S22A-0437 1330h POSTER

Heat flow, thickness, and strength of the lithosphere in the Canadian Shield

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The effective elastic thickness of the lithosphere (T_e) is estimated from the coherence between Bouguer gravity and topography. The spatial resolution is low (on the order of 1,000km) because of the size of the windows needed to determine the spectra. Within the the Canadian Shield, T_e varies significantly (from $<$ 40 to $>$100km) over distances on the order of 1,000km. Elastic thickness variations are observed within each of the provinces in the Shield and exhibit no geographic trend.
More than 300 heat flow values are available for the southern part of the Canadian Shield. The mean surface heat flow is the same for all the provinces in the Shield ($41 \pm 10(\sigma)$mW m^{-2}), but there are marked differences between sub-provinces characterized by different rock composition and mean crustal heat production. The heat flow and effective elastic thickness maps of the Shield appear to be negatively correlated with T_e highest ($>$120km) in the areas where heat flow is lowest ($\approx$ 32mW m^{-2}). From the heat flow and heat production data, we have calculated thermal models and rheological profiles of the crust and lithosphere. The results show that most of the observed variations in T_e in the Canadian Shield can be accounted for by differences in thermal regime.

S22A-0438 1330h POSTER

Mantle heat flow in the Canadian Shield from joint inversion of seismic and heat flow data

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We have used a Monte Carlo inversion of seismic surface wave data to obtain a thermal model of the upper mantle beneath the Canadian Shield in terms of Moho temperature, and mantle heat flow, and the potential temperature of the convecting mantle. The study area (40-60° N, 120-55 °W) includes several Provinces ranging in age from Archean to Paleozoic (the Appalachians). The inversion is constrained by heat flow and surface heat production data wherever they are available. The Monte Carlo inversion gives an ensemble of models that fit the data, providing estimates of uncertainties in model parameters. We also estimate the effect of uncertainties in the interconversion between temperature and seismic velocity. The analysis suggests that the lithosphere is coldest beneath the northernmost part of the study area. Mantle heat flow and lithospheric thickness vary from 11 mW m^{-2} and nearly 400km beneath the PaleoProterozoic Trans Hudson Orogen to the northwest to about 24 mW m^{-2} and less than 150 km beneath the Appalachians to the southeast. Within the Precambrian Shield, variations in shear wave velocity and Moho temperatures appear on a spatial scale of several hundred km. These variations appear not to be correlated with geological provinces tectonic history but they may be related to sub provinces with distinctive petrological characteristics.

S22A-0439 1330h POSTER

Variations in Elastic Thickness in the Canadian Shield

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We have used different spectral methods (Blackman-Tukey, Multitaper, and Maximum Entropy) to determine from the coherence between Bouguer gravity and topography the variations of the effective elastic thickness (T_e) of the lithosphere in the Canadian Shield. These methods differ mostly by their spatial resolution (1,000 to 2,000km) determined by the width of the windows applied to the data sets to obtain the spectral estimates but yield comparable results and the maps of T_e show similar trends. The highest resolution is obtained from the maximum entropy method. The Canadian Shield includes several geological provinces ranging in age from Archean to mid Proterozoic. The effective elastic thickness varies from $<$30km to $>$ 100km over distances comparable to the width of the moving window. There is no clear relationship between elastic thickness and age as high and low values of T_e are found within each of the geological provinces. The map of T_e does not show a clear geographic pattern with high elastic thickness values found near the edge as well as near the center of the continent.

S22A-0440 1330h POSTER

Relating Seismic Velocities, Permeability and Crack Damage in Interpreting the Mechanics of Active Volcanoes.

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Improvements in volcano monitoring techniques have resulted in interpretative models of the physical and chemical changes associated with the renewal of activity of volcanic systems. However, accurate and meaningful interpretation of the relationship between the build-up of tectonic stress and precursory deformation requires a knowledge of the changing physical and mechanical properties of the relevant rocks. We report simultaneous laboratory measurements of seismic velocities and fluid permeability on basalts from Etna (Italy) and Iceland, and tuffs from Campi Flegrei (Italy).
Measurements were made in a servo controlled steady state flow permeameter at effective pressures from 5 to 80MPa, during both increasing and decreasing pressure cycles. Selected samples were thermally stressed at temperatures up to 900°C to induce thermal crack damage Acoustic emission output was recorded throughout each thermal stressing experiment.
At low pressure, the P-wave velocity for the columnar Icelandic basalt was 5.4 km/s, while for the Etnean lava flow basalt it was only 2.5 km/s. On increasing the pressure to 80 MPa, the velocity of Etnean basalt increased by 80%, whereas that of Icelandic basalt increased by less than 10%. Furthermore, the velocity of Icelandic basalt thermally stressed to 900°C fell by about 2.0 km/s, whereas the decrease for Etnean basalt was negligible. A similar pattern was observed in the permeability data. Permeability of Etnean basalt fell from about 750 microD to about 150 microD over the pressure range 5 to 80 MPa, while that for Icelandic basalt varied little from its initial low value of 9nD. Again, thermal stressing significantly increased the permeability of Icelandic basalt, whilst having a negligible effect on the Etnean basalt. These results clearly show that the Etna basalts contain much more crack damage than the Icelandic material. As a consequence, their seismic velocities are much lower than those generally assumed in tomographic studies of Etna (i.e. 5-6 km/s for the basalt layer).
Campi Flegrei tuff is a strongly heterogeneous pyroclastic flow material, which includes cavities, pumice and crystals. It has an initial porosity of around 45%, and a P wave velocities that increases from around 2 km/s to around 3 km/s over the pressure range 5 to 80 MPa. In marked contrast to both basalts, significant velocity hysteresis was observed in the tuff, with only about 50% of the velocity change recovered during depressurization. Significantly, the overwhelmingly bulk of the reduction in both porosity and permeability occurs over the first 15 MPa of applied effective pressure. This observation, together with the hysteresis, strongly suggests that the main mechanism of deformation is inelastic pore collapse. In a similar manner to the Etna basalt, Campi Flegrei tuff exhibited significant decrease in velocity after thermal stressing. However, in this case, the main decrease occurred over the temperature range 300° to 600°C. This suggests that the most likely mechanism is thermal cracking induced by dehydration of the zeolite phases present.
These results clearly demonstrate the importance of understanding the details of specific rock physical properties, and how they change in response to pressure and temperature, in interpreting models derived from the results of field-scale monitoring of active volcanoes.

