spectrum of seismological techniques to AE catalogues collected in the laboratory; i.e., moment tensor analysis, Vp/Vs ratios, attenuation, event clustering statistics, Gutenberg-Richter b-value and aftershock analysis. Since AE occurs spontaneously as a result of unstable microcrack growth during rock deformation experiments, it provides a non-destructive method to observe damage accumulation. I will give examples of visualization techniques that have proven helpful in the analysis of fracture nucleation and growth based on 3D event locations in granite and sandstone samples. These techniques are useful in interpreting the development of complex fracture systems in lab samples. Complementary measurements of wave speed anisotropy and heterogeneity are used to infer both the development of damage zones and the rate of infiltration of water during fluid injection experiments. Finally, spatial clustering of AE events is evaluated in terms of the surface roughness of reactivated faults during triaxial deformation experiments.

T14A-02 1550h

Damage and recovery of calcite rocks deformed in the cataclastic regime

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Compressional and shear wave velocities have been measured during the experimental deformation of Carrara marble and Solnhoffen limestone in the cataclastic regime using the newly installed triaxial apparatus at the ENS of Paris. Experiments were performed both in dry and wet conditions, up to 260 MPa confining pressure, 10 MPa pore pressure (wet conditions) and room temperature. We measured the elastic and mechanical properties under hydrostatic conditions, during triaxial loading (at the constant strain rate of $10^{-5}.s^{-1}$) and during stress relaxation. Our results show that the seismic velocities increase during hydrostatic pressure build up as well as during the first part of the axial loading. During cataclastic deformation, the velocities decreased progressively, indicating the stress induced damage in the rock. During stress relaxation tests, most interesting results was the increase of velocities with time, which suggested a 'recovery' of the microstructure. A substantial and rapid drop in the velocities occurred when reloading, suggesting that the previous 'recovery' was only a transient phenomena. Subsequent relaxation test showed other marked increases in velocities. These experimental results suggest that during the deformation of low porosity calcite-rich rocks, dilatant micro-mechanisms (crack opening and sliding, void creation) and compactive ones (pressure-solution, pore closure) interplay. Evolutions of elastic properties (mainly sensitive to crack density) and macroscopic volumetric strain (more sensitive to porosity) are not systematically correlated and depends on the strain rate, the solid stress conditions and the pore pressure, which promote the dominant deformation mechanisms.

T14A-03 1605h

Acoustic Emissions and Seismic Velocities in a Numerical Model of Rock Fracture

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Visualizing evolving fault zones in the laboratory involves monitoring of acoustic emissions, measuring seismic velocity changes and making physical observations. Dynamic, micromechanical numerical models can complement these observations by helping to explain some of the mechanics behind the geophysical measurements and relating these to the physical observations. In this study, a numerical model is created by bonding together thousands of elastic spheres at points of contact to simulate a competent rock. The rock model is subjected to mechanical loading, and seismicity is recorded' by observing the energy release when bonds between particles break. In addition, seismic velocity changes are measured by passing dynamic waves through the modelled rock at different stress states. A laboratory study is simulated in which sets of aligned fractures are created in a cubic sample of Crosland Hill sandstone subjected to true triaxial loading. The model exhibits similar patterns in acoustic emission locations, mechanisms and magnitudes to what is recorded in the laboratory test if frictional platens are used in the model. Patterns in velocity change are also similar. All velocities increase during hydrostatic loading however the magnitude of the velocity increase is smaller in the model due to a lack of pre-existing cracks. A significant decrease in velocity is observed during deviatoric loading for waves propagating through the opening fractures in both the laboratory sample and the model - with the magnitude of velocity decrease similar in both cases. The model provides the ability to directly examine the micromechanics behind the observed velocity changes and acoustic emissions. It is shown that the velocity changes in the model can be related directly to the formation and dissolution of particle contacts and the breaking of bonds. If each lost contact or broken bond in the model is considered a microcrack, then the crack density in the model corresponds closely to the crack density calculated from the seismic velocities.

