is consistent with a barrier-clearing model for triggering where local earthquakes are caused by a redistribution of pore pressure on a fault due to the unclogging of local flow paths by the seismically-induced flow. The long-period seismic waves may be more effective at clearing fractures than short-period ones because the longer the period of oscillation, the larger the total volume entrained. The result is that thicker barriers can be removed by long-period waves than short-period ones. The thicker barriers support larger head differences if all else is equal. Therefore, long-period waves may produce larger pressure changes on the fault than short-period ones of the same amplitude. Other potentially frequency-dependent mechanisms, such as rate and state friction, cannot explain the sustained triggering after the end of the seismic waves (Gomberg, JGR, 2001).

S31G-06 1135h

How Stress Transfer Between Volcanic and Seismic Zones can Suppress or Trigger Earthquakes

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In the South Iceland Seismic Zone (SISZ), major destructive earthquakes occur at intervals of 80-100 years, the largest events reaching M7.1. Although the zone is E-W trending, with an overall sinistral movement, most of the earthquakes are associated with NNE and ENE-trending strike-slip faults. Numerical models indicate that when the SISZ is loaded to failure, stresses are transferred to, and concentrate at, its ends: tensile in the northeast and southwest quadrants and compressive in the northwest and southeast quadrants. These model results agree with observations made when the SISZ was loaded to failure in June 2000, resulting in two M6.6 earthquakes. For several years prior to the June 2000 earthquakes, compression, uplift and intense earthquake swarms (some events exceeding M4) occurred in two active stratovolcanoes, located in the quadrants of compressive stresses. Most of this earthquake activity came to an end following the June 2000 earthquakes. Also, in the decades prior to the June 2000 earthquakes, the stratovolcano Hekla, located in one of the quadrants of tensile stresses, has erupted unusually frequently. These stratovolcanoes (with shallow magma chambers) act as "soft inclusions" to which stresses from the SISZ are transferred; they may be used as precursors to large earthquakes in the SISZ. Stress is also transferred from the volcanic zones to the seismic zones. For example, stress transfer from the overpressured 27-km-long feeder dike of the Laki 1783 eruption to the nearby SISZ triggered the 1784 earthquake sequence, the largest one in the SISZ. By contrast, dike injection in 1976 in the North Volcanic Zone during the Krafla Fires resulted in suppression of earthquake activity in the Husavik-Flatey Fault (HFF), an active transform fault partly exposed on land, for nearly two decades. For regional dikes such as these, the magmatic overpressure may reach tens of megapascals; part of this pressure is transferred as compressive stress to the nearby seismic zones, the SISZ and the HFF. The models presented here indicate that stress transfer from a dike injected in a volcanic zone either triggers or suppresses earthquake activity in a nearby seismic zone, depending on the location of the dike in relation to that zone. When the dike is so located that the dike-generated horizontal displacement is opposite to the normal displacement across the adjacent seismic zone, earthquakes are suppressed; when the dike-generated displacement is consistent with the normal displacement across the adjacent seismic zone, earthquakes are triggered.

S31G-07 1150h

Remotely Triggered Earthquakes in Intraplate Regions: Distributed Hazard, Dependent Events

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The central and eastern United States has experienced only 5 historic earthquakes with Mw above 7.0, the 1886 Charleston earthquake and four during the New Madrid sequence of 1811-1812 (three principal mainshocks and the so-called "dawn aftershock" following the first mainshock.) Careful consideration of historic accounts yields compelling evidence for a number of remotely triggered earthquakes in both 1812 and 1886, including several events large enough to be potentially damaging. We propose that one of the (alleged) New Madrid mainshocks, on 23 January 1812, may itself be a remotely triggered earthquake, with a location some 200 km north of the New Madrid Seismic Zone. Our proposed source location is near the location of the 1968 southern Illinois earthquake, which occurred on a blind thrust fault at 20-25 km depth. Intensity data for the 1812 event are consistent with expectations for a similarly deep event. Such triggered events presumably do not represent a wholly new source of hazard but rather a potential source of dependent hazard. That is, the common assumption is that the triggering will cause only a "clock advance," rather than causing earthquakes that would not have otherwise occurred. However, in a low strain-rate region, a given dynamic stress change can potentially represent a much larger clock advance than the same change would cause in a high strain-rate region. Moreover, in regions with low seismicity and a short historic record, overlooked remotely triggered historic earthquakes may be important events. It is thus possible that significant events are currently missing from the historic catalogs. Such events–even if large–can be difficult to identify without instrumental data. The (interplate) 1905 Kangra, India earthquake, further illustrates this point. In this case, early seismic records provide corroboration of an early triggered event whose existence is suggested–but difficult to prove–based on detailed macroseismic data. In the central United States, where even moderate earthquakes are uncommon, our results suggest that the largest known historic earthquakes in three states (Kentucky, Illinois, and Mississippi) may have been remotely triggered earthquakes.

