intermediate spin state at 100 GPa, the observed spin-pairing transition would have significant influences on the physical properties and chemical differentiation of the deep interior of the Earth.

S21E-0377 0830h POSTER

New Experimental Evidence of "Low" Melting Temperatures of Iron

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There is still large disagreement in the properties of iron at core pressures derived from diamond cell experiments, shock compression, and theory. Theoretical estimates of the melting temperatures of iron show considerable disagreement and shock data are in disagreement with regards to the onset of melting and the question of a solid-solid transition near 200 GPa. There is, however, growing agreement on the melting temperatures among diamond cell groups using a variety of different methods to detect melting. In view of recent claims (1) that a possible hcp-bcc transition in iron could have been misinterpreted as melting, we present new evidence of melting at Megabar pressures. Visual observation of motion of molten iron is combined with the microscopic analysis of surface textures. The observed features cannot be explained by solid-solid transitions, clearly demonstrating that indeed melting temperatures were reported in the earlier diamond cell work. New high pressure X-ray measurements on laser-heated iron demonstrate a complex phase behavior which is most likely due to the small differences in the free energies of the various high pressure phases. 1) Belonoshko et al. (2003) Nature 424, 1032.

S21E-0378 0830h POSTER

An Andersonian Theory of Earth's Outer Core

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Conventional wisdom holds that the geodynamo operating in Earth's core is in a state of vigorous turbulent convective motion. This talk presents an alternative model in which the motions are vigorous but not turbulent. Turbulence in the outer core is inhibited by three independent effects. First, the Coriolis force inhibits motions which are not invariant in the direction of the rotation axis. Second, the Lorentz force quickly dampens motions which are not invariant in the direction of the magnetic field. Third, the conduction of heat down the (nearly) adiabatic temperature gradient causes material to cool as it descends, thereby becoming stably stratified. It follows that motions in the outer core must be directly driven, either by buoyant material rising from the inner core boundary (ICB) or dense material descending from the core-mantle boundary (CMB). It will be shown that the ICB is more a more likely source of motions than the CMB. Vigorous convection driven by sources of buoyancy at a boundary invariably consists of narrow rapid motions away and broad slow motions toward the boundary. It is plausible that buoyant fluid leaves the ICB, either in the form of continuous plumes or discrete parcels, at preferred locations and rises through an otherwise quiescent outer core. The possible forms of these plumes and parcels will be surveyed, and their ability to sustain the geodynamo will be investigated.

S21E-0379 0830h POSTER

Anomalous top layer in the inner core beneath the eastern hemisphere

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Recent studies reported hemispheric variations in seismic velocity and attenuation in the top of the inner core. It, however, remains unclear how the inner core hemisphericity extends deep in the inner core. Here, we analyze PKPbc-PKIKP and PKiKP-PKIKP waveforms collected from the Global Seismographic Network (GSN), regional recordings from the German Regional Seismic Network (GRSN) and Graefenberg (GRF) sampling along the equatorial path (the ray path whose ray angle is larger than 35° from the Earth's rotation axis). The observed global and regional PKPbc-PKIKP differential traveltimes and PKIKP/PKPbc amplitude ratios suggest a simple W2 model (Wen/Niu:2002) in the western hemisphere with a constant velocity gradient of 0.049(km/sec)/100km and a Q value of 600 in the top 400 km of the inner core. In the eastern hemisphere, the data require a change of velocity gradient and Q value at about 235 km below the inner core boundary (ICB). Based on forward modeling, we construct radial velocity and attenuation models in the eastern hemisphere which can explain both the PKiKP-PKIKP and PKPbc-PKIKP observations. The inner core in the eastern hemisphere has a flat velocity gradient extending to about 235 km below the ICB. We test two solutions for the velocity models in the deeper portion of the inner core, with one having a first-order discontinuity at 235 km below the ICB with a velocity jump of 0.07(km/sec) followed by the PREM gradient, and the other having a gradual velocity transition with 0.1(km/sec)/100km gradient extended from 235 km to 375 km below the ICB followed by the PREM gradient. The observed traveltimes exclude the sharp discontinuity velocity model, as it predicts a kink in differential traveltimes at distance of 151°-152° which is not observed in the global and regional datasets. The observed PKIKP/PKPbc amplitude ratios can be best explained by a step function of attenuation with a Q value of 250 at the top 300 km and a Q value of 600 at 300-400 km below the ICB. The top portion of the inner core in the eastern hemisphere is anomalous compared to the rest of the inner core, in having a flat velocity gradient, higher velocities and higher attenuation.

S21E-0380 0830h POSTER

Regional Variations in the Earth's upper inner core

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Strong regional variations in seismic velocity and attenuation have been observed in the uppermost layer of the inner core. Different studies suggest hemispherical differences within this transitional layer, with eastern hemisphere faster than the western (e.g. Garcia, 2002; Wen and Niu, 2002). The scale and the depth dependence of the heterogeneities are still in debate. In order to systematically study smaller scale heterogeneities we selected a data set of PKIKP and PKiKP phases with epicentral distances between 120° and 140°. The upper layer of the inner core was divided into bins' and the seismograms were gathered into these bins according to the ray turning points. After correcting for source, site and propagation effects we stacked traces with close epicentral distance within each bin to improve signal-to-noise ratio. Finally we performed full 3D modeling of the obtained waveforms.

S21F MCC: Level 1 Tuesday 0830h

Crustal Structure From Reflection/Refraction Seismology Posters

Presiding: **B P Luyendyk,** Institute for Crustal Studies**; L Liu,** University of Connecticut

S21F-0381 0830h POSTER

Three-dimensional seismic modeling of crustal structure in the West-Pannonian basin (Trans-Danubia) based on CELEBRATION 2000 data

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The Trans-Danubian part of the survey was designed to obtain not only in-line recordings along five profiles, but also fan recordings of the off-line shots. The station spacing was changing between 1,5 and 5 km, the average charge of the seismic shots were 500 kg TNT. The use of 409 single channel (Texan, PRS) recorders and 20 seismic sources provided a sufficient 3D ray coverage over an 250km * 240km area, and allowed for construction of a 3D model of the crustal structure. The seismic sections show clear first arrivals up to a distance of 180-200 km. For tomographic modeling 5700 picks of first arrivals were used. The P-wave velocity model was defined at equidistant nodes of the 3D rectangular grid. The distance between nodes was 0.5 km. The initial model used was established by apriori velocity data of the pre-Tertiary sediments. For the tomographic inversion of the areal data we used FAST package developed by C. Zelt (1998). The results of the 3D modeling of the CELEBRATION data were supplemented by inversion of previous seismic and other geological- geophysical data, which may enhance our understanding of the deep structure and evolution of the Trans-Danubian region.