T14A-04 1620h

Development of Shear Banding in Berea Sandstone

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Closed-loop, servo-controlled testing was used to investigate the development of shear failure in Berea sandstone under low confining pressure. The experiments were performed with the University of Minnesota Plane-Strain Apparatus, designed to allow the failure plane to propagate in an unrestricted manner. Deformation was imposed into the strain softening regime and controlled so that the specimens remained intact. Thin-section microscopy provided direct observation in, adjacent to, and around the tip of the rupture zone. The shear band appeared to initiate near a stress concentration, either the corner of the specimen or, when present, an imperfection ($3mm$ diameter hole) introduced into the specimen. Intragranular microcracking was the dominant observable failure mechanism. The intensity of grain cracking was greatest near the initiation point and decreased as the failure surface was traced towards the tip. Areas of high crack density also appeared to have the greatest amount of grain size reduction and there seemed to be a larger amount of pore space. In areas where intragranular microcracks were distinguishable, (e.g. near the tip of the rupture zone), microcracks showed very little or no shear displacement, suggesting the features were not reoriented after formation. Microcrack orientations showed a dominant direction of -16 degrees from the maximum principal stress direction and -26 degrees from the failure surface. A numerical imaging technique was developed to provide an efficient means for analyzing the relative porosity of epoxy-impregnated thin-sections. The code was set up to receive a digital image (*.bmp), where three parameters (R, G, and B) describe the color of each pixel. The intensity of the R channel consistently defined the boundary of grain and pore space and was used to differentiate blue pore space from the white grains composing the matrix. Porosity increase within the rupture zone was $3-4$ grain diameters wide. An absence of notable porosity change beyond the tip (last observable intragranular microcrack) of the rupture zone suggested the altered porosity developed contemporaneously with intragranular microcracks. A cohesive zone model with a linear distribution of traction to represent a process zone and a constant distribution of traction to represent the frictional resistance along the rupture surface were used to examine the stress field near the process zone, which showed similarities to principal compressive stress orientations interpreted from intragranular microcracks. Observations of the process zone and increased shear deformation along the rupture surface were consistent with a cohesive zone model of shear fracture.

T14A-05 1635h

Frictional Properties of Mylonite, Feldspar, and Quartz Under High-Pressure and High-Temperature Conditions

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In order to understand the earthquake generation process, we need to understand the frictional and rheological properties of fault zone materials under high-pressure and high-temperature conditions. Laboratory data on frictional properties of fault surfaces of fault zone rocks are useful for that purpose. We designed and constructed an original Japanese-type gas-medium deformation apparatus. Frictional properties of mylonite, feldspar, and quartz under high-pressure and high-temperature conditions were obtained. We carried out a series of conventional triaxial compression tests of mylonite at constant displacement rate. The strain rate of deformation was 5.5×10^{-6}. We analyzed the stress-strain relation and the frictional behavior of the fault surface formed in the tests. Mylonite samples taken from an exposed brittle-ductile transition zone, the Hatagawa fault zone, northeast Japan, are tested under the confining pressure up to 200 MPa and temperatures up to 600C both in the dry and wet conditions. Even under the same effective confining pressure, presence of pore water dramatically reduces the peak shear stress at the temperature regime higher than 600C. Frictional properties of fault surface formed during the deformation tests are investigated. In the dry conditions, stick-slip behaviors were observed at the room temperature and 200C. For the temperature range up to 600C, frictional forces are almost same level. In the wet condition, we didn't observe stick-slip behavior for all temperature ranges. The frictional force decreased as the temperature increased. Fluid such as water in the deep crust may play an important role in deformation process. We conducted frictional experiments by using albite, anorthite, and quartz gouges (about 3 micron diameter) under high-pressure and high-temperature in the wet and dry conditions. These experiments were conducted by the velocity-stepping test. Temperature varied from room temperature to 600C. In the dry conditions, experiments were conducted under the confining pressure of 150MPa. In the wet conditions, pore water pressure was applied up to 50MPa under the confining pressure of 200MPa. Sample was put between upper and lower sawcut alumina cylinders (20mm in diameter, 40mm long). The sawcut was oriented at 30 $^{\circ}$to the loading axis. The values for a-b of quartz and albite were positive under the dry condition from room temperature to 600C. On the other hand, those values of albite and quartz were negative at the temperature of 200C and 300C under the wet condition respectively. Those values of quartz decreased as the temperature increased from 100C to 300C and increased as the temperature increased from 300C to 600C. Those values of albite were switched from velocity weakening to velocity strengthening between the temperature of 200C and 300C, and increased in the temperature range up to 600C. The frictional coefficient of albite decreased gradually not exponentially after velocity-step from the temperature of 250C to 350C. We will discuss these frictional properties with the texture of samples by the SEM observations.

T21A CC: 220 C-E Tuesday 0830h

Deep Structure of the Continental Lithosphere: Combining Seismic, Heat Flow, and Other Geophysical Data III Posters *(joint with G, GP, S, V, NS, MR)*

Presiding: **R D Hyndman,** Geological Survey of Canada**; N Shapiro,** University of Colorado

