Using **P** to represent extrapolation by the pseudo-differential operator (equation 1), we have the equality

$$\mathbf{P}\left(\frac{\Delta z}{2}\right)\psi(z)=\mathbf{P}\left(-\frac{\Delta z}{2}\right)\psi(z+\Delta z) \qquad (3)$$

from which a least-squares estimate of $\psi(z+\Delta z)$ can be derived:

$$\psi(z+\Delta z)=\left[\mathbf{P}^{\dagger}\left(-\frac{\Delta z}{2}\right)\mathbf{P}\left(-\frac{\Delta z}{2}\right)\right]^{-1} \times \mathbf{P}^{\dagger}\left(-\frac{\Delta z}{2}\right)\mathbf{P}\left(\frac{\Delta z}{2}\right)\psi(z)\,. \qquad (4)$$

Using a seismic modeling algorithm, we implement the one-way operator represented by equation (4) and extrapolate a point source through a strongly heterogeneous medium. We compare the resulting wavefield to wavefields obtained by several series approximations to equation (4) implemented as operators in the same modeling algorithm. We find that, for a minimal loss of accuracy, large increases in computational efficiency can be realized by implementing the approximate operators.

S61B-1142 0830h POSTER

3D Hybrid Simulation method Using Finite Difference and Discrete Wavenumber Method

Hidenori Kawabe[1] (81-724-51-2418; kawabe@rri.kyoto-u.ac.jp)

Katsuhiro Kamae[1] (81-724-51-2369; kamae@kuca.rri.kyoto-u.ac.jp)

Masanori Horike[2] (81-6-6954-4219; horike@archi.oit.ac.jp)

[1]Research Reactor Institute, Kyoto University, Noda Kumatori-cho Sennan-gun, Osaka 590-0494, Japan

[2]Osaka Institute of Technology, 5-16-1 Omiya-ku, Osaka 533-8585, Japan

This study presents a 3D hybrid method for computation of 3D seismic motion inside basin. The hybrid method is based on the discrete wavenumber (DW) and fourth-order finite difference (FD) method. In the first step of the hybrid technique, DW method is used to calculate 3-component excitation on a finite difference grids surrounding 3D basin structure model. In the second step, FD method is used to compute the 3D wave propagation inside basin using the results obtain in the first step. The merits of this hybrid method are as follows. The first step computational model can locate the seismic source without the restriction of the finite difference grid point. The second step computational model needs less computer memory and time than the calculation using only FD method. The accuracy of the DW-FD hybrid method has been tested for homogeneous media. As the result of the test, the hybrid method solutions are in good agreement with the discrete wavenumber solutions for homogeneous media. Furthermore, we applied this method to simulation of strong ground motions from an actual earthquake, and showed the effectiveness of this method.

S61B-1143 0830h POSTER

Simulation of wavefields emanating from finite sources in anisotropic media

Gilbert Brietzke[1] (brietzke@geophysik.uni-muenchen.de)

Yehuda Ben-Zion[2] (benzion@terra.usc.edu)

Heiner Igel[1] (igel@geophysik.uni-muenchen.de)

Alain Cochard[1] (alain@geophysik.uni-muenchen.de)

[1]Department of Earth and Environmental Sciences, Geophysics Section, Theresienstrasse 41, Munich 80333, Germany

[2]Department of Earth Sciences, USC Earth Sciences, Los Angeles, CA 90089-0740, United States

The shallow crust is known to be anisotropic in most seismically active regions. Anisotropy manifests itself predominantly through shear-wave splitting which may considerably complicate the particle motion of shear wave trains. However, these arrivals may also be complicated by finite-source effects and noise.

The goal of this study is to classify and compare the effects of (weak) anisotropy and finite sources on the shear waveforms in the presence of realistic noise, and to discuss implications for the determination of source and medium properties. Three-dimensional numerical simulations are carried out using a finite-difference scheme for general anisotropic media.

Finite sources are simulated through a simple kinematic model, where rupture propagates with constant velocity in a symmetric manner from a hypocentre location to the edge of a circular fault. Regions swept by the rupture front begin to slip with a constant rate. An arrest front propagates backward from the predefined circular fault edge terminating the slip. Synthetic seismograms are calculated for a set of buried finite sources in a homogeneous half space.

We investigate the particle motion observed at the surface as a function of increasing anisotropy (from isotropic to 10% shear-wave anisotropy), increasing source area (from point source to finite source size), increasing noise, and various combinations of these factors. Particle motion effects are discussed as a function of propagation direction and frequency. We investigate whether the contributions of anisotropy and finite source size are separable in the model space considered.

S61B-1144 0830h POSTER

Coupling of Finite-Difference and Finite-Element Methods for Earthquake Source Simulations

Geoffrey P. Ely (858-822-5018; gely@ucsd.edu)

Institute of Geophysics and Planetary Physics, 9500 Gilman Drive, La Jolla, CA 92093-0225, United States

We investigate a scheme for interfacing Finite-Difference (FD) and Finite-Element (FE) models and apply it to dynamic rupture simulations. The more powerful but slower FE method allows for (1) unusual geometries (e.g. dipping and curved faults), (2) nonlinear physics, and (3) finite displacements. These capabilities are computationally expensive and limit the useful size of the problem that can be solved. Large efficiencies are gained by employing FE only where necessary in the near source region and coupling this with an efficient FD solution for the surrounding medium. Coupling is achieved through setting up and an overlapping buffer zone between the two methods. The buffer zone acts as mutual offset boundary conditions (BC). The buffer zone is itself divided into two regions; the interior portion of the buffer zone for each method corresponds to the exterior portion of the the buffer zone in the other method. Each interior buffer zone acts as a BC by passing field variables to the exterior buffer zone of the other method. This scheme eliminates the effect of the artificial boundaries at the interface and allows energy to propagate in both directions across the boundary. In general it is necessary to interpolate variables between the meshes and time discretizations used for each model, and this can create artifacts that must be controlled.

S61B-1145 0830h POSTER

Regularization Methods in Seismic Waveform Inversion

Indrajit G. Roy[1] ((512)471-0388; mrinal@ig.utexas.edu)

Mrinal K Sen[1] ((512)471-0466; mrinal@ig.utexas.edu)

[1]University of Texas at Austin, 4412 Spicewood Springs Road Bld 600, Austin, Tx 78759, United States

Seismic waveform inversion is a highly challenging task. Nonlinearity, non-uniqueness, and robustness issues tend to make the problem computationally intractable. Regularization is critical for obtaining stable and geologically realistic solutions. We have developed a simple Gauss-Newton type algorithm for inversion of seismic data in which we evaluated several different existing regularization methods with application to field ocean bottom cable data. Although Engl's regularization criterion, based on a discrfepancy principle requires prior knowledge of noise in the data, we were able to obtain excellent results by trial and error choise of the noise estimates. The robustness and stability were further improved by allowing adaptivity in the choice of the regularization weight. The commonly used L-curve and GCV criteria were also used successfully in the inversion of field seismic gathers. We evaluated some existing methods of measuring the corner of the L-curve at each iteration of the algorithm and improved the performance when the L-curve was generated in linear rather than the conventional log-log scale. The GCV method requires more computaion time per iteration step but converges faster than an algorithm based on L-curve. We also developed a new approach in which we make an estimate of noise (for use in methods based on discrepancy principle) from the L-curve. We will demnostrate the relative performance of these methods with application to field ocean bottom cable data.

Acknowledgement: Work supported by the US Dept. of Energy contract no. DE-FC26-00BC15305.

