations, we determine the distribution of rupture-plane orientations of deep- and outer-rise seismicity for the Tonga subduction zone.

NEW HORIZONS FOR GLOBAL SEISMOLOGY: POLAR REGIONS AND OCEANS

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Now that the original design goals of the IRIS Global Seismic Network are complete, we need to consider what instrumentation objectives can advance our science over the next decade. Vast areas of the earth, primarily in the oceans and polar regions, remain poorly instrumented for global seismology. The absence of instrumentation in these regions poses a severe limitation on global tomographic models and our knowledge of the structure of the earth's interior.

Antarctica remains a poorly instrumented region for seismology, since all global stations with the exception of South Pole are located along the coast in high noise regions, leaving large gaps on the interior. This distribution results from the locations of Antarctic bases that are manned year-around. Recent PASSCAL experiments have demonstrated the utility of routinely operating autonomous seismic sensors on the Antarctic interior. The Antarctic interior is generally characterized by low seismic noise; for example, the TAMSEIS PASSCAL experiment recorded clear near-antipodal PKPdf phases traversing the inner core along the fast axis of anisotropy from magnitude 5 earthquakes along the Arctic spreading center. These observations provide important constraints on the distribution of anisotropy in the inner core. In addition, the new GSN QSPA borehole station at the south pole is among the quietest of all the GSN stations. A workshop to discuss Antarctic seismic instrumentation was held in Boulder, CO in March, 2003, and recommended the establishment of approximately 10 permanent GSN-type autonomous seismic stations on the Antarctic interior. Another aspect of this workshop's recommendations was an internationally coordinated leapfrogging deployment of temporary broadband seismic stations. Discussions are also underway concerning a permanent array deployment at South Pole, in the quiet sector near QSPA. Some expansion of Antarctic seismological instrumentation may be possible as part of the International Polar Year, scheduled for 2007-2008.

The oceans represent another challenge for expanding seismological instrumentation. Low noise recordings can be obtained with either borehole or buried sensors. Several permanent seafloor seismic stations have been established as part of the Ocean Seismic Network, including the cabled H2O site in the Pacific. Future opportunities for permanent seafloor sites include additional cabled observatories and moored buoys. Long term temporary broadband seafloor deployments are now possible through the Ocean Bottom Seismograph (OBS) Instrumentation Pool, which coordinates US OBS deployments. Buried OBSs, which could provide much lower noise long period observations, are being developed. A plan for future temporary seismic instrumentation in the oceans was developed at the Ocean-Mantle Dynamics workshop at Snowbird in October, 2002. Future progress in ocean seismic instrumentation may require cooperation between several organizations and divisions at NSF.

THE CASE FOR WIDE-BAND SEISMOLOGY: FIVE ORDERS OF MAGNITUDE IN THE SOUTHWEST U.S.

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The IRIS/PASSCAL arsenal of portable seismic instrumentation includes a wide range of sensors from 40 Hz geophones, commonly used in reflection surveys, to 120-second STS-2's, the workhorse of passive teleseismic experiments. Different hypotheses are best addressed with different types of seismic energy, and require recording systems tailored to specific types of experiments. However, many solid Earth systems cannot be solved, or even adequately imaged, with a single type of seismic analysis. This talk will stress the benefits of combining seismic imaging techniques from a wide range of frequency bands, using the Rio Grande Rift in the southwest U.S. as a case study. The rift has been the subject of numerous seismic investigations over the past three decades by dozens of researchers. Each independent study has mapped some aspect of the seismic structure, from well-logs in the top few kilometers to receiver function images of the 410- and 660-km discontinuities. While each seismic image can be interpreted on its own, some of the most significant processes at work in the rift are only seen when data is combined from several different scales and frequency ranges. Specific examples include the pure shear mechanism of rifting; the strain distribution with depth in the crust; the connection between rift tectonics and (limited) volcanism; variations in lithospheric thickness across the region; the flow of mantle beneath the rift; and constraints on possible small-scale convection. Our current understanding of all of these topics is founded on the combined interpretation, and in some cases formal joint inversion, of seismic data from different frequency bands.