URL: http://pasadena.wr.usgs.gov/office/hough

S31H MCC: 3011 Wednesday 1020h

Upper Mantle and Lithosphere *(joint with V)*

Presiding: **Y Shen,** University of Rhode Island**; D L Schutt,** University of Wyoming

S31H-01 1020h

The Geometry of Recently Digested India: First Results From HIMNT Receiver Functions Spanning the Collision Zone in Nepal and Tibet

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Receiver functions from the first broadband seismic deployment to cover the plains of south Nepal, the Lesser and Greater Himalaya, and southern Tibet, reveal the base of the Indian continental crust to be descending gently from 45 km depth in the plains through a steeper ramp in the transition through the high ranges, to 70-80 km depth underneath the Tibetan Plateau. Our data from a network of 29 stations span 20 months and provide roughly 3000 high signal to noise 3-component teleseismic P-SV seismograms, allowing the construction of 3D images of the Himalayan crustal and mantle structure. Receiver functions at most stations exhibit strong back azimuthal variations, and we calculate common conversion point stacks to correctly locate P to S converters. We see a clear Moho descending from the south to the north. The crustal thickness in Tibet is consistent with results from INDEPTH studies to the east of our deployment area. At the transition from the Nepalese foothills to the high Himalaya, we observe a midcrustal conversion at an average of 20 km depth, which coincides with a zone of shallow earthquakes relocated using our stations (Monsalve et al., this meeting). We observe along-arc variations in the depth of the Moho and of midcrustal structures. It is possible that some of these midcrustal features are associated with regions of partial melt observed in the INDEPTH data. Our new seismic results allow us to constrain previous inferences from gravity and structural studies for a clearer picture of the mechanisms of the Himalayan collision.

S31H-02 1035h

Probing the Southern Indian Shield with *P*-Wave Receiver-Functions

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We demonstrate a rare, successful case of using *P*-wavefield recorded on vertical-component seismograms alone to constrain crustal properties of the southern Indian shield. The data comprise of digital seismograms recorded by the short-period Gauribidanur Array (GBA) situated on Archean crust. The *P*-wavefield contains critical information, such as average speed of the *P*-wave in the crust (V_P), which is obscured in standard receiver-functions based on *P* to *SV* conversions. Moreover, conventional receiver-functions require all three components of seismograms, thus tripling the workload. In contrast to previous reports of *P*-wave receiver functions where the results have been equivocal, primary reflection off the Moho, the *PpPmp* phase, is visible and coherent in unprocessed data across the GBA array where the signal-to-noise ratio is excellent. We use eigen-image decomposition to estimate the source wavelet whose effect (including the instrument response) is then removed from seismic profiles by deconvolution. The resulting profiles show that the coda of *P*-wave is dominated by the *PpPmp* phase, whose uniform timing relative to the direct *P*-phase indicates a sharp, sub-horizontal Moho beneath GBA. Building upon previous reports of crustal thickness (35 ± 2 km) and average speed of the *S*-wave in the crust (V_S, 3.60 km/s), the *P*-wave receiver functions indicate a V_P of 6.4 ± 0.1 km/s in the crust. Low values of V_P, V_S, and the Poisson ratio (0.268 ± 0.011) are consistent with well-constrained results from Hyderabad, bolstering the interpretation that the entire thickness of Archean crust in southern India is felsic to intermediate in composition.

S31H-03 1050h

Surface-Wave Test of the Upper Mantle Low Velocity Zone

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Surface Waves hold the potential to detect the mantle low velocity zone (LVZ). We test the influence of a LVZ in the depth range of 100-180 km on the group and phase velocity dispersion curves of the fundamental and the first few higher modes as well as on the waveforms of both Rayleigh and Love waves. We invert calculated synthetic dispersion curves and real data from the Siberian Kraton area by the non-linear inversion Hedgehog method.

Our reference structure is the average 1D-model obtained from body wave tomography along profile Kraton. S-wave velocity is calculated for typical Vp/Vs ratios and density is estimated from the Nafe-Drake relation. We test several models: the reference model itself and the reference model with velocity reductions of 2% and 5% in the LVZ for different thicknesses of the LVZ. The group and phase velocity dispersion curves of the fundamental and higher modes are calculated for an elastic flat Earth model. Average errors (± 0.06 and ± 0.04 km/s for group and phase velocity, respectively) are superimposed before the inversion. In order to check if the thickness of the LVZ can be resolved, synthetic seismograms are calculated for several depths of the sources, both for Rayleigh and Love waves, for the same source parameters and epicentral distances as for real events with travel paths across Siberia.