S61C MCC: Hall C Saturday 0830h

Crustal Dynamics, Deep Crustal Imaging Posters *(joint with T)*

Presiding: **C M Snelson,** University of Nevada, Las Vegas**; R G Keller,** University of Texas at El Paso

S61C-1146 0830h POSTER

Deep Seismic Imaging of the Crust Through Las Cárceles and Bajada de Añelo, Neuquén Basin - Argentina (38° SL)

Alberto Comínguez[1] (54-11-4323-1304; ahcominguez@yahoo.com)

Juan Franzese[2] (54-221-421-5677; franzese@cig.museo.unlp.edu.ar)

[1]Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque S/N, La Plata, BA 1900, Argentina

[2]Centro de Investigaciones Geológicas, Universidad Nacional de La Plata - CONICET, Calle 1 No.644, La Plata, BA 1900, Argentina

Deep seismic sections were obtained by mathematical reprocessing of conventional vibroseis data recorded in the central sector of the Neuquén Basin. The lines involved linear upsweeps with frequency band of 12-65Hz and time-length of 8 sec. The field records were characterized by time-lengths of 13 sec and a sampling period of 4 msec . The Self-Truncating Extended Correlation algorithm was used to compute cross-correlation between the sweep and the records. The original frequency-band of 12-65 Hz was preserved for the first 5 sec of trace. However, this band was affected by an upper-frequency decreasing from 5 sec on, at a predicted linear-rate of 6.625 Hz/sec. Hence, correlated deep-records with a time-length of 11 sec and a final trace-band of 12-25 Hz were calculated. Depth-migration was implemented on the extended traces. Consequently, progressive models of crust velocity were iteratively matched with the corresponding migrated log. The iterative process was considered concluded when it was observed acceptable coincidence between the model and the depth-migrated horizons. The basin stratigraphy in the area consists of a continental sequence of initial sinrift (Precuyano) deposited on half-grabens, followed by strong cycles of marine and continental postrift units (Cuyo, Lotena, and Mendoza groups). The initial structuration is considered of Superior Triassic-Liasic age. While, the postrif phase would have extended until Early Cretaceous. The analysis in the area of Las Cárceles reveals the following:(1)The lower-crust top is placed at about 23-24 km;(2)An oblique reflector horizon between 16 and 18 km depth, is considered as a master shear that controlled the extensional system;(3)A submaster fault, between 8.5 and 12 km depth, is partially recognized in seismic sections;(4)The top of the rift basemen is characterized by irregular depths that, from W to E, fluctuates from 9 to 5 km;(5)Evident features of tectonic inversion, including sinrift as well as part of postrift sequences (i.e. Cuyo and maybe Lotena groups) are observed to the W of Los Chihuidos dorsal (this inversion episode was possibly initiated in the Callovian). In Bajada de Añelo, the study demonstrated that:(1)The top of the pre-liasic basemen is located at about 5 km depth, showing a smooth topographic relief;(2)In the central-western sector are detected features of bipolar inversion;(3)The middle level of the Cuyo group is characterized by oblique reflections related with a strong sedimentary progradation toward the west.

S61C-1147 0830h POSTER

Results from Shallow Seismic Refraction Surveys across Range-Bounding Faults in the Southern Rio Grande Rift

Barry L Reno[1] (barry.reno@trinity.edu)

Benjamin J Drenth[2] (bjdrenth@mtu.edu)

Kate C Miller[3] (miller@geo.utep.edu)

Steven Harder[3] (harder@geo.utep.edu)

Galen Kaip[3] (gkaip@utep.edu)

[1]Department of Geosciences, Trinity University, 715 Stadium Dr., San Antonio, TX 78212, United States

[2]Department of Geological and Mining Engineering and Sciences, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931-1295, United States

[3]Department of Geological Sciences, The University of Texas at El Paso, 500 W. University Ave., El Paso, TX 79968, United States

Seismic refraction surveys provide a useful method for detecting the structure of the shallow subsurface. Presented here are the findings from two such surveys that were conducted in the southern Rio Grande Rift, one perpendicular to the Sacramento Mountains in Southern New Mexico and the other perpendicular to the East Franklin Mountains Fault near El Paso, TX. Both surveys were conducted using explosive sources. The data were collected using single channel Texan seismic recorders for the Sacramento Mountains line and a 60-channel seismograph for the East Franklin Mountains Fault. In both cases, first breaks were picked using the ProMAX software package. Forward modeling was done using MacRay, and velocity models were created by inverting the first arrival data using a non-linear travel time tomography. The model resolution was tested using checkerboard tests.

The 2.1 km long Sacramento Mountains line begins at the base of an alluvial fan, crosses a fault, and works its way eastward up the side of the mountain. The data reveal two basic layers: an upper layer with velocities of approximately 2 km/s and a lower layer with velocities of approximately 4 km/s. The higher velocity layer is at a depth of 400 m ranging from the western end of the line until 1.3 km, where it is uplifted to a depth of 100 m. At the eastern end of the line, there is a possible low velocity zone of approximately 2.5 to 3.0 km/s underneath the higher velocity uplifted block.

The East Franklin Mountains Fault line is 1.3 km long and straddles the surface trace of the fault. The fault separates the high velocity rocks of the Franklin Mountains from the low velocity sediments of the Hueco bolson. Forward modeling indicates that the fault dips about 40° to the east and that the high velocity rocks of the mountains are approximately 6 km/s and the lower velocity sediments east of the fault are approximately 1.5 to 2.0 km/s.

S61C-1148 0830h POSTER

CRS Stacking for Improved Imaging of Inversion Structures in the Donbas Foldbelt

Elive Menyoli[1] (menyoli@dkrz.de)

Dirk Gajewski[1] (gajewski@dkrz.de)

Christian Huebscher[1] (huebscher@dkrz.de)

DOBRE DOBREflection Team (menyoli@dkrz.de)

[1]Institute of Geophysics, University of Hamburg, Bundesstrasse 55, Hamburg, HH 20146, Germany

The Donbas Foldbelt in the southeastern part of the Dniepr-Donets Basin, Ukraine, displays exceptional characteristics for the study of processes involving repeated destabilisation of cratonic interiors, including rifting and its reactivation during basin uplift and inversion. To image the present state of the crustal evolution of this area a multinational study comprising a combined refraction / reflection profile was carried out in summer 2000. The reflection profile comprises 133 km of deep seismic data where Vibroseis and explosive sources were used to achieve a nominal fold of 60-85. In this presentation we focus on some key areas of the reflection section which are critical to estimate the amount of inversion of the basin. To better image these zones, which already show clear indications of substantial inversion in the conventional processed time migrated section we applied a new stacking technology, the Common Reflection Surface (CRS) stack. This new stacking technique is based on a three parametric search whereas for the conventional CMP stack only one parameter (the stacking velocity) is determined. Although this multiparameter search is more time consuming a multi-fold advantage is obtained. The signal to noise ratio of the reflection section is better than for the conventional CMP section. The continuity of the reflection events in the CRS stack is much improved against the CMP stack and additional information of the structure can be derived from the additional parameters determined by the CRS stacking method. The improved continuity and S / N-ratio is clearly visible when the CRS and CMP stack results of the key areas are compared. The enhanced image quality of the key zones of the Donbas Foldbelt better allow to estimate the amount of inversion and, thus, aid the geological interpretation and velocity/depth model construction.