S22B MCC: Level 1 Tuesday 1330h

The Fate of Seismic Waves: Measurement and Interpretation of Q of the Earth II Posters *(joint with T, DI)*

Presiding: **L Warren,** University of California, San Diego**; D McNamara,** U.S. Geological Survey

S22B-0441 1330h POSTER

The Reference Frequency of Teleseismic Body Waves

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Anelasticity of the Earth causes physical dispersion of seismic waves. Our question is addressed to how to choose the reference frequency of physical dispersion, f_0, consistent with the extensive data sets of hand-picked body wave arrival times compiled through the long history of seismology. The appropriate choice of reference frequency is also important to determine arrival times of body waves, especially later arrival times, from broadband seismograms by fitting observed to synthetic waveforms. Setting the reference frequency to be the conventional one, 1 Hz, we measured *S-P* differential travel times by waveform fitting. We found a systematic discrepancy between the measured and hand-picked *S-P* times that can be removed by changing f_0 from 1 Hz to 2 Hz. This change of f_0 requires a correction in Q of the *PREM* model: 1) if Q is strictly frequency-independent, we need a 15 % increase in Q value, or 2) if Q is fixed to the value given by *PREM* at a period of 200 s, we need to introduce a small frequency-dependence in Q, where the dependence is expressed by the power law with an exponent of 0.04.

S22B-0442 1330h POSTER

Characterization of Dispersive Rayleigh Waves Using Wavelet Transform.

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This contribution covers various aspect of the characterization of dispersive Rayleigh waves using the Continuous Wavelet Transform (CWT). We particularly show how to use the CWT with multicomponent seismic data to extract time and frequency dependent polarization attributes. In addition, we investigate the

inverse problem that aims at finding the operator governing the evolution in wavelet space of a propagating dispersive Rayleigh wave. We show how the application of this operator allows the simultaneous determination of the phase- and group-velocity dispersion curve and to some extent the associated attenuation characteristics of the propagation medium.

URL: http://www.math.uni-potsdam.de/~mamdou

S22B-0443 1330h POSTER

Towards the next generation of global 3D upper mantle Q models

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Global anelastic tomography can bring important constraints on the thermal structure of the mantle and therefore is dynamics, complementing those provided by elastic tomography. Progress in anelastic tomography has been slow, because of the inherent technical difficulties encountered in discriminating anelastic signal from elastic effects on amplitude data. It has been shown that while the elastic focusing/defocusing effects are not significant at low degrees ($\sim$ 8) (e.g. Selby and Woodhouse, 2002; Gung and Romanowicz, 2003), they need to be included to achieve a higher resolution Q model. Ideally, one would use an exact method, such as the Spectral Element Method (SEM) for predicting the focusing effects. SEM is however very heavy computationally. We present a procedure to better constrain the 3D upper mantle Q from 3 component long-period seismic waveforms. In this procedure, the amplitude and phase perturbations due to the 3D elastic structure are corrected for using higher order normal mode asymptotic theory, and applying it to current elastic models. We first evaluate the normal mode asymptotic approach by comparing the corresponding 3D synthetics with those computed using the coupled spectral element/normal mode method (CSEM). 3 normal mode based asymptotic approaches are compared: path average approximation (PAVA), non-linear asymptotic coupling theory (NACT) and NACT+F, an extension of NACT with focusing terms computed using higher order asymptotic theory. Systematic waveform comparison and inversion experiments are implemented. We find that (1) when the anomaly lies on the source-receiver great circle path, the 3 techniques are fairly accurate for fundamental mode surface waves, but NACT and NACT+F provide much better fit for overtone phases and are therefore more powerful in resolving 3D structure in the mid and lower mantle; and (2) the off-great-circle effects, which result in focusing/defocusing and not seen by PAVA or NACT, are well explained by NACT+F, at distances 30^o or more away from the source or its antipode. We discuss a preliminary 3D upper mantle Q model obtained by waveform inversion by this new procedure.

S22B-0444 1330h POSTER

Surface Wave Constraints on Q in the Upper Mantle: Isolating the Signal of Attenuation

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We use more than 60,000 surface wave amplitude measurements in the period range 150-300 seconds (Ekström et al., 1997) to construct maps of attenuation, or 1/Q, in the upper mantle. We initially calculate Q by constructing a datum that uses four consecutive wave trains to desensitize the amplitudes to effects from the source, instrument, and elastic structure. These Q measurements are inverted for maps of even-degree attenuation structure, and the results show variations of approximately 50% from PREM. When the Q measurements are averaged for nearly coincident great-circle paths, the resulting attenuation maps are nearly identical to the original ones, confirming that, despite extraneous effects, there is a robust signal in the amplitudes. Using the method of Selby and Woodhouse (2002), we invert minor- and major-arc Rayleigh and Love wave amplitudes for even- and odd-degree Q structure. When we assume that the amplitude anomaly is due entirely to intrinsic attenuation, the ability of the models obtained through this process to fit the data is poor. We next include terms in the inversion that allow the source moment and instrument gain to be corrected. These corrections greatly improve the fit of the data by the models. The path integral approximation to the amplitude anomaly (Woodhouse and Wong, 1986) is used both to predict the effect of focusing from existing phase velocity maps and to jointly invert for attenuation and phase velocity. We also perform a pure-path regionalized inversion using a six-tectonic-region model of the Earth, GTR1 (Jordan, 1981). On the most simplistic level, the results show that oceans are more strongly attenuating than continents at all periods, and that the surface wave attenuation values of PREM fall in between those of continents and oceans. The results using the great-circle Q measurements show many familiar patterns, in particular that young oceans are more highly attenuating than older oceans. Although the data set of minor- and major-arc amplitudes is somewhat noisy, its ability to match the results of the great-circle Q regionalization is a good measure of the usefulness of the amplitude corrections described above.