NUMERICAL ANALYSIS OF OVERPRESSURE DEVELOPMENT IN THE NEW MADRID SEISMIC ZONE

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We use mathematical and numerical modeling techniques to evaluate overpressure resulting from topographic-driven flow in the Mississippi Embayment and discuss potential implications for wave propagation and microseismicity in the New Madrid seismic zone (NMSZ). The mathematical model implies that the magnitude of excess pore pressure in the discharge area is determined by a basin’s geometry and the hydraulic conductivity of basin strata. Our modeling results illustrate how excess pore pressures of up to 5 atm could be sustained in a wide discharge area of the NMSZ by regional gravity flow. The predicted magnitude of excess pressure is generally consistent with observed elevation heads (10-30 m) of artesian wells that penetrate the Upper Cretaceous and Paleozoic aquifers in the basin. The modeling results also demonstrate that overpressures developed at depth in the Mississippi Embayment could be communicated to shallower layers if confining units are breached by faults. Excess pore pressures can reduce the stress required for deformation and contribute to the hydrologic response of shallow strata to earthquake events. The prevailing overpressure condition in the shallow NMSZ implies that this zone is relatively weak compared to areas under hydrostatic conditions. We argue that ambient overpressures in these basin strata can be sustained for long time periods and may explain some low seismic velocity anomalies and shallow, low-magnitude seismicity in the NMSZ.

IMPROVED RAYLEIGH WAVE PHASE VELOCITIES, ATTENUATION STRUCTURE AND STATION SITE RESPONSE IN SOUTHERN CALIFORNIA

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We use both phase and amplitude data of fundamental mode Rayleigh waves recorded at the TriNet network in southern California to invert for phase velocities, attenuation structure and station site response at periods from 25 to 143 s. By taking into account the sensitivity kernel of fundamental mode Rayleigh waves in the study region, we can evaluate focusing/defocusing effects on amplitude due to heterogeneous structure and separate them from attenuation and station amplification effects on amplitude, meanwhile improving phase velocity tomography. Improved phase velocity images have similar overall features compared to the previous method that uses Gaussian function with same characteristic length along ray path to represent sensitivity. Both methods show a pronounced low velocity anomaly beneath the Western Basin and Range, a high velocity anomaly under the Transverse Range and a slightly slow velocity anomaly under the Salton Trough. The improved method reveals more heterogeneous structure at long period, which helps to improve resolution in deep structure. The value of Q for Rayleigh waves is around 250 at short periods of 25 to 40 s, which are most sensitive to structure at depth range of 30 to 60 km. With increasing of period, Q becomes lower. At periods longer than 63s, Q is around 50 to 100. This pattern indicates high Q at short periods due to a relatively cold lithosphere and low Q at longer period due to higher temperature in the asthenosphere. The estimate of the site/station apparent amplification factor shows a systematic variation across southern California. At period of 25 s, we find a variation up to a factor of two in amplitude amplification, with lowest amplification factor near coast and in southernmost California and higher value in the Owens Valley/Long Valley region. The variation decreases with increasing periods, which is as expected. This amplification effect is well known at short period (< 10 s) as an important factor in evaluating earthquake hazards, however it is ignored at longer period as a means of constraining the earth structure.

UPPER MANTLE BODY WAVE TOMOGRAPHY BENEATH THE YELLOWSTONE HOTSPOT: CORRELATION WITH THE SEISMIC DISCONTINUITIES

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The mantle dynamics driving the Yellowstone hotspot is not well constrained by the current observations. The time-progressive trail of volcanism along the eastern Snake River Plain, the high 3He/4He ratio observed at Yellowstone, and the LIPs associated with the Columbia River and Steen Mountain basalts, all are broadly consistent with plume model. However, within the resolution of previous body wave tomography studies, a lack of low seismic velocity pipe extending through the transition zone is a provisional conclusion. A 3-dimensional P-wave tomographic study has been performed using the teleseismic travel-time residuals from the PASSCAL Yellowstone, Snake River Plain, Billings, University of Utah (UU), and USNSN stations. This array creates at surface apature of about 500 km in diameter centered at the Yellowstone Park, providing reasonably good ray coverage. Baseline array statics time shifts between these arrays have been calculated by using the UU and USNSN as a reference network of stations. The station elevation, basin depth and the Moho depth are taken into account to correct the travel-time residuals. To minimize the effects due to the irregular earthquake distribution, summary rays are formed. We use the LSQR algorithm to solve the inversion problem. A range of damping parameters is used to address the effects of regularization upon the velocity images. Our best constraint on transition zone thermal structure will be correlation of the 410- and 660-km discontinuity topography with the body wave velocity perturbations. Seismic discontinuity maps from the PASSCAL Yellowstone array show at the 410, a depression of 35 km approximately 120 km west-northwest of Yellowstone Park, perhaps consistent with a low velocity pipe in our velocity maps. This depressed 410 depth may represent elevated temperature. A temperature correlation between the body wave tomography (calculated from anelastic thermal derivatives) and the discontinuities topography (from Clapeyron slope) will be presented.