S21F-0382 0830h POSTER

Seismogenic Layer and Seismic Reflectors in the Crust With Reference to Large Earthquakes

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Most of large crustal earthquakes break out at the base of the seismogenic layer. Therefore, the heterogeneous structures, such as seismic velocity difference and/or seismic reflectors near the cutoff depth of seismicity are important to reveal the process of the large inland earthquakes. Seismic surveys in the source region of the 2000 Western Tottori earthquake of M7.2 (JMA-scale) in southwest Japan, show reflectors near the base of the seismogenic layer (Nishida et al., 2002) . Besides, high velocity patches are found nearly the same region of the aftershock area by using seismic tomography from data of a dense network observation of aftershocks just after the main shock (Shibutani et al., 2002).We analyzed seismic refraction and wide angle reflection data in southwest Japan to examine the lateral extension of the reflectors with relation to the cutoff depth of seismicity. As a result, we found reflectors at about 4-5s, 7-8s and 10-12s in two-way travel times along four measure lines. One of them passes the aftershock are of the 1995 Kobe earthquake. The 4-5s reflectors correspond roughly to the cutoff depth of seismicity at about 12-15km deep. The amplitudes of the reflected waves vary from place to place, though the reflectors exist in all areas in inland area of southwest Japan, where local seismicity of small earthquakes are relatively high. The 7-8s reflector is located in the middle crust and the 10s reflector at around the Moho discontinuity. In general, the middle to lower crust is reflective and the above described reflections are distinct. In addition, the cutoff depth changes its depth near the hypocenter of the main shock for the 2000 Western Tottori earthquake, 1995 Southern Hyogo prefecture earthquake and some other large inland earthquakes. Thus the seismogenic layer, in particular, the base of it plays an important role of the nucleation process of the large events. An fluid or gas seal-and-break effect may occur at the reflectors.

S21F-0383 0830h POSTER

Crustal Structure Derived From Refractions and Wide-Angle Reflections in The Mizuho Plateau, East Antarctica

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In 1999-2000, the 41st Japanese Antarctic Research Expedition (JARE41) conducted high density seismic experiments from the coast and inland on the Mizuho Plateau, East Antarctica, along a 180km line with station spacings of 1km. In the record sections, we can pick direct waves through the ice sheets along with refracted and reflected waves from the crust and the Moho boundaries. Previously in 1980-1981, JARE21 and JARE22 conducted large seismic explosion experiments that extended along a 300km line in the same area, although the station spacing is larger, about 10km. Some of the recorded data show especially clear waves refracted and reflected from the crust and the Moho boundaries, and the coverage of first arrivals extends from about 50 to 300km. These travel time data provide good information for investigating the deep structure in the crust. Therefore, we tried to determine a more detailed P-wave velocity model from analysis of the combined data of these two experiments using the ray tracing technique of Zelt (1992, 1994). From the results of the analyses, we conclude that the

ice sheet has a 60-100m thin surface layer with a P-wave velocity of 2.6-3.0km/s underlain by an ice sheet layer with a P-wave velocity of 3.8km/s. This velocity change in the ice sheet is consistent with that of the ice density obtained from the core drilled at the end of the observation line. The uppermost layer of the crust has a P-wave velocity of 6.2km/s, and is likely to be the old mafic rocks of the Precambrian shield located just below the ice sheet, which are seen at nearby outcrops. An abrupt valley-shaped change of the first layer is found in the middle of the observation line of JARE41. This is consistent with the variation in gravity anomalies and shows the change in the topography of the basement rock. Furthermore, a P-wave velocity of about 6.1km/s at the bottom of this valley structure, fit the observed travel times better than a velocity of 6.2 km/s, suggesting that there are moraines or weathered rocks in the valley. The crust consists of two additional layers; the second layer has a P-wave velocity of about 6.4-6.5km/s and the third layer has a velocity of about 6.6-6.9km/s. Clear reflections are observed from the upper boundary of the 6.4km/s layer. There are other reflected waves that do not seem to correspond to the above mentioned boundaries. The Moho reflections are also well observed and the Moho depth is about 40km with a gentle dip towards the inland direction.

S21F-0384 0830h POSTER

Crustal structure associated with the Atotsugawa fault system in Central Honshu, Japan

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Well-located earthquake hypocenters along the Atotsugawa fault system have been obtained as a result of recent seismic observations by a dense network. The fault system is one of the well-known active faults in Japan and the only one that has a creeping section. Seismicity is clearly high along the three faults of the fault system. A large earthquake (M7.0) occurred on the fault system in 1858. The cutoff depth of seismicity is relatively deep on the middle part of the fault and shallows towards both ends, where there are active volcanoes. In order to study the relationship between the distribution of earthquakes and the heterogeneous structure, we conducted seismic explosion surveys along the fault and in the surrounding areas.
Four explosions were shot in the northeast part of the Atotsugawa fault to study its structure in 2000. We recorded seismic arrivals from these explosions along the Mozumi-Sukenobe fault and the Atotsugawa fault. In 2001, a large-scale seismic explosion survey was carried out from the Tokai district to the Noto Peninsula, crossing the Atotsugawa fault system. We used these data to analyze the crustal structure with relation to the seismicity. From simple analyses, we obtained the thickness of the surface layer, which is estimated to be about 1 km along the fault profile, and 3 to 8 km along the profile crossing the fault. Normal move-out (NMO) corrections with static corrections using the surface layer structure, are applied to the waves to obtain a rough image of reflectors in the crust. Crustal velocity structures are derived by a ray tracing method, in which the surface and basement layer structures, mentioned above, are being used as an initial model. Furthermore, we study the spatial extension of these reflectors by use of the NMO corrections on the seismic explosion data recorded by the routine seismic network. Comparing these structures with the earthquake focal depth distributions along and across the Atotsugawa fault, we obtain the following conclusions: 1) Most earthquakes occur only in the layer with a velocity of 6.0-6.2 km/s and events are very scarce in the surface layer. 2) There are two distinct reflectors at the depths of about 12-15 km and 20-23 km. 3) The lower reflector seems to be located at the base of the seismogenic layer, regardless of whether the seismic activity is high or low. 4) The lower reflector is situated in the middle to lower crust, which is usually reflective. 5) The reflectors seem to be distributed not only beneath the fault system but also over the whole central northeast Chubu district, although the strength of the reflectors varies from place to place.

S21F-0385 0830h POSTER

Tectonic Implications of 1999 Chiayi earthquake sequence, Taiwan

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In this study, we adopt damping least-square inversion method to investigate the Vp structures and Vp/Vs ratios of the crust and upper mantle beneath Chia-Nan area, Taiwan. From many studies, the velocity structure can be used as an indicator of the geometry of fault and the general aspect of tectonics. Therefore, the first goal of this research is to analyze the degree of correlation between the velocity structure and the characteristics of seismicity, and its tectonic implications. The second intention is to study the relationship between the Vp/Vs ratio and the pressure change of crack opening in deeper crust. Finally, the distribution of Vp/Vs ratio and its association with fault activities is also investigated. Our results indicate that the variation of velocity structure beneath Chia-Nan area is caused by local geological structures, fault crossing and the existence of Ben-Kong High area in northwest. We also observe that earthquakes occur in the area that has Vp/Vs gradient varying rapidly. And according to distribution of the earthquake source, there may exist a west-dipping fault in the western of Chukou fault, however this argument needs to be investigated more in our future study.