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T21A-01 0830h POSTER

The Use of Crustal Overtones to Constrain Crustal Structure in Central Asia

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We have constructed a new data set of observations of the dispersion of the first crustal overtone for about 500 paths crossing Central Asia.The number of reliable higher modes measurements is about thirty times less than reliable fundamental mode observations made on the same seismic recordings.This difference is largely due to the fact that the higher modes are excited less efficiently by shallow crustal

events and, for a given depth of sensitivity, the overtones are at a higher frequency and therefore scatter more strongly from crustal inhomogeneities than fundamental modes.For these reasons, higher modes are typically poorly observed and the 1:30 ratio of overtone to fundamental mode measurements is anomalously large in Central Asia relative to the rest of the world. This relatively large ratio is due to the fact that crustal overtones are best excited in regions with thick crust. Central Asia, therefore, is an ideal location to observe and apply crustal overtone measurements to improve models of crustal structure. Because measurements of crustal overtones between about 5 sec to 20 sec period are most sensitive to the shear wave speeds in the middle and lower crust, the use of these measurements with existing fundamental mode data improves the vertical resolution of surface wave tomography down to depths of 50-70 km.We show first-overtone group velocity maps from 8 sec to 18 sec period across Central Asia and demonstrate the effect on the estimated structure of the crust when fundamental and higher mode data are inverted jointly.

T21A-02 0830h POSTER

Temperature Tomography in the Central Andean Mantle Wedge From Joint Inversion of P and S Seismic Wave Traval Times

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We use about 50000 of P and S arrival times from more than 1500 local slab and crustal earthquakes to image structure and temperature distribution in the lithosphere-asthenosphere system in the Central Andes. Based on available a-priori information the entire 3-D tomographic-inversion region (600 x 600 x 250 km) is subdivided into three domains: (1) slab, with upper boundary defined as intraslab seismicity envelope, (2) continental crust, with Moho topography defined by receiver-function and wide-angle-reflection Moho, and (3) mantle wedge between the crust and the slab. A reference velocity distribution in each of these 3 domains was set from a-priori information on average composition and temperature in the crust, slab and mantle wedge using temperature- and composition-dependencies of seismic velocities given by mineral-physics. An iterative procedure of tomographic inversion we employ, consists of relocation of sources using both P- and S-phases and simultaneous inversion of P and S travel times for P and S velocities (or temperatures), P and S station corrections, source coordinates and origin times. Superposition of the velocity (or temperature) anomalies with the starting model is used as a reference model in the next iteration. First we have done "usual" inversion for P and S velocities. This inversion resulted in well correlated P and S velocity distributions in the mantle wedge which pointed to the possible temperature origin of these anomalies. Secondly we have inverted the data for temperatures in the mantle wedge and seismic velocities within the crust and the slab. Direct inversion of the seismic data for temperatures provided good fit of the data which was only few percent less accurate than the data fit by the inversion in terms of P and S wave velocities. Obtained patterns and magnitudes of the temperature anomalies are remarkably similar to the results of the thermomechanical models replicating delamination of the lithospheric mantle of the South American plate associated with tectonic shortening of the lithosphere. Reliability of the inversion is confirmed by similarity of the predicted and observed seismic attenuation and gravity.

T21A-03 0830h POSTER

Complexities of the Western Margin of the Trans-Hudson Orogen in Saskatchewan, Canada.

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The north-northwest trending margin of the Trans-Hudson Orogen, from latitude 52W to 59W, in Saskatchewan, is delineated by an 810 km long, mainly positive magnetic anomaly. On the surface this anomalous zone marks the boundary between the Archean Rae/Hearne craton and the Paleoproterozoic accreted terrane of the Reindeer Zone. Three widely separated, variable length regional deep sounding reflection surveys crossed this anomalous trend and determined a consistency along the strike of the crustal images of the western margin of the orogen. Several phases of tectonic development, including multi-stage subduction and continent-to-continent collision could be inferred from the seismic images. On all seismic sections, imbricate set of well-defined thrust sheets delineate the remnants of an orogenic wedge of a near complete convergence with its characteristic pro and retro-shear zones. South of the 52W latitude the north trending magnetic signatures are suddenly terminated in a triangular shaped magnetic low, and followed by the regionally characteristic magnetic features of the Archean Wyoming craton. These complex regional magnetic images clearly indicate that the convergence of the Rae/Hearne and Superior cratons, in the south, was directly and intensively affected by the interference of the Wyoming craton

T21A-04 0830h POSTER

Precise Temperature Estimation in the Central Tibetan Crust From Identification of the α-β Quartz Transition by Project INDEPTH Seismic Profiling

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In the deep crust, temperature, which is among the key parameters controlling lithospheric dynamics, is inferred by extrapolation from the surface using several assumptions that may well fail in regions of active tectonics and fluid migration. In the rare case that temperatures of 700°C or higher are exceeded in the upper/middle continental crust composed of quartz-rich felsic rocks, the α-β quartz transition (ABQT) will occur, generating a measurable seismic signature and offering the possibility for precisely estimating temperature from the known ABQT phase diagram. Here it is shown that all expected seismic features of the ABQT are met by the boundary between the upper and middle crust below the INDEPTH III profile in central Tibet. This implies that a temperature of 700°C is achieved at a depth of 18 km under the southern Qiangtang block, that agrees well with the depth to the top of a high electrical conductivity anomaly, likely representing partially melted crust. To the south in the northern Lhasa block, the ABQT lies at 32 km depth, corresponding to a temperature of 800°C. It thus appears that this seismic boundary representing the ABQT is the result of (recent) geological processes rather than being a lithological boundary.