S61C-1149 0830h POSTER

3-D distribution of S wave reflectors and scatterers in the source region of the 2000 Western Tottori, Japan, earthquake

Kin'ya Nishigami[1] (+81-774-38-4195; nishigam@rcep.dpri.kyoto-u.ac.jp)

Issei Doi[2] (idoi@rcep.dpri.kyoto-u.ac.jp)

Keiichi Tadokoro[3] (tad@seis.nagoya-u.ac.jp)

Akiko Shimokawa[3] (asimo@eps.nagoya-u.ac.jp)

[1]Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

[2]Faculty of Science, Kyoto University, Oiwake-cho, Kitashirakawa, Sakyo-ku, Kyoto 606-8502, Japan

[3]Graduate School of Environmental Studies, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan

The Western Tottori earthquake of Mw 6.6 occurred on October 6, 2000 in southwest Japan. Since clear surface rupture did not appear and also any active faults related to this earthquake were not recognized around the source region, we have to concentrate seismological approaches in order to elucidate the properties of the buried earthquake source fault and further to understand the generating process of this earthquake. Nishigami et al. (2002) observed fault-zone trapped waves near the surface cracks with left-lateral offset appeared around the epicenter, and estimated the fault-zone structure of the earthquake source fault and a neighboring branch-fault. Tadokoro et al. (2002) analyzed the S wave splitting and inferred fault-parallel fractures existing southeast of the mainshock hypocenter. In this study, we estimated a detailed distribution of S wave reflectors in the crust and uppermost mantle below the source region, using the data of a dense seismographic network deployed by a joint-university group immediately after the earthquake. The normal moveout (NMO) correction of S coda part shows a strong reflection from the lower crust, form ~16 to 37 km depths, below the source area of the mainshock. The thickness of this reflective layer seems to change along the strike of the mainshock fault plane, and also the lowermost depth of the reflective zone seems to have an offset just below the mainshock hypocenter. The distribution of reflectors may reflect the crustal heterogeneity related to the occurrence of the Western Tottori earthquake. Deeper reflectors were also found at ~50-60 km depths southeast of the mainshock hypocenter. We are now trying to estimate a 3-D distribution of reflectors around the source area, using seismograms from several hundreds events recorded at 57 stations. Also we will estimate a 3-D distribution of S wave scatterers using the same data set, and we will try to obtain more detailed image of small-scale heterogeneities in the source region of the Western Tottori earthquake.

S61C-1150 0830h POSTER

The Crustal Structure of the NW-Moroccan Continental Margin From Wide-angle and Reflection Seismic Data

Rafael Bartolome[1] (+33 298 49 87 41; rafael.bartolome@sdt.univ-brest.fr); Julie Perrot[1] (+33 298 49 87 24); Frauke Klingelhoefer[2] (+33 298 22 42 21; fklingel@ifremer.fr); Isabelle M. Contrucci[2] (icontruc@ifremer.fr); Marc-Andre Gutscher[1] (+33 298 49 87 27; gutscher@univ-brest.fr); Jacques A. Malod[1] (+33 298 49 87 22; malod@univ-brest.fr); Jean-Pierre Rehault[1] (+33 298 49 87 23; rehault@univ-brest.fr)

[1]UMR 6538 Domaines Oceaniques, IUEM, Univ. Bretagne Occidentale, Place Nicolas Copernic, Plouzane F-29280, France

[2]DRO-GM, Ifremer, B.P. 70 Place Nicolas Copernic, Plouzane F-29280, France

The Atlantic margin of Morocco with its neighboring Jurassic oceanic crust is one of the oldest on earth, yet has been less studied than its conjugate margin in North America. The SISMAR marine seismic survey acquired over 3000 km of MCS data and 1000 km of wide-angle profiles in order to image the deep structure of the margin, characterize the nature of the crust in the transitional domain and define the geometry of the syn-rift basins. We present results from the combined interpretation of the reflection seismic, wide angle seismic and gravity data along a 310 km long profile perpendicular to the margin at $33-34°$ N, extending from nearly normal oceanic crust in the vicinity of Coral Patch Seamount to the coast at El Jadida. 14 ocean bottom seismometers (OBS) and 14 landstations were used to record a total 1957 of shots from a 4850 cu in airgun array (79 l) deployed in single bubble mode, at a shot spacing of 150 m. MCS data were acquired with a 4.5 km long 360 channel streamer, yielding 15 fold trace coverage. The shallow structure is well imaged by the reflection seismic data and shows a thick sedimentary cover which is locally perturbed by salt tectonics and reverse faults. The sedimentary basin thickens from 1.5 km on the normal oceanic crust to a maximum thickness of 6 km at the base of the continental slope. MCS data image basement structures including a few tilted fault blocks and a transition zone to a thin crust. A strong discontinuous reflector at 12 s TWT is interpreted as the Moho discontinuity. Due to the good data quality of the OBS and landstation data, the deep crustal structure (depth and velocity field) is well constrained through the wide-angle seismic modelling. The crust thins from 27 km underneath the continent to about 8 km at the western end of the profile. The transitional region has a width of 150 km. Crustal velocities are lowest at the continental slope probably due to faulting and fracturing of the upper crust. Upper mantle velocities could be well-defined from the OBS and landstation data throughout the model.

S61C-1151 0830h POSTER

Crustal Seismic Anisotropy From Waveform Modeling: Examples from the Tibetan and the Andean Plateaus

George Zandt[1] (520 621-2273; zandt@geo.arizona.edu); Heather Folsom[1] (folsom@geo.arizona.edu); Jason Erickson[1] (jasone@geo.arizona.edu); Mark Leidig[1] (mleidig@geo.arizona.edu); Jerome Guynn[1] (jguynn@geo.arizona.edu); Andrew Frederiksen[2] (frederik@cc.UManitoba.CA)

[1]University of Arizona, Dept. of Geosciences, Tucson, AZ 85721, United States

[2]University of Manitoba, Dept. of Geological Sciences, Winnipeg, MB R3T 2N2, Canada

The evolution of high plateaus often involves crustal thickening with ductile flow and metamorphism in the middle to lower crust. Such processes should leave an imprint in the crust in the form of large-scale structural fabric that can be characterized by analysis of seismic anisotropy. Measurements of crustal anisotropy at a single seismic station can be accomplished by measuring shear-wave splitting or modeling the azimuthal variation of converted phases (e.g., receiver functions). The receiver function approach has the advantage of better sensitivity to multiple layers with different orientations of anisotropy. The waveforms are sensitive to layers with thicknesses of several hundred meters to tens of kilometers. Computationally, both approaches currently require the assumption of hexagonal symmetry anisotropy with a unique fast or slow velocity symmetry axis. Computational advances in waveform modeling now permit the symmetry axis to dip and can also allow for dipping interfaces bounding isotropic and anisotropic layers. The large number of free parameters is a major challenge and requires a combination of geologic constraints and an efficient inversion algorithm. We have used both a neighborhood algorithm and a niching genetic algorithm to find families of solutions that can fit the azimuthal variations on both the radial and transverse receiver functions. We applied this approach to the eleven stations of the 1991-1992 Tibetan PASSCAL experiment and found significant anisotropy throughout the crust at most of the stations. The pattern of the fast directions across the plateau appears to be related to crust-mantle interactions. In the Andean Plateau, we found extremely strong anisotropy in the upper crust above the Altiplano-Puna magma body. The strong anisotropy is restricted to the volcanic complex, and we suggest the anisotropy is related to magma-filled cracks that act as a conduit system between the mid-crustal magma body and the surface.