S22B-0445 1330h POSTER

20-sec Rayleigh-Wave Attenuation Tomography for Central Asia

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Because of the complex crust and upper mantle structure in central Asia, lateral variations of the surface-wave attenuation are significant. To map out these variations, we construct tomographic attenuation models for 20-sec Rayleigh waves, which will be used to constrain 3-D shear-wave attenuation models of the region and to improve regional Ms measurements. In order to make reliable amplitude measurement, we use a phase-matched filter constructed from 2-D surface-wave group-velocity maps to isolate and enhance the primary surface-wave arrival. The filtering reduces the ambiguity due to multi-pathing and other noise in the data. We also use theoretical source radiation patterns and source spectra to guide our measurement and gauge the quality of the data. We take two steps in developing the attenuation model following a Bayesian approach. First, we invert two-station amplitude-ratio measurements, which are less affected by source-parameter error than single-station amplitude measurements, to obtain a 5-degree-cell model. This model is used as the a priori model in the final inversion of single-station measurements, which have much better path coverage, for a 2-degree-cell model. We found that results from two-station amplitude-ratio inversion exhibit general correlation between the model and geological provinces of the region. Single-station amplitude data collection and measurement are underway and we expect to present some tomography results at the conference.

S22B-0446 1330h INVITED POSTER

Compressional Wave Q in the Uppermost Mantle Beneath the Tibetan Plateau Measured Using Pn Wave Spectra

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Pn waves from three near-colocated seismic events in the eastern Tarim Basin are well-recorded by the INDEPTH III and II arrays, which are deployed from northern to southern Tibet with a small east-west spread (between $\sim$88 and 91°E). The paths run southward and sample the Tibetan mantle with epicentral distances increasing from 870 to 1540 km. These waves have spectral contents that are distinctly different from those collected from the Kyrghistan network (KNET), to which the paths traverse westward through the eastern Tienshan. Pn Q beneath Tibet and Tienshan must therefore be different. Xie and Patton (1999,JGR, 104, 941-954) have simultaneously estimated source spectra of the co-located events, and path-averaged Pn Q to the KNET stations. Under a simplified geometrical spreading of $\Delta^{-1.3}$, they have estimated Q_0 and η (Pn Q at 1 Hz and its frequency dependence) to KNET to be about 360 and 0.5, respectively. Using those estimates as a priori knowledge, we estimate that Q_0 and η are 180 and 0.3 along paths to northern Tibet, and $\sim$260 and 0.0 along paths to southern Tibet. The southward increase of Q_0 correlates well with a similar increase in Pn velocity contained in previous tomographic images. Additionally, we measured Pn Q using a two-station method along two profiles (from station SANG to TUNL, and GANZ to MAQI) deployed during the 1991-1992 Sino-US Tibetan Plateau experiment. Both profiles are located to the east of 92°E. Along profile SANG-TUNL, we estimate Q_0 and η to be $\sim$270 and 0.0, respectively. The Q_0 value is rather high, but correlates well with the high Pn velocities of $>$ 8.1 km/s re-measured in this study. Our results suggest that the zone of low Pn Q_0 and velocity in northern Tibet, which is likely caused by high mantle temperature and partial melting, is confined to the west of 92°E. This is so despite that the zone of high Sn attenuation extends to further east.

S22B-0447 1330h POSTER

3-D Attenuation Structure of Mt. Etna Volcano

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Seismic attenuation at Mt. Etna volcano has been studied in the last two decades using different methods and waves types. Only global attenuation properties of the etnean region are characterised in these studies. All of them corroborate that attenuation is stronger at low frequencies than at high frequencies, and that anelastic processes prevail over scattering. However, the details of the tridimensional (3-D) attenuation structure of Etna were not known. In this work, we perform an attenuation tomography of the shallow structure (depth less than 3 km b.s.l.). We apply a spectral inversion technique to the P-wave spectra, which constitutes a modification of the velocity tomography technique. We selected the spectra of 266 earthquakes belonging to the seismic swarm that marked the onset of the 2001 July eruption of Etna. The velocity model used to perform the attenuation tomography was obtained by Patanè et al. (2002). This velocity model has been also used to relocate the selected events. We assume an homogeneous initial attenuation model (1/Q=0.013), a damping value of 0.003, and a grid cell size of 2x2x1 km. The procedure has been verified with different synthetic resolution tests. The final model shows an aseismic body with low attenuation (1/Q<0.005) at a depth of 2 km b.s.l. and at 6 km from south of Central Craters (C.C.) zone. When the depth decreases, the attenuation increases in this area and it reaches the greatest values (1/Q>0.05) in the shallower layers (betwen 2 and 1 km a.s.l. If we compare the P-wave attenuation structure with the P-wave velocity and vP/vS structure (Patanè et al., 2002), we observe: a) at 1km b.s.l. and east from Bove Valley, there is a body with low vP/vS ratio and high P-wave attenuation; b) at sea level and at south from C.C. area, the P-wave velocity and attenuation are high and it is founded low vP/vS values, while in the Bove Valley, the vP/vS ratio is high and c) at 1 km a.s.l., the area at southwest from C.C. zone has low vP/vS values and high attenuation. However, in the Bove Valley, the attenuation is low and the vP/vS ratio is high.