S21F-0386 0830h POSTER

Seismicity and Lithospheric Structure in Southern California

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Southern California is a region undergoing continued deformation. Movement between the North American and Pacific plates manifests itself in high levels of seismicity. In this study we investigate the relationship between deeper structure and the seismicity of southern California. Our investigation is made possible by the release of the SCEC 3.0 Velocity Model, which incorporates the upper mantle. Primary consideration is given to the mantle downwelling centred below the Transverse Ranges. Relationships are sought with the depth, distribution and frequency of earthquakes. A wide variety of data sources are utilized and both existing and specially designed programs are used to manipulate the data, resulting in a synthesis of the regional seismicity and tectonics. Deep seismicity is found to preferentially occur in regions overlying the high-velocity upper mantle "drip". This observation is consistent with depressed isotherms. Large events appear to cluster in crust overlying high-velocity regions, however small events are almost uniformly distributed between the fast and slow regimes. This suggests no measurable variation in crustal strength, however this might be clarified with the removal of aftershock events. There is no evidence for subduction beneath the Transverse Ranges.

S21F-0387 0830h POSTER

Seismic Evidence for a Mantle Source for Mid-Proterozoic Anorthosites and Implications for Models of Crustal Growth

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Voluminous anorthosite intrusions are common in mid-Proterozoic crust. Historically, two end-member models have been proposed for the origin of these anorthosites. In the first model anorthosites derive from fractionation of a mantle source leaving a residue of meta-gabbro in the lower crust; in the second model anorthosites are the product of partial melting of the lower crust with residual pyroxene and high-grade minerals (i.e., a pyroxenitic and/or metapelitic lower crust). Although a general consensus has developed that the first model provides the best fit to petrologic and geochemical constraints, the sparse evidence for mafic and ultramafic counterparts to the anorthosites leave the issue still unresolved. We use the absolute P-wave velocity and the ratio between P- and S-wave velocities (Vp/Vs) to infer the composition of the lower crust beneath the Marcy anorthosite (New York State, USA). Seismic refraction data reveal a lower crust 20 km thick, where Vp and Vp/Vs ranges from top to bottom between 7.0 and 7.2 +/- 0.1 km/s and between 1.84 and 1.81 +/- 0.02, respectively. Laboratory measurements on rock samples indicate that these seismic properties are typical of plagioclase-rich rocks. Magmatic underplating of basaltic melts is a mechanism to form plagioclase-rich bulk composition for the Grenville crust. At the bottom of the lower crust, increase of P-wave velocity, slight decrease of Vp/Vs ratios and the presence of a low reflective seismic Moho are additional observations supporting crust-mantle interactions related to magmatic underplating. High P-wave velocity (8.6 km/s) in the upper mantle may indicate the ultramafic portion (e.g., pyroxenites) of the underplated magma has become eclogite. High average P-wave velocity (6.7 km/s) and VP/VS (1.81) and the exceptional abundance of anorthosites-norites-troctolites among the rocks exposed at the surface, indicate that the Grenville Proterozoic crust may have a unique plagioclase-rich bulk composition. We suggest magmatic underplating, occurring either over a wide time span or with separate syn- and post-collisional magmatic pulses, as being a major crust-forming mechanism operating in the Proterozoic.

S21F-0388 0830h POSTER

Crustal Seismic Velocities of the Baikal, Amur, and Sakhalin Regions, Eastern Russia

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Using combined regional network phase data from eastern Russia, we have developed a preliminary crustal seismic velocity model (Pg and Sg or Lg onset phases) for the Baikal, Chita, Amur, and Sakhalin regions in southeastern Russia. The velocities were calculated using a moving window grid search that determined the best-fit velocity which minimized the RMS sum of the residuals from a number of well located events in each grid square. The results yield fast velocities in the Aldan shield, slightly elevated velocities in the Baikal rift zone, and slow velocities in Sakhalin. The results of our method are supported by independent Russian long- and short-range refraction lines and other travel-time studies. The southern Aldan shield, a Precambrian platform, has Pg velocities of 6.2 to 6.3 km/sec and Sg velocities of 3.5-3.7 km/sec. Pg velocities along the axis of the Baikal rift zone are 6.22 km/sec, slightly greater than the 6.14 km/sec off-axis velocities to the southeast. Russian refraction studies have also indicated this trend. In Buryatia and the Chita region, a deformed Paleozoic to Mesozoic fold and accretionary belt, Pg velocities are about 6.08-6.15 km/sec, decreasing to 6.0 to 6.1 km/sec in Mongolia and northeast China. The Amur district, a complex of old platform and superposed fold belts, has slightly elevated velocities with Pg ranging from 6.0 to 6.2 km/sec. This is in dramatic contrast to Pg velocities along the axis of Sakhalin Island, generally considered a Mesozoic to present fold and accretionary belt, which range between 5.65 and 5.85 km/sec. Sg velocities are similarly reduced, 3.3-3.5 km/sec in Sakhalin as opposed to 3.5 to 3.6 km/sec in Amur. The boundary between these velocity regions appears to be very sharp. These detailed velocities can be used to further improve epicentral locations in eastern Russia and identify active faults and other seismic hazards.

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S21F-0389 0830h POSTER

Modeling Of LARSE II Refraction Data In The Western Mojave Desert, California

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The major goals of the LARSE II (Los Angeles Region Seismic Experiment, Part II) are to image the subsurface in Los Angeles region utilizing reflection and refraction surveys, to understand the detailed structure of the subsurface in relation to earthquakes. LARSE II data acquisition was accomplished in October 1999 along the 150km long main line that extended from Santa Monica Bay to the western Mojave Desert. We modeled LARSE II refraction data in the western Mojave Desert using a forward modeling technique, fitting the first arrivals in most cases less than 0.05 second. In general, layers were modeled to match the breaks in

slope of the first arrival branches. Three layers over basement were modeled. They have velocities or velocity ranges (in km/s) of 1.0 or less (Layer 1), 2.0-3.4 (Layer 2) and 3.3-3.9 (Layer 3). Preliminary interpretations are as follow: Layer 1, up to 0.2km thick, is unsaturated, unconsolidated Quaternary sediments. Layer 2 and 3, which thicken to a total of 1.5km in the central Mojave Desert, are Quaternary and Tertiary sedimentary rocks. An oil-test well in the southern Mojave Desert bottoms at the base of Layer 3 (1.04 km depth) in the Tertiary rocks. An oil-test well in the northern Mojave Desert bottoms in the basement (quartz diorite) at the depth of 1.01km. Upward steps in basements can be seen on the north and south sides of the western Mojave Desert, at or near mapped faults. In summary, maximum depth to basement is 1.7 km in the western Mojave Desert.

S21F-0390 0830h POSTER

New, High Resolution, Three-Dimensional Velocity Models for the New Madrid Seismic Zone

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We are developing high resolution three-dimensional P and S wave velocity models for the New Madrid seismic zone (NMSZ) using arrival times recorded by the 90 station New Madrid seismic network operated by the Center for Earthquake Research and Information. The new velocity models will be much more detailed than prior velocity images produced by inverting arrival times recorded by the 40 station PANDA array and will be the first models produced for the southwest portion of the NMSZ. The new models will use arrival times associated with 1,100 earthquakes recorded from 1995 until mid 2003. This data set comprises roughly 25,000 P and S wave arrivals. Previous three-dimensional velocity models determined using PANDA data imaged high velocity regions interpreted to be mafic intrusions along the axis and edges of the Reelfoot rift. Hypocenters in the depth range 4 to 10 km in the NW trending central arm of seismicity occur along the borders of the mafic intrusions. A region of low shear wave velocity was imaged at the SE end of the central arm of seismicity and was attributed to the presence of highly fractured, fluid saturated crust. This region is characterized by a high earthquake swarm rate and shallower than normal seismicity. The new velocity models will provide increased resolution along the NW trending central arm of seismicity and will help illuminate the relationship between earthquake activity and velocity perturbations. In particular, the apparent association of earthquakes and mafic intrusions will be thoroughly investigated. The station configuration will allow detailed velocity models to be constructed for the SW trending arm of seismicity; these models may provide insight into why seismicity terminates near Marked Tree, Arkansas.