S61C-1152 0830h POSTER

Seismic Refraction Surveys in Devils Lane and Cyclone Grabens, Canyonlands National Park, Utah

Glenn C. Kroeger[1] (210-999-7607; gkroeger@trinity.edu)

Eric B. Grosfils[2] (egrosfils@pomona.edu)

Richard A. Schultz[3] (schultz@mines.unr.edu)

Barry L. Reno[1] (barry.reno@trinity.edu)

John D. Godchaux[4] (jdgodchaux@hotmail.com)

[1]Department of Geosciences, Trinity University, 715 Stadium Dr., San Antonio, TX 78212, United States

[2]Geology Department, Pomona College, 609 N. College Ave., Claremont, CA 91711, United States

[3]Geomechanics Rock Fracture Group, Department of Geological Sciences 172, Mackay School of Mines University of Nevada, Reno, Reno, NV 89557, United States

[4]School of Public Affairs, Arizona State University, P.O. Box 870603, Tempe, AZ 85287, United States

Bounding fault offsets in the geologically young (60-70 ka) grabens of Canyonlands National Park have been estimated previously by adding measured scarp topography to estimates of sediment fill thickness beneath the graben floor. Published values of sediment fill thickness have ranged from 5-50 m with most estimates less than 20 m and most previous measured thickness in the 3-10 m range.

We have conducted shallow seismic refraction surveys in two grabens, Devils Lane and Cyclone. Geophysical work in this remote area is difficult due to the lack of power or water supplies, the difficulty of vehicle

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transport over one of the most technical 4-wheel drive roads in Utah, and the environmentally sensitive nature of the cryptobiotic soils in the grabens. In Devils Lane graben, 10 24-channels spreads were employed in a 2 km long line along the axis of this 3 km long graben. A 15-station gravity survey was also conducted along the axis of this graben. Three separate seismic lines were used to sample the ends and center of Cyclone graben that is nearly twice as large as Devils Lane. The seismic data were modeled using iterative ray tracing.

Our results from Devils Lane (Grosfils et al., JSG, in press) show a well-defined layer of basin sediment that deepens rapidly from the end of the graben, from depths of 30 m to over 90 m. Typical depths in the center of the graben range from 70-80 m. Under some portions of the line, the sediment thickness is so large that our cable lengths were not long enough to record the bedrock refraction, suggesting sediment thickness of over 100 m. Sediment velocities range from 700-900 m/s with underlying bedrock velocities averaging 3000 m/s. Our results from Cyclone graben are similar, with typical sediment thickness of 70-80 m in the center of the graben and abrupt shallowing at the ends of the graben. Our results indicate significantly thicker sediment fill than assumed in most previous studies and may necessitate revising estimates of both fault offsets and strain rates in these grabens.

S61C-1153 0830h POSTER

Evolution of the Kuban Basin, Northwestern Caucasus Region, Russia, Based on Seismic Reflection Data

C. Joel Luckow[1] (865-544-7311; jluckow@utk.edu)

Richard T. Williams[1] (865-974-6169; rick@utk.edu)

Vladimir A. Babeshko[2]

Ernest Kutsenko[3]

Vladimir Gulenko[3]

[1]University of Tennessee, 306 Geological Sciences Building University of Tennessee, Knoxville, TN 37996, United States

[2]Kuban State University, Applied Mathematics Kuban State University Stavropolskaya str., 149, Krasnodar 350040, Russian Federation

[3]Kuban State University, Geophysics Department Kuban State University Stavropolskaya str., 149, Krasnodar 350040, Russian Federation

The University of Tennessee and Kuban State University, Krasnodar, Russia, have acquired new vibroseis data within the Shebsh oil and gas field in the Kuban Basin, southwest Russia. The purposes of conducting the 11 km long survey were to (1) image a suspected northeast-vergent fault beneath an anticline in the Shebsh field, and (2) determine the style and timing of deformation. The Kuban Basin is one of two foredeeps of the northern Caucasus region, and has been a major source of oil and gas in Russia for the past 50+ years. It has a maximum depth between 10 and 12 km. Sedimentary cover above Hercynian basement begins with Triassic age rocks and continues to Pliocene-Quaternary at the surface. Preliminary stacked sections show approximately 6.5 km depth to Cretaceous strata, an 8 to 10 km wide anticline, and a northeast-vergent thrust fault having 0.1 km of throw. A Russian cross-section of the same structure, based on well data and Soviet-era seismic data, shows a somewhat different interpretation. The older interpretation shows a south-vergent fault not seen in the new data, 0.7 km of throw on the northeast-vergent fault, and the structure is depicted as a fault-bend fold. The current research points to the conclusion that fault-propagation style folding occurred no later than the Upper Miocene in the Kuban Basin, based on the vibroseis images and well data. The implications of this research include a better understanding of timing and style of deformation, and more accurate locations of prospective hydrocarbon reservoirs.

S61C-1154 0830h POSTER

Lateral Variations in Crustal Structure of Northern Victoria Land From Teleseismic Receiver Functions

Nicola Piana Agostinet[1] (390651860357; piana@ingv.it)

Alessandro Amato[1] (amato@ingv.it)

Massimo Di Bona[1] (dibona@ingv.it)

Andrew Frederiksen[2] (frederik@cc.umanitoba.ca)

[1]Istituto Nazionale di Geofisica e Vulcanologia, Via Vigna Murata, 605, Rome 00143, Italy

[2]Department of Geological Sciences, University of Manitoba, 341 Wallace Bldg, Winnipeg, Manitoba R3T 2N2, Canada

We investigate lateral variations in crustal structure of Terra Nova Bay (TNB) area using Receiver Functions (RFs) recorded during four austral summer campaigns (from 1993 to 2000). Seismic stations were deployed around Terra Nova Bay italian base, from the sea to reach the interior of the Transantartic Mountains (TAM), the most striking example of nocontractional mountain belt. RFs was computed from teleseismic waveforms, using frequency-domain deconvolution, following Di Bona's scheme [Di Bona, 1998]. Previous attempts to analyze the data-set, using 1-D models for S-velocity crustal structure, yielded to controversial results, but confirmed the existence of a thinned crust in the area and revealed a deepening of the Moho from the coast to inland [Di Bona et al., 1997]. However, a strong component of converted energy in tangential RFs suggested the presence of dipping and/or anisotropic layers, and stressed the limits of previous technique. To improve our knowledge about Moho geometry in TNB area, we have developed a new RFs inversion scheme. We compute RF components using Frederiksen's method [Frederiksen and Bostock, 2000] for modelling teleseimic wave propagation in anisotropic dipping structures, jointly with a Neighbourhood Algorithm [Sambridge, 1999] which explore the 24-parameters space that characterize our 3-D crustal models. Our main goals are: (1) to test our new RFs inversion methodology; (2) to map Moho-depth and intercrustal S-waves velocity discontinuities in TNB area, with the aim to emphasize dipping and anisotropic layers; (3) to analyze new teleseismic waveforms recorded near TNB base by a seismic station operating in continuous recording, from 1999 to present.

S61C-1155 0830h POSTER

The Southern Andes Between 36 and 40 deg S Latitude: A Tomographic Image of the Lithospheric Structure Inferred From Local Earthquake Data

Mirjam Bohm[1] (+49-331-2881261; mirjam@gfz-potsdam.de)

Guenter Asch[1]

Klaus Bataille[2]

Andreas Rietbrock[3]

[1]GeoForschungsZentrum Potsdam, Telegrafenberg, Postdam 14473, Germany

[2]Universidad de Concepcion, Departamento Ciencias de la Tierra, Concepcion 00000, Chile

[3]Universitaet Potsdam, Postfach 601553, Potsdam 14415, Germany

Subduction of the Nazca plate beneath South America and its associated processes cause high seismic activity along the active continental margin of South America. In order to investigate the seimic activity in the Southern Andes, a temporary seismic network was operated as part of the project ISSA 2000 (Integrated Seismological experiment in the Southern Andes) between 36 and 40 deg S reaching from the Chilean Pacific coast to 68 deg W in Argentina. The network consisted of 62 three-component seismographs recording continuously from November 1999 to April 2000. The earthquake data set comprises 328 local events with more than 8 P-wave and S-wave observations per event and a RMS error less than 0.5 s.