S

S22B-0448 1330h POSTER

Seismic Attenuation in the Carpathian Bend Zone and Surroundings

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We present measurements of crustal and upper mantle seismic attenuation in the southeastern Carpathian Arc and surroundings to test mantle responses to

Tethys closure in this region. The unusual intermediate depth seismicity, volcanism, and surface deformation at and around the most tightly curved portion of the Carpathian arc, the Vrancea bend zone (45.5^o N, 25.5^o E), has been the subject of many studies recently, culminating in a debate about the nature of the processes involved: one possible tectonic scenario to explain the Vrancea seismicity and surrounding structures invokes subduction of Tethys oceanic lithosphere, a remnant of which is presumed to be just detaching from unsubductible continental lithosphere of the East European and Moesian platforms. A second model holds that oceanic lithosphere subduction ended some time in the late Miocene, and that since then a portion of East European or Moesian platform continental mantle lithosphere has been delaminating along a horizontal mid-lithospheric interface and dripping down into the upper mantle. The active seismicity at Vrancea can be exploited to delimit both slab and asthenosphere distributions via measurements of seismic attenuation at stations distributed above the Vrancea zone. We measure attenuation via an iterative spectral ratio method which compares P and S spectra for an evolving time window of both arrivals, yielding 400 individual estimates of Q and one composite estimate derived from the stacked spectra of the idividual measurements. This procedure allows us to identify and exclude subtle multipathed phases with attenuation different from that of the direct arrivals and also yields a robust estimate of the measurement uncertainty. Measurements are retained for interpretation if the mean of the 400 individual Q estimates and the composite spectra Q estimate agree to within the (generally small) standard deviation of the 400 measurements. Results for all data recorded at the Romanian-German K2 accelerometer network during 1999 fall into clear groups: Attenuation is low (high Q) at stations east and north of the Vrancea zone on the East European platform and in the Dobrogea region. Attenuation at stations on the Moesian Platform, including those in and around Bucharest, is highly path-dependent in a complex way that probably reflects structure of the Vrancea body itself. Attenuation at stations above and near the Vrancea zone, and at stations in the Transylvanian Basin is high (low Q), most likely due to the presence of hot asthenosphere in these areas. These preliminary results may ultimately yield a strong test of the competing hypotheses put forth to explain the unusual seismicity and volcanism of the Carpathian arc. Finally, improved understanding of seismic wave propagation and attenuation in the study region will directly enhance our understanding of seismic hazard in this populous area.

S22B-0449 1330h POSTER

Body-wave attenuation across the Baikal rift zone, Siberia

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The Baikal rift zone (BRZ) is the seismically most active continental rift on Earth. It lies along the junction of the stable Siberian platform and the mobile Sayan-Baikal foldbelt. In spite of intensive geophysical and geodynamic studies during the past decade, some fundamental questions regarding its formation and evolution remain unanswered. One of the key constraints for the various models proposed for the formation and evolution of the BRZ is the existence, geometry, and property of the assumably upwarped asthenosphere beneath the rift. Recently, several seismic tomographic studies resulted in different conclusions, and thus there has been a renewed interest in the deep structure beneath the rift. Spatial variation of t^*, which is defined as travel time over Q, across the rift serves as an independent set of observations to provide more constraints on the models and tomographic images. The upwarped asthenosphere is expected to be associated with a region of high t^* relative to the areas unaffected by the rifting process. We have measured P- and S-wave t^* along a 1200 km profile traversing the Siberian platform, the BRZ, and the Sayan-Baikal-Mongolian foldbelt. Both the spectral ratio and the common spectrum approaches were used, and the two approaches generated similar results. An area of increased t^* values is observed, which corresponds to a highly attenuative region at the depth of 50-150 km. Comparison of P- and S-wave results suggests a few percent of partial melting. Those results provide independent support for some of the recent tomographic models which suggest a broad, upwarped low velocity asthenosphere beneath the BRZ (e.g., Gao et al., 2003).

S22B-0450 1330h POSTER

Attenuation and Electrical Resistivity in an Asymmetric Back Arc Extensional Environment

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We use seismic attenuation and magnetotelluric data to determine the nature and location of a boundary that marks the transition from extension to compression, North Island New Zealand. This boundary, termed the Taranaki-Ruapehu Line (TRL), has long been recognised as a fundamental boundary between lithosphere of contrasting nature. Geophysical evidence indicates that the TRL runs approximately east to west, nearly perpendicular to the present day plate boundary configuration. The area north of the boundary is associated with slightly elevated heat flow (70-80 mWm^{-2}), thinned crust (25 km) and crustal extension. The area south of the boundary has normal continental heat flow (60 mWm^{-2}), crustal thickness of 35 km and is in geodetically determined compression. Previous attenuation studies indicate that attenuation is higher to the north of the boundary. A steep gravity gradient connects the two regions. In 2002 six long period magnetotelluric soundings straddling the boundary were recorded in a line 120 km long. These data have been used for 2D inversion models of resistivity down to 45 km. Modelling indicates low resistivity ($<$ 300 ohmm) present below 25 km depth in the north that is absent in the south. This change in resistivity structure is north of most estimates for the boundary position. A new seismic network of six short period instruments was deployed along the same line to collect local earthquake data. Preliminary results from this data suggest the attenuation boundary is contiguous with the resistivity boundary. For earthquakes greater than 150 km depth path averaged P wave values of Q are as low as 200 on the extensional side of the boundary, which is comparable with Q values found below many volcanic arcs. On the compressional side of the boundary Q values are $>$1500.