S21F-0391 0830h POSTER

Seismic Structure of the San Fernando and Antelope Valleys, Southern California: Results From LARSE II Refraction, Industry Reflection, and Oil-Test Well Data

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The second phase of the Los Angeles Region Seismic Experiment (LARSE II) recorded refraction and low-fold reflection data from the Santa Monica Mts. to the southern Sierra Nevada, in southern California. The LARSE II corridor crossed two sedimentary basins, underlying the San Fernando and Antelope Valleys, for which we have both industry reflection and oil-test well data to aid in interpretation of geologic structure. In the San Fernando Valley (SFV), refraction modeling of the main line and three cross lines reveal five primary layers. Layer 1 (1.3 km/s), up to 0.1 km thick, represents unsaturated, unconsolidated Quaternary (Q) sediments, and Layer 2 (1.8-2.3 km/s), up to 0.4 km thick, represents saturated, unconsolidated Q sediments and weathered Tertiary (T) sedimentary rocks. Using industry reflection sections and oil-test well data, we observe the following for deeper layers: South of the Northridge Hills fault (NHF), located in the northern SFV, Layer 3 (2.3-3.2 km/s), up to 1.6 km thick, corresponds chiefly to reflective T rocks, including Modelo through Saugus Formations, and Layer 4 (3.6-4.8 km/s), up to 2.2 km thick, corresponds chiefly to non-reflective Topanga Formation and older rocks. North of the NHF, the relationship of velocity layering to stratigraphy becomes more complex, and velocities appear to increase somewhat throughout the stratigraphic section. Layer 5 (5.0-6.0 km/s) is interpreted as basement rocks and may include Mesozoic igneous and metamorphic rocks. The top of layer 5 is deepest (4 km) just north of the surface trace of the NHF. Layers 3-5 thicken markedly northward in the southern SFV, and the boundary between layers 3 and 4 is offset, up to the north, along the north-dipping NHF. In the Antelope Valley (AV), located in the western Mojave Desert, refraction modeling has identified four basic layers. Preliminary interpretations are as follows: Layer 1 (0.1 km/s or less), up to 0.2 km thick, is unsaturated, unconsolidated Q sediments. Layers 2 and 3 (2.0-3.9 km/s), which total 1.5 km in the central AV, are Q and T sedimentary rocks. An oil-test well in the southern AV bottoms at the base of Layer 3, at 1.04-km depth, in T rocks. An oil-test well in the northern AV bottoms in Layer 4 (4.4 km/s and up), at 1.01-km depth, in quartz diorite. Layer 4, thus, is interpreted as basement. The top of basement reaches a maximum depth of 1.7 km in the central AV, and upward steps in the top of this layer can be seen on both the north and south sides of the AV, at or near mapped faults.

S21F-0392 0830h POSTER

Subsurface Structure of the Eastern Santa Clara Valley From Downtown San Jose to the Calaveras Fault

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The Santa Clara Valley, located in the southern San Francisco Bay area, is a topographically low-lying region that is bound on the southwest by the Santa Cruz Mountains and the San Andreas fault system and on the northeast by the Diablo Mountains and the Hayward-Calaveras fault systems. In addition to the major valley-bounding faults, other faults have been mapped in bedrock near the southern end of the Santa Clara Valley, and these faults are believed to trend northward beneath the alluvial fill of the valley. Two large basins, the Evergreen and the Cupertino basins, have been identified on the northeastern and southwestern sides, respectively, of the valley. The basins and the subsurface faults are potential sources of strong shaking from local or regional faults. To better understand the basin, velocity, and fault structures of the Santa Clara Valley, the U.S. Geological Survey acquired an approximately 20-km-long, northeast-southwest-trending, combined reflection and refraction seismic imaging profile across the eastern Santa Clara Valley from downtown San Jose to the Calaveras fault in May 2003. The seismic profile was centered on the Evergreen basin, crossing the Hayward and Silver Creek faults and terminating at the Calaveras fault. Seismic sources were generated by 5-to-50-kg buried explosions in 15-to-20-m-deep holes, spaced approximately 1 km apart. We used approximately 400 "Texan" seismographs, spaced at 50-m intervals along the profile to record the data. P-wave velocities were measured from the near surface to maximum depths of about 5.5 km, with velocities ranging from about 1.8 km/s near the surface to greater than 6.3 km/s at 5 km depth. On the basis of the 4.0 km/s velocity contour (basement rocks), the Evergreen basin is an approximately 6-km-wide, 2.5-km-deep (maximum), well-developed basin, with basement highs to the northeast and southwest. Southwest of the Evergreen Basin, the downtown San Jose area is underlain by a basement high with depths to basement less than about 1 km. Northeast of the Evergreen Basin, velocities indicative of basement rocks approach to within a few hundred meters of the surface in the Diablo Mountains. Between the northeastern end of the Evergreen Basin and the Diablo Mountains, basement rocks are underlain by a northeastward-dipping, vertical low-velocity zone. Seismic imaging data from this study and previously acquired data from the western side of the valley, suggest that the Santa Clara Valley is underlain by a series of faults and a complex basin structure derived from tectonics associated with those faults.

S21F-0393 0830h POSTER

Shallow Geometry and Velocities Along the Rialto-Colton Fault, San Bernardino Basin, California

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The Rialto-Colton fault, part of and located southwest of the San Jacinto fault zone, extends along the southwestern margin of the San Bernardino basin. There, the Rialto-Colton fault is buried beneath Quaternary alluvium. Ground-water studies suggest that the Rialto-Colton fault extends northwestward, structurally bounding the San Bernardino basin and acting as a ground-water barrier. Potential-field studies also show evidence for variations in basement depth along the presumed trace of the fault. To better locate the Rialto-Colton fault and to better assess its potential earthquake hazard, the U.S. Geological Survey acquired five combined, high-resolution seismic reflection and refraction profiles along the expected trace of the fault. Our seismic reflection images show that the Rialto-Colton fault consists of an approximately 1-km-wide zone of small-offset (approximately 20 to 30 m) faults in the upper 1 km depth. No single large-offset fault was imaged along any of the seismic profiles. Reflections extend to depths of at least 800 m along most of the seismic profiles, suggesting that basement is at least 800 m deep. We also used tomographic methods to invert first-arrival refractions for the velocity structure along each of the seismic profiles. P-wave velocities range from about 300 m/s at the surface to about 2500 m/s at depths of about 100 m. Our seismic velocity images show that the ground-water table largely correlates with the 1500 m/s contours, and the velocity images show that the ground-water table is disrupted across the reflection-imaged fault zone at shallow depths. Some of the faults extend to within a few meters of the surface, suggesting that there has been recent activity on the Rialto-Colton fault. Because the densely populated and growing cites of San Bernardino, Rialto, Colton, and Fontana are located along the projected trend of the Rialto-Colton fault, rupture along the fault may present a significant earthquake hazard to the region.