Crustal seismicity concentrates in the forearc region along fault zones. Benioff seismicity is observed down to 150 km depth.

From this data set we selected 150 well locatable events, with a GAP less than 180 deg, to invert for three-dimensional P-wave velocity structure and hypocenter locations. The final data set provides 2283 P-wave and 1322 S-wave observations. Here we will present a tomographic model for P-wave velocity and Vp/Vs ratios. Velocity structures can be resolved down to a depth of 80 km. Resolution is best in the forearc, where ray coverage is densest, whereas in the backarc the resolution is low.

Average P-wave velocities in the continental crust are 6.3 km/s for the upper crust and 6.9 to 7.4 km/s for the lower crust indicating felsic to mafic composition. Mantle velocities near 8.0 km/s are found below 55 km depth, rising to 8.34 km/s at 90 km depth. The downgoing slab is defined by the location of the earthquakes and characterized by fast velocities (8.2 km/s). Low Vp values in the crust beneath the Coastal Cordillera are due to basal accretion of sediments. Increased Vp values beneath the Longitudinal Valley correlate with the relatively fast velocities obtained by the refraction seismic survey of the ISSA project.

S61C-1156 0830h POSTER

Fault Zone Discontinuity of Mozumi-Sukenobu Fault Inferred from the 3D Finite-Difference Simulation of the Fault Zone Waves Excited by Explosive Sources

Yutaka Mamada[1] (+81-298-61-3552; y-mamada@aist.go.jp)

Yasuto Kuwahara[1] (y-kuwahara@aist.go.jp)

Hisao Ito[1] (hisao.itou@aist.go.jp)

Hiroshi Takenaka[2] (takenaka@geo.kyushu-u.ac.jp)

[1]Institute of Geoscience, AIST/ Geological Survey of Japan, GSJ AIST Central 7, Higashi 1-1-1, Tsukuba 305-8567, Japan

[2]Dept. Earth and Planet. Sci. Kyushu Univ., Hakozaki 6-10-1, Fukuoka 812-8581, Japan

Fault zone waves which consist of fault zone head waves propagating along material discontinuity interfaces, direct body waves propagating within a low-velocity fault zone and trapped waves due to seismic energy trapped in a low-velocity fault zone are sensitive to a structure of fault zone. The modeling of these waves is one of the useful procedures to reveal fine structure of fault zone. We use 3D finite difference (FD) method to simulate fault zone waves and to determine the fault zone structure. A linear array consisting of 32 three component seismometers spacing roughly 15 m is across the Mozumi-Sukenobu fault in research tunnel at a depth of 300 m. Seismic records from four explosive sources, two of which were designed to be located in (shot 1) and out (shot 2) of fault zone at about 2 km from an array along fault and the other two in (shot 3) and out (shot 4) at about 4 km, were collected at the array. Fault zone waves were recorded for shots 1, 3 and 4 but were not for shot 2. This suggests that fault zone is not uniformly extended from shot 1 to shot 3 along the fault. We modeled fault zone waves by 3D FD simulation so that the synthetic seismograms for the four shots were fitted to the observed ones and inferred shallow structure of the fault down to a few hundreds meter from the surface. We found that the low-velocity zone is approximately 200 m wide, has 20 % velocity reduction from the surrounding rock for P wave and the low-velocity zone extends from an array to 2km along the surface fault trace from the simulation for shots 1 and 2. However the fault low-velocity zone must disappear or become very narrow at the distance of more than 2 km from the array to explain the observation result that seismograms for shots 3 and 4 include fault zone waves and to explain the arrival time of fault zone trapped waves on seismograms from shots 3 and 4.

S61C-1157 0830h POSTER

Depth Dependent Intrinsic And Scattering Attenuation In The Lithospheric Structure Of The Friuli Region Italy

Francesca Bianco[1] (+39 0816108328; bianco@ov.ingv.it)

Edoardo Del Pezzo[1] (+39 0816108328; delpezzo@ov.ingv.it)

Aybige Akinci[2] (akinci@ingv.it)

Francesca Di Luccio[2] (390651860486; diluccio@ingv.it)

Luca Malagnini[2] (390651860370; malagnini@ingv.it)

[1]Istituto Nazionale di Geofisica e Vulcanologia - Osservatorio Vesuviano, Via Diocleziano 328, Napoli 80124, Italy

[2]Istituto Nazionale di Geofisica e Vulcanologia., Via di Vigna Murata, 605, Roma 00143, Italy

For a selected range of both scattering and intrinsic attenuation parameters we generated the seismic energy envelopes for several non uniform earth models reproducing the main features of the litosphere for the Friuli region (north-eastern Italy). The simulations were compared to the envelopes obtained for a earth model with constant velocity and scattering coefficient. Results were organized in nomograms.

At the same time we obtained the envelopes calculated using the Multiple Lapse Time Window Analysis (MLTWA) applied to short period records of local and regional earthquakes occurred in the same area in the distance range 0 120 km for a uniform model. We used 11 frequency bands centered at respectively 1, 2, 3, 4, 5, 6, 8, 10, 12, 14 and 16 Hz with 1 Hz bandwidth. The three energy windows for the analysis were calculated for a duration of 15 seconds, and coda normalization factor was evaluated at between 60 to 75 seconds from the origin time of each earthquake.

After comparing the energies obtained by the application of MLTWA to the ones resulting from the uniform model, we extract qualitative information on the attenuative depth dependent structure for the investigated area.

S61C-1158 0830h POSTER

Deep Structure of Active Faults Estimated From Underground Observation of Fault-zone Trapped Waves -the Nojima and the Mozumi-Sukenobu Faults, Japan-

Takashi Mizuno[1] (+81-774-38-4188; tmizuno@rcep.dpri.kyoto-u.ac.jp)

Kin'ya Nishigami[1] (nishigam@rcep.dpri.kyoto-u.ac.jp)

[1]Research Center for Earthquake Prediction, Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 6110011, Japan

Analyses of fault-zone trapped waves are one of the effective approaches for imaging deep fault structures. Usually, trapped waves are detected by surface array observations, however, in these observations, seismograms are affected by attenuation and strong scattering near the surface. In this study, we used seismograms with high signal-to-noise ratio recorded by underground observations: one is the 1800-m-deep borehole drilled into the Nojima fault, southwest Japan, and the other is the 300-m-deep survey gallery that penetrated the Mozumi-Sukenobu fault, central Japan.

We analyzed 465 events that occurred along the Nojima and the Rokko fault system from January 1, 1999 to May 14, 2000. To search for the candidates of trapped waves with Love wave type, we analyzed the polarization of the shear wave and following wave trains in each seismogram. We also calculated envelopes of a band-pass filtered (5-19 Hz) seismogram of the fault-parallel component (N30E). Then we obtained fundamental and first-higher-mode dispersion curves of the trapped waves. The shear wave velocity and the width of the low velocity fault-zone were estimated by comparing observed and synthetic dispersion curves and waveforms, which were calculated by the algorithm of Ben-Zion and Aki (1990). We assumed the shear wave velocity of the surrounding rock to be 3.4 km/s in this study. Finally we obtained 6 candidates showing trapped waves. From the location of these events with trapped waves, the Nojima fault seems to dip southeastward at 75 degrees down to 10 km depth. The modeling of the dispersion curves and waveforms shows that the fault-zone width and shear wave velocity range from 150 to 240 m, and 2.6 to 3.0 km/s, respectively. A record section shows that the apparent group velocity of trapped waves increases with hypocentral distance. This shows that the shear wave velocity of deeper part (3.0 km/s) is higher than in the shallower part (2.6 km/s).