The differences between the seismograms are small, even when the source is located in or around the LVZ, which is the only situation where a LVZ can be detected. The LVZ cannot be identified in the ambient

noise from the phase or group velocities of the fundamental mode. However, for the higher modes at short periods, the difference exceeds the observational error for a pronounced LVZ.
We use non-linear inversion to check the set of solutions for the dispersion curves of the different models. As expected, the data is more sensitive to Vs than Vp. The solution space requires a low velocity only when the LVZ is pronounced (> 80 km (40 km) thick for a velocity reduction of 2% (5%)). However, the calculated thickness and velocity contrast are smaller than in the original model.

S31H-04 1105h

The Telltale Moho and Novel Views of the Crust and Upper Mantle in the Gulf of California

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One of the outstanding questions about the Gulf of California remains: what is the composition of the crust; more specifically, is there any continental crust beneath the thick sedimentary layer in the Gulf or is it all new oceanic crust. An answer to this question places bounds on the strength and the mechanical behavior of this actively extending region and may help explain the curious lack of seafloor spreading despite 300 km of upper crustal separation over the last 6 myrs. We use receiver functions (RFs) from teleseismic events recorded by the NARS-Baja array to map crustal thickness in the margins of this newly forming ocean basin and use these results to constrain the amount of continental crust within the Gulf. The RFs show clear P-to-S wave conversions from the Moho beneath the stations. The delay times between the direct P and P-to-S waves indicate thinner crust closer to the Gulf along the entire Baja California peninsula. This approximately W-E shallowing in Moho depths is significant with extremes in crustal thickness of $\sim$ 20 and 40 km. A similar trend on the opposite side of the rift may be established with better spatial data coverage. Similar results have, however, been obtained at the northern end of the peninsula by previous workers, who proposed a mechanism of lower crustal flow associated with rifting in the Gulf Extensional Province for thinning of the crust. We also interpret the Gulf-ward thinning of the crust as related to ductile flow in the lower crust during the early stages of rifting and further suggest that the amount of lower continental crust within the Gulf itself is significant. Besides the conversion from the Moho, a number of interesting lithospheric features above and below the Moho are also prominent in the RFs. These may be an indication of isotropic dipping layers or anisotropic layers. In addition, we observed P-to-S conversions from the 410 and 660 upper mantle discontinuities and were able to map these features over a wide area. In contrast to the 660, which is relatively flat lying and continuous, there is evidence of some topography associated with the 410 discontinuity.

S31H-05 1120h

Teleseismic imaging of upper mantle structures around the Taiwan area

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Teleseismic events that had been clearly recorded across TTSN and CWBSN through the past 7 years (1987-1995) has been identified and compiled. Recorded waveforms of those with epicentral distances 30° 90° away from Taiwan are analyzed by the multi-channel cross correlation algorithm to yield a set of consistent relative differential travel times across the area covered by the seismic networks. After careful quality control, 140 events that yield relative differential travel times within the range of 1.5 seconds across the area are retained. These events compose about 2455 rays going through the upper mantle around the Taiwan region. Tomographic inversion of these travel-time residuals are undertaken by assuming that the heterogeneities of the velocity structure of the target area, within 20.5°-26.5° N, 118°-124°E and with the depth above 400 km, is responsible for causing the relative differential travel times. Preliminary model structures obtained from three different inversion strategies, including the damped least squares, the convolutional quelling regularization and the multiscale parameterization, are cross-analyzed to probe for the possible upper mantle structure. Although the data seems to be noisy and the ray coverage is very likely too sparse, there are still some interesting implications for upper mantle structures underneath the Taiwan area. We will discuss some of these preliminary results as well as proposing for directions of future study.

S31H-06 1135h

Seismic Evidence for Accumulated Oceanic Crust Above the 660-km Discontinuity Beneath Southern Africa