T21A-05 0830h POSTER

Compositional Variations in the Continental Lithosphere From Seismic Elastic and Anelastic Tomography and Heat Flow Data

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Global seismic tomography models reflect large-scale compositional variations in the mantle; however they are substantially masked by temperature anomalies. Data on the thermal regime of stable continental lithosphere provides an exceptional information on lithospheric properties as it permits to separate thermal and non-thermal effects in global geophysical models. Global elastic and anelastic seismic tomography models based on Rayleigh waves (Billien et al., GRL, 2000) are analyzed jointly with thermal model for the upper 150 km of the continental mantle (Artemieva and Mooney, JGR, 2001). Theoretical Vs(T) and Qs(T) based on experimental data on T-dependence of seismic parameters are used to evaluate the relative contributions of thermal and non-thermal effects into anomalies of seismic velocity and attenuation. The results show that T-variations alone are sufficient to explain seismic Vs and Qs only in ca. 50 per cent of continental regions. In these regions, more than 50 per cent of amplitude of Vs and Qs anomalies should be attributed to non-thermal mechanisms (i.e. compositional variations, fluids, partial melts, scattering). Compositional anomalies due to Fe-depletion can explain the misfit between seismic and theoretical Vs in cratonic lithosphere. In regions of active tectonics, partial melts and/or fluids are likely to affect seismic parameters.

T21A-06 0830h POSTER

Density Structure of the Continental Lithosphere: From Global to Regional Scale

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We use gravity, thermal, and seismic data to reveal density variations within the continental lithosphere and to determine their origin in order to separate the impacts of temperature and compositional variations. Mantle gravity anomalies obtained by removing the crustal gravity effect from the observed field were used as a basis for this analysis. We found that the mantle gravity anomalies vary globally from - 250 mGal to + 150 mGal, with the largest negative anomalies, indicating a low-density lithosphere, being associated with vast Cenozoic regions of plume-lithosphere interaction: the East-African Rift, and the Basin and Range Province of the western USA. The largest positive anomalies over the continents were associated with the Andes, the East European Platform, the Alpine-Mediterranean fold belt and the central - southeastern part of North America. For cratonic areas, we deduce a large range of density anomalies in the subcrustal lithosphere, produced by both temperature and compositional variations. The temperature-induced gravity anomalies under cratons are well correlated with mantle gravity anomalies, however the average density decrease due to depletion for the individual cratons varies only slightly: the maximal values of the compositional density reduction are within 1.7-2.5 %. Large positive compositional mantle density anomalies are found in two distinct regions: (1) near ocean-continent and continent-continent subduction zones, and (2) within some continental interiors, e.g. in the southern part of North America. For North America we construct a detailed model which is based on high resolution seismic data. The density structure of the Canadian Shield perfectly fits the global model and is consistent with chemical depletion. Temperature variations in the upper mantle mostly explain the mantle anomalies in the Western US. The strongest positive compositional anomaly is co-incident with the Gulf of Mexico. Two linear positive anomalies are also seen in the eastern USA and beneath Texas, New Mexico, and Colorado. These anomalies are interpreted as reflecting the evolutionary history of the North American upper mantle.

T21A-07 0830h POSTER

New Heat Flow Map of North and Central America

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A new heat flow map of North and Central America has been compiled. The map is based on all the available standard heat flow measurements on land and marine heat flow data, as well as on bottom hole temperature data, and constraints from geothermal springs. This new map confirms many established trends and improves the information on small scale heat flow variations.

Both on the continent and in the oceans, there is a strong contrast between the eastern and the western parts of North America.

For the oceanic part, the heat flow is high in the Pacific and heat flow contours closely follow the age of the sea floor. The heat flow is lower in the Atlantic than in the Pacific, but it also follows the age of the sea floor. There are small scale heat flow variations in the Labrador Sea and on the margin of Nova Scotia

that do not fit a clear pattern.
On the continent, heat flow variations occur at many different scales with a strong contrast between the low heat flow in the stable eastern provinces (30 – 60mW m^{-2}) and high heat flow in the active western provinces (> 60mW m^{-2}) . The very low heat flow (< 40mW m^{-2}) on the east slopes of the Appalachians, Florida, and in the Gulf of Mexico are possibly due to the effect of groundwater flow and sediment deposition. There are small scale variations in heat flow within the Appalachians, the Canadian Shield, and the stable platform due to variations in crustal heat generation. In the dominantly high heat flow regions of Mexico, the western US and Canada, and Alaska, a striking contrast is formed by a low heat flow band (< 45mW m^{-2}) parallel to the present and past subduction zones.
The map and CD Rom containing all the relevant information are available from the American Association of Petroleum Geologists.