We also analyzed 146 events that occurred in and around the Mozumi-Sukenobu and the Atotsugawa fault system from August 11, 1997 to May 5, 2001. We used the same method used for the Nojima fault. We found 7 events having trapped waves. The hypocenter distribution of events showing trapped waves suggests that the eastern end of the Mozumi-Sukenobu fault may be connected to the Atostugawa fault. The shear wave velocity and the width of the fault-zone ranged from 2.8 to 3.0 km/s, and 180 to 260 m, respectively.

Our estimated width and shear wave velocity for the Nojima fault are significantly larger than those of previous studies; 40 m and 1.7 km/s (Li et al., 1998), and 20 m and 1.0 km/s (Nishigami et al., 2001). However, we cannot observe fundamental mode over 15 Hz that is expected from the previous narrow fault-zone model. Also, at the Mozumi-Sukenobu fault, our wide fault-zone model is comparable with the wide distribution of fractured rocks at the survey gallery. Therefore, our wider fault-zone model seems to be more reliable than previous ones.

URL: http://www.rcep.dpri.kyoto-u.ac.jp/˜tmizuno

S61C-1159 0830h POSTER

Observation of P-wave Crustal Anistropy due to Material Tilt of Foliated Crustal Rocks in Moving-Source Seismic Profiling, KTB Borehole, Germany

David Okaya[1] (1-213-740-7452; okaya@usc.edu)

Wolfgang Rabbel[2] (49-431-8803916; wrabbel@geophysik.uni-kiel.de)

[1]David Okaya, Dept. Earth Sciences, Univ. Southern California, Los Angeles, CA 90089-0740, United States

[2]Wolfgang Rabbel, Institut fuer Geowissenschaften, Univ. Kiel, Kiel 24118, Germany

Surface exposures of metamorphic terranes show planar structures such as slaty cleavage, schistosity, and foliation which have developed in response to penetrative flow and are often pervasive for tens to hundreds of kms. In such rocks, preferred orientations of minerals are widely prevalent and the crust is highly anisotropic to seismic waves. The physical processes needed to produce such preferred orientation of minerals are associated with deformation and metamorphism. In these cases, the orientations and amounts of anisotropy may serve as proxies for crustal deformation.

The KTB deep borehole is located in the western margin of the Bohemian massif in southern Germany. This massif has complex and heterogeneous crystalline crust composed of granites and a tectonometamorphic unit containing paragneisses, orthogneisses, and amphibolites. These metamorphic rocks are in steeply dipping layers (60-90 degrees) with a penetrative foliation (50-80 degrees), all with regional uniform NW-SE strike and bulk tilt.

A recent seismic experiment at the KTB borehole is "moving source" seismic profiling. This experiment was designed to look at azimuthal variation in the region immediately surrounding the borehole. The experiment consists of six 7.5-km surface profiles radiating from the borehole oriented approx. 45 azimuthal degrees apart. A seismic vibrator was used along each profile at 150 m spacing. The source energy was recorded at borehole depths of 0, 3.8, 7.8, and 8.5 km. From these MSP data an analysis of average upper crustal P-wave velocity was made using P arrival times and source-borehole geometries. Map contours of average Vp based on surface source position are to first order elliptical in shape with fast axis oriented NW-SE, as would be expected for this regional metamorphic block with vertical foliation. The elliptical contours are not symmetric about the borehole, however. This asymmetry can be explained by the regional steep tilt of the metamorphic textures. We show the MSP seismic data, the quantification of the asymmetric P-wave velocity contours, and Christoffel equations for tilted media to explain the asymmetric contours.

S61C-1160 0830h POSTER

Detection of Deep Seismogenic Zone Properties Using Seismic Reflection Techniques

Amy M Kwiatkowski[1] (607-255-3432; amk44@cornell.edu)

Larry D Brown[1] (ldb7@cornell.edu)

[1]Cornell University, Institute for the Study of Continents Snee Hall, Ithaca, NY 14853, United States

Seismic reflection profiling is capable of imaging subsurface properties of the deep crust and uppermost mantle with greater detail than other remote geophysical methods. Whether reflection techniques can adequately detect and reveal variations in physical characteristics related to seismogenesis along deep rupture zones, however, has yet to be resolved. Designing a seismic reflection survey for real-world conditions that is both affordable and capable of producing a detailed image of the targeted deep subsurface features, though, can be challenging. Low-fold profiling can help alleviate a large portion of the budget strain for costly seismic reflection surveys, but this method can also compromise image quality. We present synthetic seismograms produced using ray-tracings from realistic surface reflection experiments modeled on real-world rupture settings. This study focuses on the feasibility of applying low-fold reflection techniques to detect variations in fault zone physical properties at seismogenic depths. The case studies include detecting 1) overall fault morphology along the Main Himalayan Thrust near Nepal, 2) rupture zone reflectivity related to possible overpressuring of fault zone pore fluids and to physical asperities (bumps) at the down-dip rupture limit of the Nankai Margin beneath Shikoku Island, Japan, and 3) offsets of layers with displacements that can result from a single large earthquake event, such as the offsets produced during the Mw=7.6 1999 Chi-Chi Earthquake of Taiwan. Synthetic seismograms simulating both shot-gathers for common midpoint (CMP) processing and zero-offset sections for ideal response cases were generated. Modeling confirms that the first-order morphology of the Himalayan Thrust in Nepal should be distinguishable using conventional source frequencies and receiver spacings, even for low-fold acquisition geometries. For Shikoku, recognition of velocity variations along the interplate fault zone on the order of 20% at depths around 15-20 km is achieved with reasonable acquisition parameters, even following the addition of random noise similar to that recorded in actual surveys. A bump on the scale of 1000 x 250 m at similar depths should also be imaged. Detection of the asperity, though, is largely influenced by the positional relationship between the asperity and the source-receiver array, as well as the relative size of the asperity. Stratal layer offsets of around 10 m at 12 km depth modeled after the Chi-Chi earthquake appear to be discernable using low-fold profiling, if an appropriate scale of interpretation is employed. Limiting the vertical viewing window to 0.51 seconds and the number of traces viewed to around 150, which represents approximately 15 km in the model, helps to emphasize reflector offset. The study also includes evaluation of the effects of ambient noise, statics, and ray-path distortion caused by subsurface velocity heterogeneity on imaging effectiveness.

S61C-1161 0830h POSTER

Crustal Profiling in Iceland Using Earthquake Source-Arrays

Kristín S. Vogfjörd[1] (354-522-6000; vogfjord@vedur.is); G. Nolet[2]; W. J. Morgan[2]; R. M. Allen[3]; R. Slunga[4]; B. H. Bergsson[1]; P. Erlendsson[4]; G. Foulger[5]; S. Jakobsdóttir[1]; B. Julian[6]; M. Pritchard[5]; S. Ragnarsson[1]; R. Stefánsson[1]

[1]Dept. of Geophysics, Icelandic Meteorological Office, Bustadavegur 9, Reykjavik 150, Iceland

[2]Dept. of Geosciences Princeton University, Guyot Hall, Princeton, NJ 08544, United States

[3]Dept. of Geology and Geophysics, University of Wisconsin, W Dayton St., Madison, WI 53706, United States

[4]Dept. of Geophysics, Uppsala University, Villavagen 16, Uppsala S-75236, Sweden

[5]Dept. of Geological Sciences, University of Durham, South Road, Durham DH1 3LE, United Kingdom

[6]U.S. Geological Survey, Middlefield Road, Menlo Park, CA 94025, United States

Data from microearthquake swarms are used to build seismic record sections at individual stations of the Icelandic SIL network and the temporary HOTSPOT/Passcal network. The earthquakes have been relatively located by cross correlating all the P and S waveforms at each SIL station and inverting the relative time differences. This gives good enough location accuracies to build seismic profiles. The magnitude range of the earthquakes used are Ml=2.0-3.6, making amplitudes large enough to be observed out to distances of 250 km, but also ensuring short and impulse-like source time-functions to facilitate identification of secondary arrivals.