S22B-0451 1330h INVITED POSTER

Q in the Mantle Wedge beneath the Philippine Sea

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Seismic wave attenuation provides important constraints on the structure and the physical properties of the Earth. Attenuation is sensitive to the variation in water and/or melt content as well as the variation in temperature. In this study, we focus especially on Qp/Qs and the frequency dependence of Q. Qp/Qs is sensitive to the presence of melt that could cause bulk attenuation as opposed to shear attenuation. The frequency dependence α ($Q \propto \omega^{\alpha}$) is also an important parameter: the conversion of variation in Q to the variation in viscosity depends strongly on this parameter. We investigated the upper mantle attenuation beneath the northern Philippine Sea region, including the Izu-Bonin subduction zone and the Shikoku Basin. We used regional waveform data from the events in the Pacific slab, recorded on F-net and J-array network broadband stations in western Japan. Two kinds of phase-pair method which measure the difference in spectral decay between two phases are employed to measure the differential attenuation. P-P and S-S methods measure the difference in spectral decay of two P and S waves which sample different paths. We obtain P-P and S-S spectral ratio curves with high S/N ratio over the frequency range $0.5-8.0$ Hz and $0.5-2.5$ Hz respectively. For S-S method, the available frequency range is limited to below 2.5 Hz because of P-coda spectra. Qp/Qs are estimated from both P-P and S-S methods which suggest some geographical variations. Regions with low Qp/Qs are found in the middle part of Philippine Sea and many data corresponding to long path-length show relatively small Qp/Qs. Values of Qp/Qs less than ~ 2 imply significant bulk attenuation implying the presence of mechanically heterogeneous materials possibly partial melt. Frequency dependence of attenuation is estimated by fitting the P-P spectral ratio curve as a power-law function of frequency. The estimated values of power-law exponent range $\sim 0.2-0.7$ with some regional variations. This corresponds to a variation of viscosity by a factor of $\sim 3-200$ corresponding to the observed variation of Q (a factor of $2-3$ at a same depth: Shito and Shibutani, 2003).

S22B-0452 1330h POSTER

Constraints on the Mechanism of Attenuation and Thermal Structure in Subduction Zones: Results from BEAAR

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In the sub-lithospheric mantle, seismic attenuation is likely controlled by temperature. Global attenuation models, when compared with estimates of upper-mantle temperature, show consistency with laboratory measurements and indicate that $1/Q\mu$ (shear attenuation) could be a viable proxy for temperature. In most models, $Q\mu$ increases with depth in the upper mantle at a rate similar to that inferred from laboratory studies. Thermally-activated relaxation affects $1/Q\mu$ much more than bulk attenuation ($1/Q\kappa$). However, at low temperatures such as present in subducting slabs and in crust, other processes could dominate the apparent absorption of seismic energy, and $1/Q\kappa$ could be significant. Inversion of regional body-wave spectra from the recent Broadband Experiment Across the Alaska Range (BEAAR), a 2.5-year PASSCAL array, provides some insight into these processes. The 10-15 km station spacing of the 17-36 BEAAR stations allows resolution at scales comparable to travel-time tomography to depths of 150 km, and allows attenuation to be measured separately for wedge, overlying crust, and slab. From body wave spectra (0.5 to 20 Hz) of over 2000 upper-mantle paths, we estimate $1/Q$ for P and S waves. These data are then inverted for spatial variations in $1/Q$. Two aspects of the results provide constraints on the mechanism of attenuation: they require frequency dependence, and they constrain the relative significance of bulk attenuation ($Q\kappa$) to shear. In the mantle wedge, $1/Q\kappa$ is negligible, and $1/Q\mu$ varies as $(frequency)^{-\alpha}$ with $\alpha = 0.2$ to 0.6. The low end of this range is consistent with laboratory estimates for thermally-controlled attenuation in high-temperature peridotites. In lower temperature regions of the slab and overlying crust, $1/Q\kappa \sim 1/Q\mu$ and $\alpha = 0.6$ to 0.7, indicating that a different physical mechanism operates, perhaps a combination of scattering and thermoelasticity. The mantle wedge values for attenuation ($Q \sim 100$ to 150 at 1 Hz) then can be used to constrain temperature. The Q values suggest that near-solidus conditions prevail in the wedge, at least at resolution of tens of kilometers. Similar studies in Japan and the Andes indicate slightly higher temperatures beneath the volcanic arc.

S22B-0453 1330h POSTER

Measuring Quality Factors From Multicomponent Reflection Seismic Data and its Significance for Lithology and Fluid Type Prediction

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Relationships among shear and compressional wave velocities (VP and VS) and quality factors (QP and QS) for predicting lithology and fluid content, have been previously studied and proposed by some researchers. Thus, for example, VP/VS has been used as a lithology indicator for sandstone, shale and limestone. Likewise, QP/QS has been related to fluid content, mainly to discriminate oil, brine, and gas saturation. The velocities and quality factors for both P and S waves can be obtained from multicomponent reflection seismic data. Multicomponent data are most commonly recorded from compressional sources in the oil industry. Converted P to S waves or PS waves are generally measured in the radial component. In cases where there are heterogeneity and/or azimuthal anisotropy, the transverse component is also considered. Processing of the converted wave results in a PS image and an interpreted converted-wave velocity field (VPS). Likewise, it is possible to estimate a converted-wave quality factor (QPS) field. The converted-wave quality factor can also be used as a lithology and fluid content indicator since this parameter depends on VP/VS and QP/QS ratios. Crossplots involving QPS obtained from previously published laboratory measurements of P- and

S-wave velocities and quality factors, reveal the significance of estimating QPS from multicomponent seismic data. An important advantage of using QPS as a lithology indicator is that it can be mapped directly from multicomponent surface seismic data. In this work we present a new methodology to obtain QPS. In the pure mode case, approaches for estimating Q are well known. However for converted-waves, some simplifying assumptions need to be made due to the propagation characteristics of the converted P- to S-wavepath.

URL: http://www.imp.mx/investigacion/ynf/smc/

S22B-0454 1330h POSTER

Diffusion waves in seismology?