T21A-08 0830h POSTER

Scale of heat flow variations in the Canadian Shield: Implications for the deep structure of the lithosphere

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We compare the two end-member models have been proposed to explain the variations in surface heat flow in stable continents. These models call for changes of either crustal heat production or heat flow at the base of the lithosphere. We show that the scale of the surface heat flow variations controls how these variations affect the thermal structure and thickness of the lithosphere, and provides constraints on these models.
We have used the data from the Canadian Shield and the Appalachians that are now extensive enough to adress problems of scale and relationship between average heat flow and heat production. We have analyzed the global data set as well as data from five compositionally distinctive subprovinces where a meaningful average could be calculated. Within each province, on scales < 500 km, observed heat flow variations are linked to changes of local crustal structure. For the five subprovinces, the average values of heat flow ($\overline{Q}$) and heat production ($\overline{A}$) conform to the simple relationship $\overline{Q} = Q_o + H\overline{A}$, where $H \approx$ 9km and $Q_o \approx$ 33 hfu. This shows that, on scales larger than the dimensions of these provinces (> 500 km), there is no variation in basal heat flow and hence that variations in crustal heat production dominate. The large heat flow step at the Grenville-Appalachian boundary (≈ 16 hfu) may be accounted for by a change in crustal heat generation only. In that case, the lithosphere is ≈ 50km thinner in the Appalachians than in the Shield.
At wavelengths of 500 km or more, mantle heat flow variations are constrained to be smaller than the detection limit of heat flow studies, or about ±2 hfu. Such variations imply temperature differences which may be as large as 400 K at 150 km depth, which are consistent with seismic shear wave velocity variations and geothermobarometry studies on mantle xenoliths.

T21A-09 0830h POSTER

Thermal Expansivity and Elastic Properties of the Lithospheric Mantle Derived From Mineral Physics of Composites

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The elastic properties and the coefficient of thermal expansion (CTE) of the lithospheric mantle are important parameters that affect the results of lithospheric modeling. However, there is still no consensus on which values are the most appropriate to model the lithosphere, and "average" values are used for lithospheres of different age, thermal state, and composition. We present an integrated approach to calculate the elastic properties and the CTE of mantle rocks, based on the mineral physics of composites and considering the spatial heterogeneity of the lithospheric mantle. Representative values are calculated for three lithospheric domains: a) Archean/Proterozoic lithosphere (AL), b) Phanerozoic continental lithosphere (PL), and c) oceanic lithosphere (OL). The method considers the dependence of parameters on pressure and temperature, following a procedure based on an extension of the shear-lag model (Cox, H.L., Br. J. Appl. Phys. **3**, 72-79,1952) and thermal expansivity systematics. For the case of AL, values of CTE between 3.04 and 3.11x10^{-5} K^{-1} are acceptable for numerical modeling, and a constant depth-derivative for P waves $\partial V_p/\partial z \sim$2.3x10^{-3}s^{-1} is estimated. The corresponding temperature-derivative, using a type geotherm, is $\partial V_p/\partial T \sim$ 5x10^{-4} km s^{-1} K^{-1}. Results for PL show that no single average value of CTE can be used in modeling these lithospheric sections. Values range nonlinearly between 3.05 and 3.47x10^{-5} K^{-1} at pressures equivalent to depths of 10 and 100 km, respectively. The P-wave velocity variation with depth exhibits a steep decrease in the range of 10 – 40 km, followed by almost a constant value of ∼8.08 km s^{-1} between 40 and 60 km, and a systematic increase with a depth-derivative $\partial V_p/\partial z \sim$ 1.12x10^{-3}s^{-1} from 60 km downwards. The variation in the CTE is largest in OL. In young plates (< 20 Ma), values of the CTE range non-linearly from 3.05 to 3.82x10^{-5} K^{-1} at pressures equivalent to depths of 5 and 50 km, respectively. In old OL (∼ 100 Ma), the CTE is slightly smaller, with predicted values in the range of 3.04 to 3.7x10^{-5} K^{-1} at 10 and 80 km, respectively, giving a typical average value of ∼ 3.44x10^{-5}K^{-1}. P-wave velocity in young OL decreases from ∼ 8.14 to 8.05 km s^{-1} in the first 30 km, then follows a nearly constant path downwards. In old OL, on the other hand, a systematic reduction from ∼ 8.2 to 8.09 km s^{-1} in P-wave velocities is predicted as depth increases form 10 to 80 km.