The earthquake swarms are in two separate locations. The June-1998 Hengill swarm is in SW Iceland, at the intersection of the Western Volcanic Zone and the South Iceland Seismic Zone (SISZ). The other swarm, in the Bárdarbunga-Gjálp region in E Iceland, took place in Sept./Oct.-1996 and preceded the Gjálp eruption. From the Hengill swarm, which generated over 300 usable earthquakes, it is possible to construct 6-km-long record sections at stations to the east and west. The westward profile extends 80 km along the Reykjanes Peninsula, wereas the 230-km-long eastward profile runs along the SISZ and crosses the Eastern Volcanic Zone. At stations to the north of Hengill, individual record sections can span up to 11 km and the length of the profile, which runs NNE to the northern coast is 250 km. Record sections from the Bárdarbunga-Gjálp region can be 4-8 km long at each station and profiles built to the north are up to 220 km long.

The apparent velocities of the diving Pg and Sg waves on the record section at each station constrain the P and S velocities at their bottoming depth. At some stations clear secondary arrivals, 2Pg and 2Sg are also observed and indications of reflections from a discontinuity (?Moho) are also observed at distances beyond 120 km. On the profiles constructed thus far, apparent P velocities above 7.6 km/s have not been found. For each profile an average 1-D velocity model is presented, which matches over-all travel times as well as apparent velocities observed at each station.

S

S61C-1162 0830h POSTER

Crustal Structure and Seismicity of Taiwan Region from Three-Dimensional Vp and Vs Tomographic Images

Kwanghee Kim[1] (9016784473; kim@ceri.memphis.edu); Jer-Ming Chiu[1] (9016784839; chiu@ceri.memphis.edu); Jose Pujol[1] (9016784827; pujol@ceri.memphis.edu); Yih-Hsiung Yeh[2] (886-2-27839880; yehyh@earth.sinica.edu.tw); Bor-Shouh Huang[2] (886-2-27839910 x323; hwbs@earth.sinica.edu.tw); Kou-Cheng Chen[2] (886-2-27839910 x324; chenkc@earth.sinica.edu.tw)

[1]The University of Memphis, Center for Earthquake Research and Information, Memphis, TN 38152, United States

[2]Institute of Earth Sciences, Academia Sinica P.O. Box 1-55, Nankang, Taipei 115, Taiwan

Three-dimensional crust and upper mantle P and S wave velocity models have been constructed around Taiwan region using a selected subset of P- and S-arrival time data from a modern instrumental earthquake catalog of more than 30 years available from Central Weather Bureau (CWB) of Taiwan. The revised nonlinear travel time tomography method of Benz et al. (1996) has been applied to 3-D velocity determination using 220094 P- and 37402 S-arrivals from 20415 events. A representative 3-D crust and upper mantle

velocity model has been determined after 12 iterations during which the RMS of arrival time residuals have been reduced from 0.66 s to 0.22 s and from 0.83 s to 0.32 s for the P- and S-waves, respectively. Overall, the Taiwan region is characterized by very significant lateral and vertical variations of Vp and Vs structures as shown by many anomalous high and low velocity regions. A north-northwest dipping high velocity zone can be identified in northeast Taiwan which can be associated with the known subducting Philippine Sea plate. The relocated subduction zone earthquakes are distributed mostly near the top of this high velocity zone. A thin zone of very significant low Vp extending to a depth of 80 km can be clearly identified just above subducting slab which can be interpreted as the corresponding eclogite layer in the region. In contrast to the high velocity anomalies at depth less than 10 km, the deeper portion of the Central Mountain Range (CMR) is characterized by large scale of low velocity anomalies where seismicity is extremely low comparing to the surrounding regions. The western boundary of this large low velocity region beneath the CMR coincides with the eastern terminus of Chi-Chi aftershock sequence. Low velocity and low seismicity beneath CMR can be attributed to high temperature and high geothermal activities at depth. The velocity structure anomalies associated with the Longitudinal Valley and Coastal Range in eastern Taiwan can be traced to a depth around 30 km. Selected earthquakes are relocated simultaneously during the tomographic inversion using the resultant 3-D velocity model which has provided a very significant impact on the epicentral and depth determination. For example, the mainshock of the 1999 Chi-Chi earthquake has been relocated about 2.0 km to the west, 1.3 km to the north and 3.7 km shallower than its location determined by CWB. This suggests that the mainshock occurred at a depth of 4.3 km along the 30^{o} easterward dipping Chelunpu fault rather than near the intersection of the bottom of the Chelunpu fault and the gently eastward dipping detachment fault. The resultant 3-D Vp and Vs velocity models and the spatial distribution of relocated earthquakes provide key information to explore seismogenic structures associated with the oceanic-continental collision and subduction processes in Taiwan region

S61C-1163 0830h POSTER

The Northern Walker Lane Seismic Refraction Experiment

John N. Louie[1] (louie@seismo.unr.edu)

Shane B. Smith[1] (sbsmith@unr.nevada.edu)

Weston Thelen[1] (thelenwes@netscape.net)

James B. Scott[1] (jscott@seismo.unr.edu)

Matthew Clark[1] (mclark@seismo.unr.edu)

[1]Seismological Lab and Dept. of Geological Sciences, University of Nevada 174, Reno, NV 89557

We are developing a three-dimensional reference seismic velocity model for the western Great Basin region of Nevada and eastern California. The northern Walker Lane had not been characterized well by previous work. In May 2002 we collected a new crustal refraction profile from Battle Mountain, Nev. across western Nevada, the Reno area, Lake Tahoe, and the northern Sierra to Auburn, Calif. Mine blasts and earthquakes were recorded by 199 Texan instruments (loaned by the PASSCAL Instrument Center) extending across this more than 450-km-long transect. The seismic sources at the eastern end were mining blasts at Barrick's GoldStrike pit. We recorded additional blasts at the Florida Canyon and other mines between Lovelock and Battle Mountain, Nevada. The GoldStrike mine produced several ripple-fired blasts using 10,000-40,000 kg of ANFO each. First arrivals from the larger blasts are obvious to distances exceeding 250 km in the raw records. A M2.4 earthquake near Bridgeport, Calif. also produced pickable P-wave arrivals across at least half the transect, providing fan-shot data. We recorded only during working hours, and so missed an M4 earthquake that occurred at night. Events of M2 occurred during our recording to the west on the San Andreas fault near Pinnacles, Calif.; M3 events occurred near Portola and Mammoth Lakes, Calif. Arrivals from M5 events in the Mariana and Kuril Islands also appear in the records. Time-picks from these earthquakes may be possible after more work on synthetic-time modeling, data filtering, and display. We plan to record blasts at quarries in the western Sierra in future experiments, for a direct refraction reversal. We will compare our time picks against times generated from regional velocity models, to identify potential crustal and upper-mantle velocity anomalies. Such anomalies may be associated with the Battle Mountain heat-flow high, the northern Walker Lane belt, or the northern Sierran block.