S21F-0394 0830h POSTER

Seismic Images and Subsurface Structure of the San Bernardino Basin Between the San Jacinto and San Andreas Faults, Southern California

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We acquired an approximately 20-km-long, combined seismic reflection and refraction profile across the San Bernardino basin that shows the complexity of this tectonically active area. The seismic profile spanned both the San Jacinto and San Andreas faults and had nominal shot and seismograph spacings of 1 km and 50 m, respectively. The refraction profile shows that the deepest part of the basin is centered about 1 km southwest of the San Jacinto fault, where the basin is about 2.0 km deep and about 5 km wide. For about 2 km to the northeast of the deep basin, depth to basement

decreases along a series of abrupt, apparently faulted steps to about 800 m. For about 6 km farther northeast, the basin depth remains at about 800 m across most of the seismic profile except within about 4 km of the San Andreas fault, where a sub-basin extends to a depth of about 1.2 to 1.6 km. Structure of the San Bernardino basin is largely related to fault activity, as the most active trace of the San Jacinto fault is located over the central part of the deep basin, and the Rialto-Colton fault, part of the San Jacinto fault zone, appears to be the basin-bounding fault on the southwest side. Seismic reflection images suggest that many of the faults within the San Bernardino basin, including the Rialto-Colton fault, form a flower structure; individual faults dip toward and merge with the San Jacinto fault. The flower structure converges at a depth of about 5 km or less. Dipping reflectors within basement rocks at a depth below 3 km suggest layering of the crystalline basement, or that a decollement extends between the San Jacinto and San Andreas faults. Seismic P-wave velocities range from about 1.8 km/s immediately below the surface to about 6.0 km/s within the upper 4 km. The relatively low velocities within the basin and the proximity of numerous fault strands in the highly populated areas above the basin suggest that even moderate earthquakes on any of these faults may result in amplified shaking.

S21F-0395 0830h POSTER

Subsurface Structure of San Leandro From the San Francisco Bay to the Hayward Fault

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The city of San Leandro, California is located in the eastern San Francisco Bay area between the Bay and the East Bay hills (Diablo Mountains). The major known tectonic structures in the immediate San Leandro area are the Hayward fault to the east and the San Leandro basin, a deep sedimentary basin, beneath the western side of the city. To better understand the San Leandro basin, its subsurface fault structures, and the effect of these structures on ground water and earthquake hazards, the U.S. Geological Survey acquired an approximately 10-km-long, high-resolution, combined reflection and refraction seismic imaging profile across the city in June 2002. The seismic profile originated within the waters of the San Francisco Bay and ended at the Hayward fault. Seismic sources were generated by a combination of 400-grain, Betsy-Seisgun blanks in 0.3-m-deep holes and 0.25-to-0.5-kg, buried explosions in 1.5-m-deep holes. The combined spacing of seismic sources was 5 m. The seismic data were recorded on an array of four 60-channel Geometrics Strataview seismographs, with 40-Hz single-element, vertical sensors spaced at 5 m. P-wave velocities range from about 800 m/s at the surface to greater than 2000 m/s at about 100 m depth. Prominent lateral low-velocity areas are evident at several locations along the profile. Reflection images show that the low-velocity areas are largely related to zones of faulting. Near-surface faults are observed on the reflection images, including southwest-dipping faults at the edge of the bay and near-vertical faults within the Hayward fault zone, but the most prominent fault occurs approximately 1 km east of the bay, where it bounds the 1-km-deep San Leandro basin. Because the near-surface faults are observed within a few meters of the surface and because epicenters of small-magnitude earthquakes correlate with these faults, it is likely that they are active and represent potential hazards. The reflection and velocity images show that some of the near-surface faults vertically offset the upper ground-water aquifer, suggesting that lateral flow of ground water in the East Bay region is affected by the faults.

S21F-0396 0830h POSTER

Seismic velocity structure in the Australian-Antarctic Discordance, Segment B4 revealed by airgun-OBS experiment

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The Australian-Antarctic Discordance (AAD) is a part of the Southeast Indian Ridge and has an anomalously depth and chaotic zone. In addition, the AAD has rift valleys in spite of its spreading rate (74 mm/yr). These characteristics are considered to be caused by a low temperature mantle. The AAD is divided into five segments, B1 to B5 from east to west. The area between B3 east and B5 has anomalous seafloor topography. A seismic structure of uppermost mantle and crust beneath the ridge area is essential to consider the tectonic of the AAD. However, no seismic survey has been performed in the B4 segment. From January 31 to February 3, 2002, we carried out seismic survey with airguns, Ocean Bottom Seismometers (OBSs) and multi-channel hydrophone streamer in the B4 segment to obtain the structure of the uppermost mantle and crust by using the R/V Hakuho-maru, the University of Tokyo. Five OBSs were deployed at an interval of 20km on a line perpendicular to the ridge axis. Two airguns with total capacity of 37-liter were used as controlled sources. The airguns were shot every 60 seconds on the main profile which ran over the five OBSs and were shot every 20 seconds on the other six profiles. Apparent velocities of first arrivals in the OBS records vary with offset distances corresponding to complicated geographical features. First the 1-D P-wave velocity structure beneath the OBS on the ridge axis is derived from the data of the line along the ridge axis using the tau-p method and the ray tracing method due to relatively smooth topography beneath the line. The uppermost layer has a P-wave velocity of about 2.0 km/s and is very thin. Below the uppermost layer, P-wave velocity gradually increases with depths from 3.5 km/s to 7.5 km/s. At the depth of about 3.6 km from the sea floor, P-wave velocity reaches 7.8 km/s. This structure was used as an initial data for 2-D modeling. Next, the 2-D velocity structure beneath the main profile was derived using the ray tracing method. The layer with approximately 2.0 km/s exists only near the ridge axis. The thickness of the crust is almost constant below the profile, however the topography high considered to be megamullion has relatively thin crust and the shallow region in the crust has large P-wave velocity.

S21F-0397 0830h POSTER

A 3-D seismic model of the Eastern Alps derived from CELEBRATION 2000 and ALP 2002 data

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CELEBRATION 2000 and ALP 2002 are two large 3-D-refraction campaigns, which target the crustal and upper mantle structure in Central Europe. This study is based on these seismic data sets and concentrates on the area of the Eastern Alps region and the surrounding forelands and basins. The tectonic setting of the investigation area is characterized by a continent-continent-collision of the Adriatic and European plate and subsequently by a lateral extrusion eastwards to the Pannonian basin. As a consequence of these geodynamic processes we have to expect a complex structure of the lithosphere demanding a 3-D interpretation. The model parameters describing the crust by continuous velocity-depth functions and the depths and velocities of refractors (basis of sediments and Moho) are given in a 31x34-horizontal grid with 20 km spacing. The depth nodes of the velocity-depth functions have a spacing of approximately 1 km, starting with smaller intervals near the surface. Signal detection and stacking techniques were applied to the data in order to guarantee a reliable interpretation even in areas of degraded seismic energy transmission. The essential elements of these techniques are the STA/LTA algorithm, the sorting to common cell gathers with the common midpoint (CMP) or the source and receiver locations (SRC&RCV) as sorting keys and the stacking to offset bins. The signal detection and stacking techniques and the related inversion methods will also be presented at this meeting (Brueckl et al., 2003). The offset stacks of CMP-sorted traces enhance significantly Pg-phases at large offsets, thus gaining greater penetration depths. A 3-D velocity depth model covering an area of about 300000 km2.was generated inverting these data by a 1-D tomographic approach at all grid points with sufficient coverage. The penetration depth of the method is 15 - 20 km in the Alps up to 40 km. As a test, the same method was applied to Sg-phases along one line. An S-wave velocity-depth section was created similar in penetration depth to the corresponding P-wave section and showing similar structures. The quality of Pn-arrivals in the Alpine area is generally low. By the generation of CMP-sorted and SRC&RCV-sorted offset stacks and an inversion technique based on the delay time decomposition Pn-velocities and a reliable image of the delay times was generated. The significance of the model is checked by 3-D ray tracing. Brueckl, E., M. Behm and W. Chwatal, (2003). The application of signal detection and stacking techniques to refraction seismic data. Abstract submitted to AGU Meeting, San Francisco, 8-12 December 2003.