GLOBAL FINITE-FREQUENCY SURFACE-WAVE TOMOGRAPHY

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We investigate finite-frequency effects in global surface-wave tomography, using long-period fundamental mode phase-delay measurements. Inversions based on ray theory and finite-frequency sensitivity kernels show similar large-scale geographic patterns, but different small-scale structures. Overall, finite-frequency tomography recovers anomalies with stronger amplitude, as they account for wave-front healing effects. Resolution tests show that ray theory may introduce significant artifacts, especially in regions where the depth sensitivity is weak or the ray-path coverage is relatively poor. Separate inversions of Love-wave data and Rayleigh-wave data show an apparent discrepancy in shear-wave velocity structure, indicating strong (radial) anisotropy in the upper mantle. Roughly, in the top 250 km, the globally averaged SH velocity is faster than the SV velocity, this is dominated by anisotropy signatures beneath continental roots and the old Pacific plate; below the depth of 250 km, the SH velocity becomes slower than the SV velocity, especially beneath mid-ocean ridges. Possibly, the shallow part of the upper mantle anisotropy is associated with horizontal flows beneath those old tectonic regions; while below a depth of ~250 km, anisotropy may be introduced by vertical mantle flows around mid-ocean ridges.

AN INTEGRATED EXPLOSION SOURCE PHENOMENOLOGY EXPERIMENT IN SOUTHWESTERN US – FROM 10 M TO 500 KM

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The purposes of these experiments were to examine the source function of single- and delay-fired explosions and to quantify near-source phenomenology and its role in the generation of shear waves observed at regional distances. Experiments were conducted at a copper mine in SE Arizona and a coal mine in NE Arizona. A diverse set of instruments were deployed including high-g accelerometers within the nonlinear zone, high frequency velocity instruments (including Texans) to document the transition from near source to regional and broadband portable instruments to supplement permanent regional seismic stations. In addition, detailed refraction surveys were conducted in and around the source region to constrain local material properties. Single-fired explosions ranged in size from 91 to 12700 kg. Refraction data document the effects of weathering in the both the granitic (copper) and sedimentary (coal) rocks in and around the sources. Accelerometer data characterize the failure of the near-source materials in spall. High frequency velocity instruments in the 1 to 100 km range capture the generation of strong shear arrivals in addition to P waves and their development into surface waves. The broadband instruments record the regional propagation of these phases. Strong differences between the single-fired and delay-fired explosions are also noted and linked to the extended source duration of the production mining explosions. Support from PASSCAL made it possible to deploy this diverse set of instrumentation and thus document the combined source and propagation path effects in this regional experiment.

STRUCTURE OF THE INNER CORE-OUTER CORE BOUNDARY INFERRED FROM PKPBC DIFFRACTED WAVES

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Examining the structure of the inner core-outer core boundary (ICB) is important for understanding the evolution and dynamics of the Earth's core. Seismic waves that diffract past the C caustic (PKPCdiff) preferentially sample the ICB and so contain important clues about this region. Just as Pdiff has been studied to infer core-mantle boundary structure, we expect that analysis of PKPCdiff will reveal ICB structure. However, there have been few systematic studies of PKPCdiff . Here we present an analysis of PKPCdiff data recorded during the PASSCAL INDEPTH-III experiment. This regional array was deployed in Tibet for approximately one year and consisted of 40 broadband and 10 short-period seismometers with station spacing of about 5 km. We apply the multi-channel cross-correlation method to the broadband waveforms to extract the differential travel times of PKPCdiff across the array, and use a weighted least-squares technique to invert theses times for the three-dimensional PKPCdiff slowness vector. We generate standard errors for the ray parameter and backazimuth using a bootstraptype resampling algorithm. For four earthquakes occurring at distances of 154°--158° we find PKPCdiff ray parameters that vary from 1.75±0.05 to 2.15±0.05s/deg. In order to lessen the effect of shallow structure on the travel times, we also invert the differential travel times (PKPCdiff-PKPDF) for differential slowness vectors. We find less variation in the different ray parameters (0.93±0.05 to 1.09±0.05 s/deg), however the differences appear to be significant. Therefore, our initial results support the idea of modest lateral heterogeneity at the ICB. We intend to examine the robustness of this result by refining our observational technique, quantifying the relationship between PKPCdiff ray parameters and ICB structure, and identifying more PKPCdiff phases to make a global study of ICB heterogeneity.