T21A-10 0830h POSTER

Seismic Wave Velocities and Poisson's Ratios of Ultrahigh-Pressure Metamorphic Rocks: Implications for Deep Structure of the Continental Lithosphere and Origin of Mantle Reflections

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The P-wave velocities (Vp), S-wave velocities (Vs), pressure derivatives (V'), anisotropy (A) and Poisson's ratios (σ) of three types of eclogites and country rocks from the Dabie-Sulu ultrahigh-pressure (UHP) metamorphic belt, China, have been determined for confining pressures up to 1000 MPa. Type-1 eclogites are coarse-grained and subjected to recovery-accommodated dislocation creep at peak metamorphic conditions (in the diamond stability field). Type-2 eclogites are fine-grained reworked Type-1 materials that experienced recrystallization-accommodated dislocation creep under quartz/coesite boundary conditions during the early stage of exhumation. Type-3 eclogites are retrograde samples that were overprinted by amphibolite facies metamorphism during a late stage of exhumation within the crust. Type-1 eclogites are richer in Al_2O_3 and MgO but poorer in SiO_2 and NaO_2 than Type-2 and Type-3 eclogites. Seismic anisotropy of Type-1 and Type-2 eclogites is generally low (< 4% at 600 MPa), while Type-3 eclogites can exhibit high anisotropy (> 10% at 600 MPa) due to the presence of strongly anisotropic retrograde minerals such as amphibole, plagioclase and mica. The velocity-pressure relationship can be described by $V = a(\ln P)^2 + b\ln P + c$ $(P \leq P_c)$ and $V = V_0 + gP$ $(P \geq P_c)$, where P_c is the critical pressure depending mainly on the density and distribution of microcracks and in turn on the deformation history of rocks; a and b are constants describing the closure of microcracks below P_c; c is the velocity when P is equal to one; V_0 is the projected velocity of a crack-free sample at room pressure, and g is the intrinsic pressure derivative above P_c. The mean seismic velocities of the eclogites in the linear regime: $Vp = 8.42 + 1.42 \times 10^{-4}P$ and $Vs = 4.751 + 1.428 \times 10^{-4}P$ for Type-1, $Vp = 7.796 + 1.58 \times 10^{-4}P$ and $Vs = 4.44 + 1.743 \times 10^{-4}P$ for Type-2, $Vp = 7.33 + 2.073 \times 10^{-4}P$ and $Vs = 4.22 + 1.966 \times 10^{-4}P$ for Type-3, where velocity is in km/s and P in MPa. The decrease in V_0 and increase in g from Type-1 to Type-3 eclogites is attributed to a decrease in garnet content and an increase in retrograde minerals. Seismic results for the lower crust in the Dabie orogenic belt (Vp = 6.8 km/s, σ = 0.27) are consistent with an appropriate mixture of felsic gneiss and quartzite with eclogite, marble, anorthosite and serpentinized peridotite, as observed in the surface exposures and drill holes. Furthermore, the NE-SW trending and NW-dipping, slab-like high Vp anomaly (8.72 km/s at a depth of 71 km), which extends from the Moho to at least 110 km beneath the Dabie-Sulu region, can be interpreted as the remnant of a subducted slab that is dominated by Type-1 eclogites and has frozen in the upper mantle since about 220-200 Ma. Such relic crustal materials, subducted and preserved as eclogite layers intercalated with felsic gneiss, garnet-jadeite quartzite and marble, could be responsible for regionally observed seismic reflectors in the upper mantle.

T21A-11 0830h POSTER

Thermal-Rheological Structure of the Continental Lithosphere in Western and Eastern China: Constrains on Cenozoic Intra-continental Deformation

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As a typical region of lithospheric thinning/ thickening, the continents of the eastern and western China are one of the best natural laboratories for Cenozoic intra-continental deformation . Here we investigated the thermal-rheological structure of the continental lithosphere in Eastern and Western China and its implication for Cenozoic geodynamic process. Our results show that the basins in eastern China are of high thermal regime, characterized by relatively large heat flow derived from mantle and high temperature at Moho, and belong to cold crust and hot mantle of high temperature type; whereas the basins in western China are of low thermal regime and have hot crust and cold mantle of low temperature type. Rheological profile reconstruction of the continental lithosphere shows that eastern China has relatively low lithospheric strength, characterized by shallow brittle-ductile transition depth and a relatively thinner thermal lithosphere, and its mechanical competent layer is the upper crust. Contrarily western China has a stiffer lithosphere with deep brittle-ductile transition depth and large thermal thickness, and its mechanical competent layer is the upper mantle. These differences in thermal-rheological characteristics of the continental lithosphere between eastern and western China can account for the distinct Cenozoic tectonic deformation that is associated with the subduction of western Pacific plate into southeastern Asia and the India-Asia continental collision, respectively. In the northwestern China, due to the interplaying between relatively rheological stiff blocks such as Tarim Basin, Dzungar Basin and the weak one of Tianshan Mountain, Cenozoic deformation is characterized by tectonic uplifts of the Tianshan and the western Kunlun Mt., and the flexural deformation of the Tarim basin caused by tectonic and sedimentary loads during this orogenic event. On the contrary, eastern China developed a series of extensional basins with NNE trending due to tectonic inheritance of pre-existing weak zones, in response to back-arc spreading associated with the subduction of western Pacific plate into Southeast Asia. In conclusion, thermal-rheological heterogeneity of continental lithosphere and tectonic inheritance of pre-existing weak zones account for the intra-continental deformation, taken the applied plate boundary condition and geometry of the continent into account.