S21F-0398 0830h POSTER

Results from a Temporary Seismic Network in Bhutan

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We report preliminary results from a five-station network deployed as a pilot experiment to examine seismicity patterns and lithospheric structure in central and western Bhutan. The seismic stations, comprised of equipment from the PASSCAL instrument pool, were installed in January of 2002 in cooperation with the Geological Survey of Bhutan and removed in March 2003. We are processing 14 months of data, and have detected both local and regional events. We located events and have computed magnitudes of these microearthquakes. Further analysis will allow for lithospheric studies, including velocity model development and receiver function and shear-wave splitting analysis. We attempt to identify the seismogenic structures in the region and to contribute to the understanding of the tectonic evolution of the region. The country of Bhutan lies in a relatively unexplored but geologically significant portion of the eastern Himalayas. Few geologists have entered the country, yet it lies in a strategic position near the south end of the INDEPTH seismic transect in Tibet. One model for ongoing deformation in the Himalayas has been derived from observations on and southward extrapolation of the INDEPTH profile. This model attributes the high mountains to accommodation of the Tibetan plate as it pushes over bends in a crustal ramp. This model essentially calls for brittle behavior of the entire crust under Bhutan. An alternate model derived from geologic studies in Bhutan calls on the southward extrusion within a channel from mid-crustal depths under Tibet to account for the high relief. This model predicts ductile deformation and thus little mid-crustal seismicity. With our results, we hope to gain insight into which deformation model, if either, is appropriate for this region of the Himalayas.

S21F-0399 0830h POSTER

Crustal structure along the DESERT 2000 Transect inferred from 3-D gravity modelling

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A three-dimensional interpretation of the newly compiled Bouguer anomaly map is part of the DESERT 2000 Transect. That is multi-disciplinary and multinational project studying for first time the Dead Sea Transform (DST) fault system (DST) from the Mediterranean Sea to Saudi Arabia across the international border in the NW-SE direction. The negative Bouguer anomalies (with magnitude reached C130 mGal), located into transform valley, are caused by the internal sedimentary basins filled by the light density young sediments (10 km). A high-resolution 3-D model constrained with the seismic results reveals a possible crustal thickness and density distribution beneath the DST valley. The inferred zone of intrusion coincides with the maximum gravity anomaly over the eastern flank of the DST. The intrusion is displaced at different sectors along the NW-SE direction. The zone of the maximum crustal thinning (30 km) is attained in the western sector at the Mediterranean. The southeastern plateau, on the other hand, shows by far the largest crustal thickness in the region (38-42 km). Linked to

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the left lateral movement of 105 km at the boundary between the African and Arabian plate, and constrained with the DESERT 2000 seismic data, a small asymmetric topography of the Moho beneath the DST was modelled. The thickness and density of the crust suggest that a continental crust underlies the DST. The deep basins, the relatively large nature of the intrusion and the asymmetric topography of the Moho lead to the conclusion that a small-scale asthenospheric upwelling(?) might be responsible for the thinning of the crust and subsequent rifting of the Dead Sea graben during the left lateral movement.

S21F-0400 0830h POSTER

Rifting processes in the centre of Siberia revealed by BEST (Baikal Explosion Seismic Transects)

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The Baikal Rift Zone is located in Siberia at the centre of the world's largest continental area. It offers a unique opportunity for studying the processes of intracratonic rifting. The BEST project (Baikal Explosion Seismic Transects) comprises two deep seismic profiles at the southern end of Lake Baikal. The field project was carried out in October 2002 after a pilot project in September 2001. The aim of the project is to determine the crustal and upper mantle seismic velocity structure. The two profiles are: (1) a 360 km long, NS-trending profile across the rift zone from the Mongolian border to Cheremhovo, and (2) a 360 km long EW-trending profile along-strike of the rift zone at the northern shore of the lake into the Tunka depression to the Mongolian border. 180 Texan one-component seismographs were deployed along each profile. The primary seismic sources were 13 explosions in boreholes, each with a 500 to 3000 kg charge. Supplementary sources were airgun shots in the lake (one 100 l airgun on profile 1, one 30 l airgun on profile 2) and the supervibrator located at Babushkin near the cross point between the two profiles at the shore of the lake. We present the preliminary modelling results of the BEST data from tomographic inversion of first arrival times and 2D ray tracing modelling of the seismic velocity structure of the crust and uppermost mantle. The models show: (1) A pronounced sedimentary graben structure to depths of at least 10 km; (2) No significant crustal thinning below the rift zone; (3) Strong seismic reflectivity underneath the rift zone, indicative of pronounced magmatic intrusion into the lower crust, despite the non-volcanic appearance of much of the rift zone; (4) No sign of significant reduction of the seismic Pn wave velocity; and (5) No clear indication of continuation of the cratonic crust underneath the rift zone in disagreement with a recently published model of the rifting process. Instead the model is in agreement with a model in which the rift zone developed in the suture between the Siberian Craton and the Palaeozoic fold belt to the SE of Lake Baikal.

S21F-0401 0830h POSTER

Crustal Structure of the Tibetan Plateau and Surrounding Area

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In the early Cretaceous (140 Ma), after the break up of Pangea, the Indian and Eurasian plates began moving towards one another. Initially the movement was accommodated by subduction of oceanic crust and a series of non-terminal collisions with microplates and arcs. Eventually, at approximately 45 Ma the terminal suture of India and Eurasia began. Since then, the plates have moved a further 2000 -3000 km together. Scientists are still uncertain as to how and where this crust has been accommodated. Geological and geophysical data should enable us to answer this and other questions governing the behavior of the continental crust and deformation processes in operation. In order to answer these questions and investigate the crustal structure of the area, two datasets have been examined. The first is a deep seismic profile running northeast across the northeastern flank of the Tibetan Plateau and into the Ordos Block, part of the Sino-Korean Terrain. The profile is modeled using the reflectivity method. The second dataset compiles existing data points that comprise velocity-depth information for mid-Asia. We found that the crust increases in thickness from 40 km in surrounding areas, to 60 km under Tibet. The upper crust is much thicker than normal (between 40% and 100% thicker). There is no increase in lower crustal thickness, in places there is no crust with 'normal' lower crustal velocities. The Moho is a complex interface, suggestive of an undulating boundary. Thickness changes are more sudden along the southern margin of the plateau.