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Attenuation and reflection of seismic waves from fluid-saturated rocks is crucial for adequate interpretation of seismic data. Processing of low-frequency laboratory and field data shows seemingly anomalous phenomena of high reflection amplitudes and phase shifts, as well as very low values of attenuation factor ($Q = 1-5$), which can not be explained by the classical Biot-Gassman theory of poroelasticity. We apply the pressure-diffusion wave theory to explain the observed low values of Q. Two prototype examples of diffusion wave model have been considered: elastic fluid flow in single and dual porosity media. In either case, Q is a function of the frequency approaching at low frequency limit a very low value of 0.5. Estimates show that the diffusion waves have relatively slow velocities and high attenuation. The other interesting result consists of wavelengths being inverse proportional to the phase velocities. This mechanism partially explains the observed high reflection amplitudes and phase shifts and promises obtaining of high-resolution seismic images of thin fluid-bearing layers.

S22B-0455 1330h POSTER

Shear-wave Seismic Attenuation in Southern California and Taiwan: A Comparison

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There have been numerous studies of the 3D seismic P- and S-wave velocity structure of both Southern California and Taiwan. These studies have provided a framework for the relocation of seismicity and for investigations of the composition of the crust and uppermost mantle. Here we address another useful seismological parameter, attenuation, or inverse Q. Attenuation studies are important because this parameter is sensitive to such properties as temperature and fluid content, both of which can be important for the interpretation of active tectonic processes. Schlotterbeck and Abers (2001) determined the 3D Q-structure of Southern California. They found relatively low Q within the Los Angeles basin and Transverse Ranges, compared with the Mojave Desert to the east. They also found low Q in the Salton Trough. Thus, there is a large degree of lateral variation in Q values even within the generally low-Q western USA. It is interesting to compare crustal attenuation in Southern California with attenuation determined for the island of Taiwan. These two regions are similar geologically, and both exhibit high levels of seismic activity. Furthermore, the dense strong motion network in Taiwan provides abundant data to determine the 3D Qs structure. An inversion for Qs in Taiwan shows a close correlation with geology. At shallow depths (4-9 km), relatively high Qs is found in NW Taiwan, while low Qs is found in SW Taiwan. The relative low Qs of SW Taiwan appears to be related to thicker sediments, while the higher values found to the NW are associated with crystalline rocks of the foreland belt. It is also possible to distinguish the Qs values between western and eastern Taiwan: high Qs is found at depth (27-38 km) beneath eastern Taiwan, and this zone can be correlated with the actively subducting slab that marks the active margin of eastern Taiwan. In contrast, a zone of low Qs is found beneath the Central Range at depths of 30-40 km. This low Qs zone correlates with a low velocity zone in both P- and S-waves, as determined from seismic tomography studies. One of the most remarkable features is the observation that the causative fault of the 1999 Mw = 7.6 Chi-Chi earthquake (the Chelungpu fault) exhibits clear lateral (cross-fault) variations in Qs, with the footwall showing higher Qs. The 3D Qs image of the crust of Taiwan is of higher resolution that what is presently available for Southern California. Nevertheless, in both regions we can see that there is a clear correlation between Q values and deep geologic structure. In addition, we anticipate that these results will provide important constraints of P-wave and S-wave Q values to be used in the synthesis of strong ground motions in both regions.

S22B-0456 1330h POSTER

Coda Q Factor of the Hong Kong Region and Tectonic Implications

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The coda-Q factor of the Hong Kong Region has been estimated using 25 local earthquakes of ML=2.7-4.6 and with epicentral distances within 200 km digitally recorded by eight short-period stations in Hong Kong. FFT and regression analysis were conducted on the coda waves within a 35 s window starting at t=2ts to obtain Q values for 10 frequencies from 2 Hz to 20 Hz for each record. Records with a S/N ratio < 5.0 during the last 5 sec of the coda window, and Q values with a correlation coefficient < 0.45 were rejected from the data set. A total of 260 data points yielded a Q-f relation of . The data were also divided into three groups based on epicentral distance (R), resulting in Q0 (Q at f=1 Hz) values of 224 (R< 50 km), 342 (R=50-100 km) and 262 (R=100-200 km). The results are consistent with the spatial variations of the Q factor in the wider region of South China, and yield useful information on the crustal attenuation conditions in the Pearl River Delta region. In spite of the lack of major historical seismic events in the region, the relatively low Q-factor implies a tectonic setting more akin to areas with active seismicity, giving support to the existence of a major tectonic boundary between South China and the adjacent plates. (Support from HKU and PROCORE programme is gratefully acknowledged.)

S22B-0457 1330h POSTER

Basin Attenuation and the characteristics of simple spectral ratio and H/V site response estimates

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Site response estimates are commonly used to characterize potential ground shaking during future earthquakes. These estimates are generally computed by taking either the spectral ratio (SR) of ground shaking at the site relative to a nearby bedrock site, or the spectral ratio of the horizontal to vertical components of the shear wave arrivals at the site (H/V). In the H/V method, the vertical component of the shear wave arrivals is assumed to be a converted phase from the base of the shallow deposits, making it a proxy for the signal entering the base of the shallow deposits. The site response at frequencies of 1 to 20 Hz is generally interpreted in terms of the velocity structure of shallow sedimentary deposits. Seismic waves reaching sites above thick sedimentary basins, however, undergo attenuation in the deeper basin-filling sediments. This frequency-dependent attenuation results in decreasing spectral ratios with higher frequency in the SR method, but will have little effect on the H/V method because all three components used in computing the latter ratio have undergone nearly the same attenuation. To demonstrate the effects of attenuation in deep sedimentary basins on both SR and H/V site response estimates, we calculated the site response at 50 locations in the Puget Lowland of Washington State using both methods. Spectra were computed from recordings of three local earthquakes of magnitude 2.1 to 2.8, which provided a useful signal-to-noise ratio across the spectrum. The SR estimates at sites over deep basins consistently show a decrease in the spectral ratio with increasing frequency, whereas at non-basin sites the SR estimates do not exhibit a systematic decrease with frequency. Using the H/V method, responses determined at the deep basin sites show little or no systematic decrease in spectral ratio with increasing frequency, suggesting that the method is indeed measuring primarily the response of the shallow deposits. Computing values for the attenuation factor (Q) from the SR site response estimates using the method of Anderson and Hough (1984) results in reasonable values of 15 to 200 depending upon the total thickness of the basin sediments. Removing the trend of decreasing amplitude with frequency from the SR ratio using these attenuation estimates significantly improves the fit of the SR site response estimates with those computed using the H/V method.