T21A-12 0830h POSTER

Multiphase Modeling in the Fate of Detached Slabs in the India-Asia Collision

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P-wave velocity anomalies under Tibet, India and north of Indian Ocean reveals the existence of cold patches at different depths ranging from one to two thousand km. These are interpreted as fossil detached slabs due to former subducting Tethyan oceanic lithosphere, while a regional northward-dipping slab under the Hindu Kush region in northeastern Afghanistan and southern Tajikistan in the entire upper mantle is believed to be the remnants of delaminated subcontinental Indian lithosphere (Van der Voo et al., 1999). In our previous studies we have shown the influence of depth-dependent viscosity profiles on the fate of these descending slabs which were believed to have been recycled in deep mantle during the last 45 Myr, past from India-Asia collision. In this work we study the influence of double-phase transition at 400 km and 670 km depths and its contribution for this retarding effect. Employing finite differences in a full cylindrical shell we compare the results of double-phase and single-phase boundary models with the results of no-phase boundary models with both constant and depth-dependent viscosity profiles.

T21A-13 0830h POSTER

The Subsurface Geometry of The Peel Fault from Magnetic Data, NSW Australia

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The Peel Fault is the present-day boundary between the Tamworth Belt (forearc basin) and the Tablelands Complex (accretionary wedge) of the New England Fold Belt, eastern Australia. Previous magnetic survey data suggests a dip on the Peel Fault of 65° to the east with 5 km depth extension, but seismic data proposed that the Peel Fault has had a complex movement history, a west-dipping structure probably truncating the east-dipping Peel Fault, at a depth of about 1 km. The ultramafic rocks (most serpentinized) associated with the Peel Fault in the southern New England Fold Belt have a strong magnetic signature that provides a possibility to determine the extent of their depth and the angle of dip along the fault plane. Six ground magnetic surveys were conducted, and data has been modelled to constrain the subsurface of the Peel Fault. Both bulk susceptibility and remanence have been incorporated into model. The NRM of the magnetic bodies parallels the present geomagnetic field. Magnetic properties were assigned to match the anomalies and still be within measured values for serpentinite. The sensitivity analysis of the susceptibility of the serpentinite illustrates the observed anomalies of around 2000 nT over the Peel Fault require a susceptibility of at least 4000 to 5000×10^{-6}CGS, which is consistent with the measured susceptibilities of serpentinite samples, ranging from 2000 to 10000×10^{-6}CGS. The sensitivity analysis of the depth extension of the serpentinite bodies shows magnetic responses at 3 km, 4 km, and 5km are very similar. The extension of the depth of the serpentinite can't be fully excluded by the modelling. The modelling of the six magnetic profiles indicates that the serpentinite has a vertical dip or a relatively steep dip to the east. The minimum depth to the base of the serpentinite is variable from 800m at Bingara to 3 km at Attunga, but a maximum depth extent cannot be established. The modelling of a magnetic profile located 6 km north of the seismic line indicates that the serpentinite dips to the east and has a depth extension of at least 2 km with an average susceptibility, but if a higher than average susceptibility is used than the depth to the base of the serpentinite could be of the order of 1 km.

T21B CC: 220 C-E Tuesday 0830h

Assembly and Poststabilization Evolution of the Cratonic Lithosphere I Posters *(joint with G, GP, S, V, NS, MR)*

Presiding: **C Lee,** Rice University**; S E Zaranek,** Brown University

T21B-01 0830h POSTER

Correlation of Effective Elastic Thickness and Seismogenic Thickness in the Continental Lithosphere of India