S21F-0402 0830h POSTER

High-Resolution Geophysical Investigation of Late Quaternary Deformation in the Lower Wabash Valley Fault System, Central United States.

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High-resolution SH-wave seismic profiles in the lower Wabash Valley Fault System (WVFS) have been used to characterize late Quaternary deformation in the vicinity of the Wabash Island Fault in southern Posey County, Indiana. Seismic images suggest Paleozoic extensional faults have been reactivated by compressional neotectonism. The Quaternary structural inversion is evidenced by pronounced positive folding and displacements in the hanging wall of the primary faults, the broadened deformation area in the nearer surface, and the opposing apparent dip angles in the deformation zone's fault strands. The geophysical data indicate deformation to within 9 m of the ground surface. A maximum bedrock displacement of $\sim$20 m (across a 200 m fault zone) and a displacement of $\sim$1 m in the earliest arriving reflector was measured along the 2 km profile. Associated drilling and C14 dating of organics found in the disrupted horizons suggest movement between $\sim$26,000 and 42,000 YBP. Although liquefaction, contemporary seismicity, and geodetic measured strain suggest neotectonism in the WVFS from the Pleistocene to present, these images represent the first physical evidence for primary coseismic neotectonism. The identification of seismogenic source structures (i.e., faults) is an integral part of seismic hazard analysis, and can ultimately aid in hazard mitigation.

S21F-0403 0830h POSTER

Seismic Imaging Evidence for the Extension of the Silver Creek Fault from the Southern Santa Clara Valley into the East Bay

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The San Francisco Bay is bounded by several strike-slip faults of the San Andreas fault system, including the San Andreas fault to the west and the Hayward and Calaveras faults to the east. Other faults in this complex system, however, are less well-mapped. The northwest-southeast trending Silver Creek fault (SCF) has been mapped in the southern Santa Clara Valley and seismically imaged in the northern part of the valley. Two seismic reflection profiles, gravity data, and water-well data, obtained between the Santa Clara Valley and Fremont, suggest that the SCF extends farther northwest of San Jose into the East Bay. To investigate the possible northwestward extension of the SCF into the East Bay, the USGS High Resolution Seismic Imaging Group acquired two high-resolution, combined seismic reflection and refraction profiles in the Fremont area along Coyote Creek at the southernmost San Francisco Bay. Each profile was about 1.5 km long with geophone and shot spacings of 5 m. Seismic sources were generated by a Betsy Seisgun using 8-gauge shotgun blanks in 0.3-m-deep holes. Each shot was recorded for 2 s at a sample rate of 0.5 ms on 180 channels using three Geometrics Strataview RX-60 seismographs. We observe reflections to about 1000 ms. Preliminary analysis of the data indicates shallow velocities range from 1000 to 1600 m/s in the upper 50 m with multiple low- and high-velocity zones. Shot gathers indicate unusual structure in the Coyote Creek Area (in the vicinity of Albrae Slough) along the northward projection of the SCF, suggesting that the structure may be related to the SCF. Farther northward projection of the SCF and the Albrae Slough structure aligns with a fault imaged in the San Leandro area, an INSAR lineament in the Oakland area, and a mapped fault in the Richmond area. If these indicators of faulting are all associated with the SCF, then the SCF can be interpreted to extend the length of the East Bay.

S21F-0404 0830h POSTER

Differential Semblance Velocity Analysis by Wave Equation Migration, Applications to High Resolution HAFB Dataset

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In pre-stack migrated seismic reflection data, common image gathers in angle are flat at correct velocity, and gathers in offset are concentrated at zero offset. Differential semblance measures the deviation from flatness or concentration. The objective function of differential semblance optimization (DSO) responds smoothly to velocity changes. Therefore gradient descent methods are attractive for DSO velocity updates. Because of their kinematic fidelity, wave equation (depth extrapolation) migration methods are a natural means for velocity analysis in complex structure. We demonstrate the computation of the differential semblance gradient formulated through the adjoint of the linearized wave equation migration and its use in constructing velocity updates by optimization. A synthetic example with a low velocity lens has been tested and shows satisfactory velocity reconstruction by differential semblance optimization. We apply this algorithm to the high resolution land surface data collected at Hill Air Force Base. Images and velocity reconstruction are compared with results of waveform type of analysis, and with more conventional data processing results.

URL: http://terra.rice.edu/~pshen

S21F-0405 0830h POSTER

Physical Modeling of Long-offset Seismic Data

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Long-offset seismic data illuminates the subsurface differently than the conventional near-offset data and therefore contains additional information about the earth. To calibrate long-offset seismic acquisition and processing solution, specifically address the issues involved with long-offset imaging, a multi-layer "gradient" physical model, built by aluminum powder and clear resin, was used to examine the feasibility of modeling long offset data. The acquired data was utilized to examine the information contents of long-offset data, gain insights into the occurrence of feature waves.

Different offset range of data was analyzed and migrated using reverse-time pre-stack depth migration algorithms. The results show that long-offset data provides improved illumination of the vertical impedance boundaries.

S21F-0406 0830h POSTER

Shallow Seismic Trapping Structure in the San Jacinto Fault Zone, California

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We analyze a waveform data set generated by 385 events and recorded by linear seismic arrays across the Clark Valley and Coyote Creek faults in the trifurcation area of the San Jacinto fault zone (FZ). The goal is to obtain structural information from a comprehensive analysis of FZ trapped waves in the data. A previous work based on selected waveforms suggested a low-velocity waveguide continuous to a depth of at least 18 km (Li and Vernon, JGR, 2001). If so, events located clearly outside the FZ proper should not generate any FZ trapped waves. On the other hand, a shallow FZ waveguide can produce (Fohrmann et al., PAGEOPH, 2003) trapped waves for events clearly off the fault. Our analysis of trapped waves in the larger considered data set is compatible with the existence of shallow non continuous waveguide layers along both the Clark Valley and Coyote Creek faults. Ben-Zion et al. (GJI, 2003) found in the context of the North Anatolian fault that many events off the fault produce FZ trapped waves and suggested that a better term for such data may be FZ related site effects. Within a distance of roughly 90 km, a subset of 159 events including many off the fault are suitably recorded by the arrays for analysis. A spectral ratio method is used to calculate the concentration of seismic energy within the FZ stations, producing a systematic measure of the quality of trapped waves or FZ related site effects. We find that FZ site effects are observed at FZ stations for the majority of the earthquakes, with the generating events located at various distances from the fault trace and various angles and distances from the receivers. The distribution of the events implies that the trapping structures are not continuous along the strike of either fault branch and do not extend bellow the depth of the shallowest events (e.g., 5 km). A travel time analysis of the difference between the direct S and trapped wave group arrivals shows no systematic increase with hypocentral distance or event depth, compatible with shallow discontinuous waveguide structures. Synthetic waveform fits to the data generated using the 2D analytical solution of Ben-Zion & Aki (BSSA, 1990) indicate propagation distances within the low velocity FZ layer of around 5km, supporting the other analyses. We obtain good fits to the data produced for the Coyote Creek fault using a model consisting of a single low velocity layer in a half space. However, on the Clark Valley fault the waveguide appears to be weaker and the synthetic waveform fits are not as good. A feature of all the waveform modeling for both the arrays is that the waveguide center is located to the NE of the surface trace.