S22B-0458 1330h POSTER

A tomographic method to calculate Lg Q across the continental US

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Lg attenuation studies are generally successful in discrete regions with a good distribution of earthquakes and recording stations. In such regions ray-path coverage is adequate to resolve a 1D average Q. In our attempt to describe the spatial variation of Lg attenuation throughout the continental United States, we found numerous regions with inadequate coverage due to a limited number of earthquakes and recording stations. To solve this problem we have developed a tomographic method to compute frequency dependent Lg Q, that enables us to use ray-paths that may originate or end outside of a particular region. Fourier amplitude spectra of Lg phases (windowed from 3.7-3.0km/s), recorded at high frequencies (0.5-8Hz), were used to determine regional frequency-dependent attenuation. We divided the continental US into 5 degree cells and solved for source, and station terms for each ray-path and Q-values for each cell using a singular value decomposition (SVD) procedure in five frequency bands (0.75, 1.5, 3.0 and 6.0 Hz). We collected broadband data for over 2500 Lg source-station paths throughout the United States from U.S. National Seismograph Network (USNSN), Advanced National Seismic System (ANSS), Canadian National Network and cooperating stations. Path lengths range from 150 to 4000 km. In regions where we have overlap, our calculated values of Lg Q closely match those previously determined from the analysis of data from discrete regions. The current data set is adequate to resolve the gross distribution of Lg Q across the continental US, with low Q in the West, high Q in the East and well resolved transition values in previously poorly described regions.

S22B-0459 1330h POSTER

Frequency Dependent Lg Q Within the Continental United States

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A frequency-dependent quality factor, Q(f), is determined for three previously unstudied and four previously studied tectonic regions across the continental United States by inverting Lg time-domain amplitudes. Broadband seismic stations record high frequency (0.5 to 16 Hz) energy to determine regional attenuation for Southern and Northern California, the Basin and Range Province, the Pacific Northwest, the Mountain States, Central United States, and the Northeast United States. The Pacific Northwest, Northern California, and the Mountain States regions are new regions where there are no previous Lg Q results. Lg Q is determined at each of the five full octave bands with center frequencies at 0.75, 1.0, 3.0, 6.0, and 12.0 by assuming a geometrical spreading exponent of 0.5 and inverting for Q and source and receiver terms. The frequency-dependent quality factor is often modeled in the form of η. A delete-j Jackknife resampling technique is utilized for error analysis. In general, active tectonic regions have a low Qo value and a high frequency dependent variable η, whereas stable regions have a high Qo term and a low value for η. Southern and Northern California, the Basin and

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Range Province, the Pacific Northwest, and the Mountain States are all tectonically active regions and have frequency-dependent functions of Q = 152(±37) f $^{0.72}$ (±0.16) , Q = 105(±26) f $^{0.67}$ (±0.16) , Q = 200(±40) f $^{0.679}$ (±0.12) , Q = 152(±49) f $^{0.76}$ (±0.18) , and Q = 166(±37) f $^{0.61}$ (±0.14) respectively. The remaining two regions, Central U.S. and Northeastern U.S., fall into the stable tectonic region category and have frequency-dependent functions of Q = 640(±225) f $^{0.344}$ (±0.22) and Q = 650(±143) f $^{0.36}$ (±0.14) . Both scattering and intrinsic attenuation mechanisms are likely to play an equal role for the range of frequencies considered in this study.

S22B-0460 1330h POSTER

Factors affecting the evaluation of scattering attenuation

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The scattering of waves is a near ubiquitous phenomenon in the earth and has been widely studied in seismology. Scattering attenuation can be calculated by a formulation based on an approximation allowing for both multiple forward-scattering and a single backscattering process. In this approximation possible interaction between scattering in the forward and backward directions is neglected. In this study we examine the effects of multiple scattering and propagation distance on the evaluation of scattering attenuation through numerical experiments on highly heterogeneous models. A change in propagation distance results in the variation of the radius of the Fresnel zone, which controls the interference volume of scattered waves. We find that primary waves display a characteristic attenuation pattern depending on both the frequency content of the incident waves and the change in propagation distance. On the other hand, the coda energy is determined to be nearly constant for changes in the random model and perturbation level.

S22C MCC: 3009 Tuesday 1340h

Mechanical Strength of the Continental Lithosphere I *(joint with T, V)*

Presiding: **W Chen,** University of Illinois, Urbana-Champaign**; B Evans,** Massachusetts Institute of Technology

S22C-01 1340h INVITED

Metamorphism, Metastability, Mechanical Strength, and the Support of Mountain Belts