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High-pressure assemblages of subducted oceanic crust are denser than the normal upper mantle but less dense than the uppermost lower mantle. Thus subducted oceanic crust may accumulate at the base of the upper mantle. Direct observational evidence for this hypothesis, however, remains elusive. We present an analysis of a negative-polarity shear wave converted from compressional wave at a seismic discontinuity near 570 - 600 km depth beneath southern Africa. The negative polarity of the converted phase indicates a 2.2 $\pm$ 0.2% S-velocity decrease with depth at the seismic discontinuity. This velocity reduction is associated, however, with a low velocity contrast at the 660-km discontinuity. Accumulated oceanic crust at the base of the upper mantle provides a plausible explanation for the apparent paradox between the negative velocity discontinuity and the low velocity contrast at the 660-km discontinuity. Measurements of the elastic constants supplemented by estimates based on systematics and first principles theoretical predictions suggest that subducted oceanic crust has a shear wave velocity 2% lower than that of pyrolite at 530 - 630 km depth. From 600 km depth to the base of the upper mantle, Ca-perovskite exsolution in former oceanic crust could increase the shear wave velocity by 1-2 percent. This scenario is in general agreement with an anomalously large P-wave velocity gradient over a depth range of 80 km around 660 km depth inferred from the travel times and waveforms of direct P waves beneath southern Africa.

S31H-07 1150h

Variations in Lithospheric Structure Across the Canadian High Arctic Region.

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The CHASME (Canadian High Arctic Seismic Monitoring Experiment) project began in summer 2000 with the deployment of 7 temporary seismograph stations in communities across the Canadian High Arctic and western Greenland, adding to the sparse network of existing permanent stations in the region. Data from two temporary seismograph stations on central Baffin Island and from the POLARIS seismograph network in the Northwest Territories are also used in the study. Using regional and teleseismic surface waves recorded at pairs of seismograph stations across the Canadian High Arctic, a number of Rayleigh wave phase velocity dispersion curves have been obtained for the region, using the 2-station method of Gomberg et al. (1988). The relationship between phase velocity and wave period is broadly consistent with those for continental shields worldwide, though significant variation in the characteristics of the dispersion curves exists across the region. The average shear wave velocity structure along each of the 2-station paths is obtained using the linearised inversion method of Herrmann (2002). We use the velocity models to investigate the variations in the thickness and character of the seismological lithosphere across the region, and compare our findings with those from previous structural studies of northern Canada and mainland Greenland.

S31H-08 1205h

Crustal Structure and Mantle Anisotropy from Florida to Edmonton

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New constraints on crustal thickness and velocity and mantle anisotropy beneath the east-central United States and southern Canada were obtained using data from the Florida to Edmonton Broadband Seismometer Experiment (FLED). This array included 28 broadband IRIS/PASSCAL seismometers that were in the field from May, 2001 to October, 2002, and adjacent permanent stations from the IRIS/GSN, the USNSN and the CNSN. Crustal properties were determined using Ps phases scattered from the Moho and, where possible, crustal reverberations. Waveforms at each station were corrected with an inverse free surface transform, simultaneously deconvolved, migrated to depth in one dimension, and modeled using migrated propagator matrix synthetic seismograms. Crustal thickness varies from 30 km to 50 km along the array. Significant features include zones of thickened crust beneath the southern Appalachian mountains and the late-Proterozoic Mid-Continent Rift in Iowa. The thickness of the southern Appalachian crustal root relative to surface topography is consistent with the root to topography ratio found in the northern Appalachians of Pennsylvania using data from the Missouri to Massachusetts Broadband Seismometer Experiment. However, both are large when compared to root/topography ratios in young orogens. These results are consistent with global trends in orogenic crustal thickness, mountain topography and gravity anomalies that suggest a systematic decrease with age in the buoyancy of crustal roots relative to the mantle. To constrain anisotropy beneath the FLED array, shear-wave splitting was measured in SKS and other teleseismic core phases. At southeastern stations located between the continental margin and the Appalachian Front and at stations within the central U.S. craton, where the lithosphere defined by tomographic studies is significantly thicker, shear-wave splitting fast directions are roughly parallel to North American absolute plate motion, and splitting times range from 0.6 s to 1.4 s. One exception occurs in the Mid-Continent Rift Zone in Iowa where a significantly different (roughly N) fast direction was obtained. Apart from this latter observation, the measurements are consistent with splitting found elsewhere in the craton and southern Appalachians by previous studies. Fast directions over this broad region may in general be explained by lattice-preferred orientation of olivine in the asthenosphere as it flows beneath and around the base of the lithosphere, although contributions from anisotropy due to past deformation in the lithosphere are also possible. In contrast, the N fast direction in the Mid-Continent Rift is not easily modeled by asthenospheric flow alone and is evidence for a local lithospheric fabric possibly associated with extension at roughly 1.1 Ga.

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S32A MCC: Level 2 Wednesday 1330h

Jingle All The Way: Receiver Function Imaging Posters *(joint with MR)*

Presiding: **J Park,** Yale University**; R L Nowack,** Purdue University

S32A-0829 1330h POSTER

Fault Plane Detected Through Receiver Function Analysis

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