S21G MCC: 3011 Tuesday 1020h

Coda the Destroyer: Rupture Kinematics and Dynamics I *(joint with T)*

Presiding: **D Lavallee,** Institute for Crustal Studies**; A M Rubin,** Princeton University

S21G-01 1020h

Dynamic Heterogeneities Versus Fixed Heterogeneities in Earthquake Models

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A debate has raged over whether fixed material and geometrical heterogeneities or alternatively dynamic stress heterogeneities arising through frictional instabilities dominate earthquake complexity. It may also be that both types of heterogeneities interact and are important. This work makes a first step in examining this interaction, combining two previously separate lines of research. One line examined friction which have attractors (the subset of phase space the system evolves towards in the long run) on homogeneous faults which are simple, and then added fixed heterogeneities to the faults to obtain complex attractors. Another line examined frictions which produced complex attractors on homogeneous faults. Here, we examine frictions which produce complex attractors on homogeneous faults, and study them on heterogeneous faults, in order to study the interaction of dynamic stress heterogeneities and fixed fault heterogeneities. We consider two types of fixed heterogeneities: an additive noise and a multiplicative noise to the frictional strength of the fault. Because of the linearity of the bulk elastodynamics, the attractor is unaffected by additive fixed noise in the strength of the fault: adding an arbitrary function of space, fixed in time, to the friction leaves the resulting attractor unchanged. In contrast, multiplicative fixed noise multiplying the friction can have a profound effect on the resulting attractor. In the small multiplicative noise amplitude limit, the frictional weakening attractor is little perturbed; at finite amplitudes, fixed heterogeneities substantially alter the attractor. We see, as one consequence, a shift toward longer length events at larger amplitudes. Fixed heterogeneities are seen to reduce the irregularities created by the frictional instability we study, but by no means destroy them. We quantify this by examining a measure of variability of importance to hazard, the coefficient of variation of large event recurrence times. The coefficient of variation is seen to remain substantial even for large fixed heterogeneities. For friction which weakens with time, so the underlying uniform fault attractor is simple, fixed heterogeneities increase irregularity. For all frictions examined, at low fixed heterogeneity the stress concentrations left over by the ends of the large events dominate where most of the small events occur, while at higher heterogeneity the stress irregularities left over by fixed fault heterogeneities begin to dominate where the small events occur. This may be the strongest signature of fixed heterogeneities, and should be examined further in the Earth. Finally, in what may have important implications for more sophisticated estimates of earthquake hazard, we see a correlation of locations with lower strength drop having higher variation in large event repeat times.

S21G-02 1035h

Dynamic Rupture Processes on Fault Models under Stress Fields Estimated from Active Fault Information: The 1995 Kobe, Japan, Earthquake

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We tested our 3-D finite-difference dynamic rupture model by comparing the rupture process of the 1995 Kobe earthquake estimated from waveform inversions. In our model, the stress fields are estimated from geomorphological and geological studies of active faults. Surface rupture of the Kobe earthquake appeared only on the fault southwest of the rupture initiation (Hokudan segment). The waveform inversion results indicate that large moment releases occurred in the entire Hokudan segment and deep part of the Rokko-san segment, northeast of the epicenter. We tested many fault models, by varying the location of discontinuity, because the geometry of the segment boundary is located beneath Akashi strait and not well known. In our 3-D finite-difference model, we modeled the variation of fault strike and dip angles by introducing heterogeneity of the initial stress field. We assumed hydrostatic condition, and also assumed several patterns of stress drop distribution along the fault dip (in the depth direction). We used observed surface slip, both horizontal and vertical, as the constraints of model. When the two segments are discontinuous and stress drop is zero in the top 8 km of the Rokko-san segment, our dynamic modeling produces rupture area similar to the Kobe earthquake. The rupture propagates smoothly on the Hokudan segment. The rupture on the Rokko-san segment, however, is delayed for 8 seconds, which is inconsistent with the waveform inversion results. In order to rupture the Rokko-san segment first, the two segments must be continuous or the Rokko-san segment must have some discontinuous subfaults. In such cases, however, surface slip is 0.5 m or larger on the Rokko-san segment regardless of the stress drop distribution, hence, the surface ruptures are expected to appear. We need to consider more heterogeneous stress drop distribution to reproduce the observed rupture process.

S21G-03 1050h

Evidence for Self-Similar, Triangular Slip Distributions on Earthquake Faults, and Implications on Fault and Earthquake Mechanics

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The objective of our work is to characterize slip distributions for earthquake faults. We have compiled three types of data available in the literature: 1) Surface measurements of slip performed by geological mapping after earthquakes; 2) "total" earthquake slip distributions deduced from published finite-source rupture models (Mai, 2002); 3) Source time functions of large earthquakes known to have propagated unilaterally. Overall, the data sets include about 100 earthquakes of various magnitudes (5.5-8.1) and kinematics. Both surface and total slip profiles are broadly similar in overall shape (along both strike and dip), being roughly triangular and asymmetric regardless of magnitude and kinematics. This suggests that distribution of slip on an earthquake fault is not random, and that seismic slip distributions are self-similar overall. The observation of triangular, self-similar seismic slip distributions together with roughly constant stress drops during earthquakes, cannot be accounted for by the available mechanical models. Earthquakes with such an asymmetric triangular slip profile initiate close to one fault tip and mainly propagate unilaterally along-strike toward the other end of the fault. Most hypocenters locate at or close to where total slip is higher along-strike, but some initiate at or close to where total slip is minimum (fault taper). However, no earthquake is observed to initiate where total slip is minimum both along-strike and -dip. This demonstrates that earthquakes cannot initiate without any "stress concentrator" or barrier capable of sustaining high stresses and strain. As a matter of fact, earthquakes seem to accumulate less total slip (per length or width) along either strike or dip when their hypocenter is close to the fault taper along strike or dip, respectively. The triangular, self-similar seismic slip distributions resemble those recently found on long-term cumulative normal faults (0.1-60 km-long; 0.01-1 Ma-old) and rift systems (10-1000 km-long; 0.1-10 Ma-old). This further suggests that features created in tens of seconds and in tens of thousands years or millions years may share some common mechanical explanations. We suggest that the observation of triangular, self-similar slip profiles can be mechanically understood if some form of off-fault inelastic deformation is included. We use an elastic (static) modeling to show that large triangular zones of off-fault damage can explain the observed triangular, self-similar slip profiles provided damage is anisotropic and in the form of cracks and/or secondary faults subparallel or slightly oblique to the main fault. This suggests that on-fault processes may be insufficient to explain the dynamics of earthquake ruptures, with wide ranging implications for understanding earthquake processes.

S21G-04 1105h

Effect of a Material Contrast on a Dynamic Rupture: 3-D

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We use numerical simulations of spontaneously propagating ruptures to examine the effect of a material contrast on earthquake dynamics. We specifically study the case of a lateral contrast whereby the fault is the boundary between two different rock-types. This scenario was previously studied in two-dimensions by Harris and Day [BSSA, 1997], and Andrews and Ben-Zion [JGR, 1997], in addition to subsequent 2-D studies, but it has not been known if the two-dimensional results are applicable to the real three-dimensional world. The addition of the third dimension implies a transition from pure mode II (i.e., plane-strain) to mixed-mode crack dynamics, which is more complicated since in mode II the shear and normal stresses are coupled whereas in mode III (i.e., anti-plane strain) they