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The earthquake focal depths depend on many of the same parameters as effective elastic thickness (Te). Studies show that the focal depth distribution of earthquakes and the association of gravity anomalies with topography are the most accessible indicators of the lithospheric strength. In the present study, estimates of effective elastic thickness (Te) in the continental lithosphere of India have evidenced a good correlation with the average earthquake focal depths, commonly known as the seismogenic thickness (Ts). Earlier Te estimations based on 2-dimensional multitaper method for diverse tectonic provinces of South Indian Shield yielded consistently lower values in the range of 11-16 km, which is even lower than estimates in other shield regions of the world. The northern parts of the Indian Shield yielded relatively higher values of Te in the range 20-25 km, marking the Central Indian Tectonic Zone acting as a major Proterozoic tectonic divide between the Northern and Southern blocks. The available earthquake focal depth data also shows a similar difference between these two blocks. The southern block characterizes relatively shallow focus earthquakes, compared to the depth of occurrence in the northern block. The Te values in the Southern block, almost coincident with the upper crustal thickness, suggests that its lithospheric strength is mostly confined in the upper crust. On the other hand, the higher Te obtained in the Northern Block suggests its lithospheric strength contribution from both upper and parts of lower crusts. The brittle-ductile transition is also important, since it gives a correlation with the depth of seismicity. The low mantle heat flux calculated for the Jabalpur earthquake occurred at a depth of 35 km, suggests a relatively cooler and brittle lower crust. However, the seismogenesis of stable continental region (SCR) earthquakes show different source mechanisms, as evidenced in Kachchh, Kilari and Jabalpur earthquakes. Also, it is to be noted that the nucleation of lower crustal earthquakes need not necessarily discard the ductile nature at that depth, since the instabilities in ductile flow itself may act as nuclei for deep crustal earthquakes. The Te extending to the lower crustal layers observed in the Northern block of the Indian shield suggests a possibility that the lower crust contributing even more strength than the upper mantle and support the surface and subsurface loads, at least in some parts of the shield.

T21B-02 0830h POSTER

A Merged Surface-Wave Based Image of the North American Upper Mantle

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The North American lithosphere is an assemblage of a wide variety of continental domains and ages, ranging from the Archean Slave province to the young orogenic belts of the Cordillera. North America is therefore a target of great interest for lithospheric tomography. We apply the partitioned waveform inversion method, a well-established form of surface-wave tomography, to a combined data set containing results from two previously published studies centered on Canada and the United States, as well as additional data exploiting the geometry of the combined model, for a total of over 1400 seismograms. We select a final model based on data fit, smoothness of features and limited anomalous structure. The final model is compatible with both data sets used for the previously published regional models, providing a state-of-the art model tying together structures across the Canada-U.S. border. The most important large-scale features of the model are the high-velocity, rigid root beneath the Canadian shield, which extends to depths of 200-300 km, and the low velocities beneath the tectonically active Cordillera, which reach 200 km depth. The boundary between the two features is a sharp line which follows the Rocky Mountain Front for most of its length.

T21B-03 0830h POSTER

Seismic evidence for the lateral and vertical growth of cratons

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Deep seismic reflection profiles collected across Proterozoic-Archean margins are now sufficiently numerous to formulate a consistent hypothesis of how continental nuclei grow laterally to form cratonic shields. Similarly, teleseismic (earthquake) studies across the cores of cratons now provide evidence of growth structures in the form of seismic velocity and anisotropy variations and layers bounded by discontinuities. Within the upper 150 km of several Canadian cratons seismic anomalies and discontinuities indicate that the earliest continental blocks grew by underthrusting and stacking of relatively thin (80-100 km) lithosphere. At the craton margins, the older (Archean) block appears to form a wedge of uppermost mantle rock embedded into the more juvenile (Proterozoic) block by as much as 100-200 km at uppermost mantle depths and Archean lithosphere is therefore more laterally extensive at depth than at the surface. Particularly bright reflections along the Moho are cited as evidence of shear strain within a weak, low-viscosity lower crustal channel that lies along the irregular top of the indenting wedge. The bottom of the wedge is an underthrust/subduction zone, and associated late reversal in subduction polarity beneath the craton margin emerges as a common characteristic of these margins although related arc magmatism may be minor. The Proterozoic subduction zones can be traced beneath the cratons at 150-300 km depths. Geochronology of granitic intrusions and xenoliths suggests that the stacked cratonic core was intruded, metasomatized and generally modified by melts rising from these subduction zones. An increasingly better documented history of sporadic kimberlite eruptions indicates that mantle melts unrelated to subduction also contributed to craton growth at depth by partly destroying lithopshere.

T21B-04 0830h POSTER

On the possible role of chemical boundary layers in regulating the thermal thickness of continents and oceans

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One of the most important observations made during the early developments of plate tectonic theory was that the depth of the seafloor initially (for the first 70 Ma) increases with the square root of the crust's age and that the accompanying heat flow decreases as the inverse of the square root of age. It was subsequently shown that the sqrt(t) relationships could be explained by approximating the growth of the upper thermal boundary layer (TBL: the boundary layer over which the mode of heat transfer changes from advective to conductive) of the Earth's convecting interior by an infinite half-space conductive cooling model. This model, which we term the boundary layer model, predicts that the thickness of the TBL increases monotonically with the square root of seafloor age according to the relationship, L = sqrt(4kt), where L is the thermal thickness, t is time, and k is thermal diffusivity. For a thermal diffusivity of 30 km2/Ma, this relationship takes the form, 11 sqrt(t), where L is in km and t is in Ma. By accounting for thermal contraction and the decrease in thermal gradient across the growing TBL, the evolution of seafloor depth and heat flow with time follow accordingly. The success of