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We explore links between geophysical observations related to mechanical strength of the lithosphere and geological observations of metamorphism and metastability in the lower continental crust. Our recent studies of elastic thickness (T_e), determined from gravity measurements, and seismogenic thickness (T_e), determined from teleseismic waveforms, led to the view that everywhere on the continents $T_e < T_s$ and that all significant long-term strength of the continental lithosphere resides in a single seismogenic layer within the crust. We found no significant evidence for teleseismically-recorded earthquakes in the continental mantle, and we suspect their absence is related to small amounts of water in nominally anhydrous mineral phases. The strong, seismically active, lower crust of northern India appears to underthrust much of southern Tibet, where the crust is up to 80 km thick. Several authors have pointed out that the lower crust in this region must consist of granulite, not eclogite. Psuedotachylites that formed in lower continental crust under eclogite conditions in southern Norway are ancient analogues of earthquakes that occur today in the lower crust of southern Tibet at depths of 70-80 km. These psuedotachylites show that the dry granulite host rocks in which they occur were metastable at pressures 10–15 kbar beyond their equilibrium range, and that their partial conversion to eclogite was controlled by water infiltration along fractures. The change from granulite to eclogite was accompanied by a dramatic loss of mechanical strength, and a change in deformation style from localised brittle failure to distributed ductile flow. We suspect the same processes observed in Norway are occurring today beneath S. Tibet. Argument by analogy suggests that: (1) earthquakes at depths of 70-80 km beneath S. Tibet occur in the dry, strong, granulite lower crust of the Indian shield; (2) those earthquakes represent the start of a process that will eventually convert, and possibly remove, the lower crust by eclogitization; (3) the sequence of metamorphic and mechanical changes is driven, and limited by, the supply of water — probably from the underlying mantle of the Indian shield and originating from the breakdown of hydrous mantle phases. In this view, the rheology of the continental lithosphere in S. Tibet is controlled by composition, rather than by temperature, and suggests that the support of the highest mountains on Earth would not be possible without the metastability of dry continental lower crust.

S22C-02 1355h

Earthquake Focal Depths and Crustal Structure of Northern India: Implications for Crustal Rheology

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Most intraplate continental earthquakes occur in the upper ∼15 km of the crust but occasionally earthquakes occur at deeper levels beneath the continents in some regions. This observation coupled with laboratory measurements of rock properties as a function of temperature and pressure, led to a model for the continental crust consisting of a brittle upper layer and a weak lower layer, overlying a brittle uppermost mantle. Key observations leading to this model came from earthquake foci and crustal structure in northern India. We re-examine these observations. We use receiver function and published refraction/reflection results to determine the variation in crustal structure of India. We find that the crust beneath the south Indian shield is relatively uniform with a thickness of ∼ 36 ± 2 km, but the north Indian crust thickens to about ∼50 km as a result of the down-bending of the Indian plate as it thrust beneath the Himalaya and southern Tibet. The Moho of the Indian crust beneath southern Tibet is at ∼85 km depth. We redetermine focal depths for earthquakes in northern India using this crustal model. For recent events we determine focal depths using waveform modelling or from the timing of depth phases on broadband waveforms. We correct the foci of published event hypocenters using our crustal velocity model. Earthquakes occur to ∼35 km depth in central India, ∼50 km depth beneath the Himalaya, and ∼80 km depth below southern Tibet. All major earthquakes across northern India and southern Tibet occur in the crust and there is no evidence for significant sub-Moho seismicity beneath northern India and southern Tibet.

S22C-03 1410h

Depths of Earthquakes in the Central Tien Shan

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Using a variety of techniques, we relocated local and regional events recorded by the GHENGIS deployment of Broad Band sensors in the central Tien Shan from 1997-2000 in order to determine the extent to which earthquakes occur within the lower crust in the Tien Shan and surrounding regions. We generated probability density functions using a new spherical coordinate adaptation of the Eikonal Equation solver in combination with refined tomographic images which should provide accurate estimates of travel time in this complicated structure. We also used a new algorithm based on the Progressive Multiple Event Location (PMEL) that associates each event in the catalog with one or more control points in a 3D grid and locates these events with PMEL. The implementation allows us to resolve the traditional bias problem by folding in anomalies computed from a 3D model through a set of matrix projectors. These relocation efforts significantly improve the spatial resolution of the GHENGIS catalog. We find that while hypocenters from some regions where lower crustal earthquakes were previously reported were in fact poorly constrained, there appear to be several well constrained depths in the central Tien Shan south of Lake Issyk-Kul, and a large number near the Jiashi region of western China. A combination of tomographic and receiver function images suggests that these events are clearly located in the lower crust.

S22C-04 1425h

New Evidence for Strong Lithospheric Mantle: Mantle Earthquakes beneath the Himalayan-Tibetan Collision Zone

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The mechanical strength of lithospheric mantle beneath continents has far-reaching implications for understanding continental dynamics. For two decades, one of the key evidence for a strong lithospheric mantle is the occurrence of intra-continental earthquakes in the mantle, originally discovered beneath southern Tibet in 1981 (Chen et al., JGR, p. 2863). To a large extent, recent debate on this issue hinges on whether BOTH focal depths and crustal thickness are well enough determined in the same region to resolve if earthquakes near the Moho occurred in the mantle. We present a significant amount of new data and a comprehensive compilation of focal depths, fault plane solutions, and crustal thickness in and around the Himalayan-Tibetan collision zone to show that there are a number of mantle earthquakes, reaching a body-wave magnitude of 6, beneath the western Himalayan syntaxis, the western Kunlun, and southern Tibet (near Xigaze). Focal depths for some of these earthquakes reach over 100 km, as evidenced by matching broad-band (high-resolution) waveforms. Frequent occurrence of intra-continental earthquakes in the mantle is clear, in situ, evidence that the lithospheric mantle is strong enough to accumulate elastic strain under geological strain rates. (Supported by NSF Continental Dynamics Program, Project Hi-CLIMB.)

URL: http://www.uiuc.edu/∼wpchen

S22C-05 1440h

Rheological Consequences of Rapid Erosion in Active Orogens

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It has long been recognized that erosion can influence the geodynamics of an orogen by redistributing mass. However, only recently has it become appreciated that rapid exhumation can locally alter the three-dimensional thermal structure of the crust, profoundly changing its rheology and weakening portions of the crustal profile. This process in turn permits feedbacks between erosion, rheology, and deformation. Specifically, based on geological and geophysical observations at Nanga Parbat in the northwestern Himalaya, we have proposed the "tectonic aneurysm" model, in which significant erosion (at Nanga Parbat, along the large Indus River valley) is sufficient to weaken the crust and divert crustal flow into the region. This in turn facilitates coupled rock uplift and erosion, which further weaken the crust as the shallow thermal gradient steepens, localizing and enhancing deformation. Geological observations at the Nanga Parbat antiform in