URL: http://www.seismo.unr.edu/geothermal

S61C-1164 0830h POSTER

Techniques for Obtaining Crustal Structure from Inversion of Receiver Functions by Using Additional Data Constraints

Zhijun Du[1] (+44 1223 333463; du@itg.cam.ac.uk)

Gillian R Foulger[2] (g.r.foulger@durham.ac.uk)

[1]Institute of Theoretical Geophysics, Department of Earth Sicences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, United Kingdom

[2]Department of Geological Sciences, University of Durham, South Road, Durham DH1 3LE, United Kingdom

Teleseismic receiver functions contain information on shear velocity interfaces in the Earth, and the relative traveltimes of converted waves that reverberate between those interfaces. However, the interpretation of such data is hindered by velocity-depth trade-off. Independent constraints from other data are thus required. We developed three independent methods for solving this problem in the course of processing data from the Iceland Hotspot Project. These involve combining surface-wave dispersion data, local earthquake P and S waves, and receiver functions to jointly invert for crustal structures. Depending on the heterogeneity of the local structure, a joint simultaneous inversion of receiver functions and surface-wave interstation dispersion curves was developed for backazimuthally varying structures and for cases where there the volume around the stations is relatively homogeneous. In regions where there are significant structural differences between the station localities and their immediate neighbourhood we jointly model surface-wave dispersion curves and the waveforms of local earthquakes and receiver functions. We select, as the final result, the models that satisfy all three data sets best. In regions without a priori information, we first invert surface wave dispersion curves using a global searching GA (genetic algorithm) inversion. We then use the results of the GA as a starting model for the receiver function inversions. A few constraints obtained from GA inversion are introduced into the receiver function inversions. In this way we retain the long-wavelength structural features while using receiver functions to constrain local structural details. This approach helps the inversion by excluding unreasonable competing models, thereby reducing the nonuniquness of the receiver function inversion.

S61D MCC: 134 Saturday 0830h

Young Continent-Continent Collisions I *(joint with T)*

Presiding: **E Sandvol,** University of Missouri**; N Turkelli,** Kandilli Observatory and Earthquake Research Institute, Bogazici University

S61D-01 0830h INVITED

Doug Nelson's Contributions to our Understanding of Young Continent-Continent Collisions

Simon L Klemperer[1] (sklemp@stanford.edu)

Larry D Brown[2]

Alan G Jones[3]

[1]Stanford University, Department of Geophysics, Stanford, CA 94305, United States

[2]Cornell University, Department of Earth and Atmospheric Sciences, Ithaca, NY 14853, United States

[3]Geological Survey of Canada, 615 Booth Street, Ottawa, ON K1A OE9, Canada

K. Douglas Nelson, Department Chair and Jessie Page Heroy Professor of Earth Sciences at Syracuse University, died suddenly of heart failure on August 17th, 2002, age 49. At the time of his death he was at the heights of an increasingly distinguished career, and had, just prior to his death, agreed to be an invited speaker in this session of the 2002 Fall AGU meeting.

Doug began his professional career as a field structural geologist, writing his PhD on the Newfoundland Appalachians, and as a post-doc in South Island, New Zealand. From there he went to Cornell University to join COCORP; he learned to interpret deep seismic reflection data and became hooked on the value of geophysics to the study of large-scale processes in mountain belts. He became one of the proponents of taking the COCORP methodology overseas, to the world's type example of young, continent-continent collisions, the Himalaya.

For 10 years from 1992, by now a faculty member at Syracuse, Doug provided operational and intellectual leadership to the INDEPTH program (International Deep Profiling of Tibet and the Himalaya). His talk in this session would undoubtedly have focused on our new understanding of Tibet that resulted in large part from the work that he led and supervised. From the initial conception of INDEPTH as a single reflection profile across Earth's highest mountain range and largest plateau, the program grew through three major stages to encompass a full range of geophysical and geological surveys in a transect that now reaches from the High Himalaya across Tibet. Doug more than anyone was the enthusiastic integrator in the large multinational group of investigators (from the U.S., China, Canada and Germany), not bound by a single technique, and best able to synthesize the seemingly disparate observations from all the techniques. In recent years he was particularly interested in the combination of magneto-telluric with seismic results to better constrain interpretation of deep geology. Although Doug cannot now write the synthesis of the INDEPTH-3 results from central Tibet, nor lead the final INDEPTH-4 campaign across the northern margin of Tibet that he was already planning, our picture of Tibet, and hence of all continent-continent collisions, has changed and grown far richer as a result of his efforts.

Among other things, INDEPTH has traced the top of the Indian plate descending beneath the Himalaya, located the likely limit of penetration of Indian mantle beneath central Tibet, and amassed considerable evidence for widespread melt within the Tibetan crust. The first observation, identification of the suture in an active collision, was a natural outgrowth of Doug's earlier contributions to the geometry of the Applachians and Ouachitas. The second observation directly relates to Doug's interest in the evolution of the deep crust/uppermost mantle in old orogens through delamination. The last observation, that melt is widespread in Tibet, was perhaps the most surprising result of the INDEPTH surveys, and the one that Doug used to greatest effect in his synthesis of deformation and crustal evolution around the Tertiary Indus-Tsangpo suture. Doug's articulate and enthusiastic arguments on the inferred role of low viscosity of the middle crust of the Tibetan plateau have been widely echoed in the latest generation of models by many authors that appeal to the flow of crustal material outwards from the central plateau to its southern and eastern margins. This emphasis on crustal mobility in young continent-continent collisions is already influencing our interpretations of ancient orogens.

S61D-02 0850h INVITED

Crust and Upper Mantle Structure of the Northern Portion of the Arabia-Eurasia Collisional Belt

Eric Sandvol[1] ((573) 884-9616; sandvole@missouri.edu); Niyazi Turkelli[2] (turkelli@boun.edu.tr); Ekrem Zor[2] (zor@boun.edu.tr); Rengin Gok[2] (gok@boun.edu.tr); Tolga Bekler[2] (bekler@boun.edu.tr); Hayrullah Karabulut[2] (kara@boun.edu.tr); Kuleli Sadi[2] (kuleli@boun.edu.tr); Cemil Gurbuz[2] (gurbuz@boun.edu.tr); Ali Al-Lazki[3] (lazki@geology.cornell.edu); Dogan Seber[3] (seber@geology.cornell.edu); Forsyth Donald[4] (Donald_Forsyth@brown.edu); Barazangi Muawia[3] (barazangi@Geology.Cornell.Edu)

[1]University of Missouri, Columbia, Department of Geological Sciences, Columbia, MO 65201, United States

[2]Bogazici University, Kandilli Observatory and Earthquake Research Institute, Istanbul 81220, Turkey

[3]Cornell University, Institute for the Study of the Continents, Ithaca, NY 14853, United States

[4]Brown University, Geological Sciences, Providence, RI 02912, United States

The Eastern Turkey Seismic Experiment (ETSE) was designed to image the crustal and upper mantle velocity structure beneath the northernmost Arabian plate and beneath the Anatolian Plateau, constraining geodynamic models for young continent-continent collision. ETSE was composed of a 29 station broadband PASSCAL array which was deployed from October 1999 until August 2001. A receiver function profile along the western transect of the ETSE array indicates that there is no significant crustal thickening across the East Anatolian Fault Zone (EAFZ). This implies that the northward convergence of the Arabian plate is being largely accommodated by the westward extrusion of the Anatolian plate. The profile does suggest, however, the presence of a crustal root near the northern part of the Anatolian plateau and across the North Anatolian Fault. Results from Sn attenuation tomography and Pn travel time tomography imply a fundamental change in the properties of the uppermost mantle in the vicinity of the Bitlis suture and EAFZ: our observations of very low Pn velocities and very high Sn attenuation beneath the easternmost Anatolian Plateau are