

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 sub-continental 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 serpentinitized) 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 5 km 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 (T_e). 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 (T_e) in the continental lithosphere of India have evidenced a good correlation with the average earthquake focal depths, commonly known as the seismogenic thickness (T_s). Earlier T_e 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 T_e 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 T_e 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 T_e 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, Kilar 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 T_e 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 lithosphere.

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

the boundary layer model in linking the kinematics of seafloor spreading to the depth and heatflow of <70 Ma old lithosphere represents the strongest evidence so far that plate tectonics and convection are linked. However, the boundary layer model breaks down at 70 Ma after which the heat flow and seafloor depth saturate at constant values. At the same time, it appears from seismic studies that the TBL thickness also saturates at a maximum value of 90-100 km. Many models have been proposed to explain the discrepancy between the predictions of the boundary layer model and the geologic features of post-70 Ma lithosphere. Most of these models, however, are difficult to test. Here, we present a testable model that explains the evolution of oceanic TBLs by invoking a pre-existing chemical boundary layer (CBL). We base this hypothesis on a growing understanding of the deep thermal and compositional structure of continents. Continents are underlain by a thick melt-depleted and dehydrated mantle layer, the former resulting in buoyancy and the latter resulting in increased viscosity. Radiogenic isotopic studies indicate that these CBLs do not significantly deform over billion year timescales, implying that on the timescales of mantle convection, such CBLs act as rigid lids resting on top of and separated from the convecting mantle. For this reason, the upper TBL of the convecting mantle therefore consists of a purely conductive layer (represented by the rigid CBL) and a convective sub-layer (CS-L), which lies just beneath the CBL and represents the actively convecting part of the TBL. We show using petrologic and geodynamic arguments that the thickness of the CBL beneath continents may limit the thickness of the convective sublayer and accordingly, the thickness of continental TBLs. Petrologic observations require that the seafloor also be underlain by a melt-depleted and dehydrated mantle layer, albeit thinner than that beneath continents. The base of this layer roughly coincides with the thermal thickness at which the boundary layer model breaks down. By analogy with our continental studies, we suggest that the presence of a CBL beneath oceanic crust may also be responsible for maintaining a constant thickness of oceanic TBLs beyond 70 Ma. A future test of this hypothesis would be to seismically map whether there exists a crossover between the CBL and TBL beneath oceans and, if so, whether the crossover occurs at 70 Ma.

T21B-05 0830h POSTER

Geodynamic Setting of Kimberlites

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As an alternative to the plume/hotspot hypothesis for kimberlite distributions, the role of inherited lithosphere anisotropy and episodic deviations to the lithosphere stress state is reviewed using Southern Africa as a test case. The analysis includes (a) a framework of lineaments defined by geology, aeromagnetics, gravity and geomorphological data, (b) the distribution of some 2000 kimberlites, 10 % of which have been dated, (c) the record of global tectonic events. The distribution of kimberlites in Southern Africa is strongly clustered. Occurrences within clusters resolve variable trends, depending on the age and position of the cluster. Rocks are commonly hosted by en-echelon fault arrays, (anti-)Riedel, P- or T-structures. However, on a regional to continental scale, the distribution of clusters appears controlled by trans-continental and probably trans-lithospheric structural elements, e.g., an association of kimberlites with tips or shoulders of rifts, with major pre-existing dyke swarms, with bends or step-overs of continental fracture zones. This deviation from the conventional plume/hotspot model is supported by a strong dependence to the inherited lithosphere architecture, but also the common lack of time-progressive volcanic tracks, and parallelism of same-age volcanic tracks across the subcontinent. Similar lithosphere trends are observed as anisotropies associated with the cratonic keel, craton edges and marginal orogenic belts, the Karoo event, the East Africa Rift, as well as the extension of oceanic fracture zones into the African continent. We suggest that peaks in kimberlite magmatism in southern Africa at 140, 120, 85 and perhaps 67 Ma are caused by major plate reorganizations following the break-up of the supercontinent Gondwanaland. These events are also closely associated with internal deformation of interior basin and passive margin sediments of the African plate and abrupt changes in the relative plate vector of Africa with respect to Eurasia. It appears that the lithosphere structure (rheological anisotropies) not only localised sites of eruption but also provided the required conditions for melting. Bulk horizontal shear strain and resultant tension caused localized decompression melting of metasomatised mantle lithosphere, generating kimberlites and related magmas.

T21B-06 0830h POSTER

The surface geodynamic expression of ongoing density stratification in heated continental crust

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In addition to vertical density variations, continental crust has significant lateral density variations caused by lithological differences. In stable crust, these loads are supported by elastic stresses. Thermal reactivation of the crust thins the elastic upper crust, reducing its ability to support such loads. Mid-crustal loads may detach entirely from their elastic support if this thermally induced thinning is pronounced enough, and sink through the ductile lower crust to a depth where they are neutrally buoyant. Over time, this process should help generate stable density stratification of the crust despite magmatic processes that should lead to density inversions, as noted by Glazner (1994). We have numerically modelled this process with a fully coupled large deformation thermal-viscoelastic code (THERMAX2D, based on the commercially available FEMLAB PDE solver). The (Newtonian) viscosity is temperature-dependent; upper crustal brittle failure is modelled in a distributed way using a plastic yield stress. We confirm Glazner's approximate analytic estimates of foundering velocities of several km/Ma. A new and striking result is that vertical displacements of intracrustal material of 20 km or more can occur with a relatively minor geodynamic expression at the surface. Once the elastic upper crust sheds a load into the ductile lower crust, it is almost completely mechanically decoupled from the load's further behaviour. A basin with a depth of a few km develops initially as the elastic crust initially thins; after the load is shed, this basin inverts in response to residual flexural stresses in the upper crust.

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T23A CC: 516 D Tuesday 1330h

Mantle Dynamics and Surface Observables I (joint with G, GP, P, S, SEDI)

Presiding: R Pysklywec, University of Toronto; S L Butler, University of Saskatchewan

T23A-01 1330h

Formation and Exhumation of UHP Metamorphic Crustal Rocks Within an Evolving Mantle Lithosphere Downwelling

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Ultrahigh-pressure (UHP) metamorphism of certain crustal rocks suggests that such material has traversed to significant sub-crustal depths and back to the surface while being maintained at relatively cool temperatures. The process has commonly been explained in terms of plate subduction, with the continental crust subducted to great depths and then returned within a subduction channel or as an extruding slice. Using numerical models of the thermomechanical evolution of the crust-mantle system, we investigate an alternative mechanism to account for the genesis of UHP crustal rock. The numerical experiments show that in the early stages of collision, packages of lower crustal material are entrained to depth into a thickened mantle lithosphere root beneath the young model orogen. Subsequently, the mantle lithosphere root "drips" into the mantle as a Rayleigh-Taylor-type gravitational instability, resulting in deep burial of the entrained crust. The buoyant crustal material eventually separates from warming mantle drip and rises to the base of the crust. Late stage exhumation of the crust to the surface occurs more slowly, related to exhumational processes operating within the still active collisional orogen. The P-T evolution of the buried crust is tracked in the experiments and we find its history is consistent with those observed for UHP metamorphism. We propose

this model of burial and uplift of crustal material enclosed in an mantle lithosphere drip/downwelling during young, cold continental plate collision as an alternative to traditional subduction models of UHP crustal burial. The mantle drip model is consistent with a number of geological observables of UHP rocks in continental collision zones and may have several favourable features over a subduction channel/extruding slice models.

T23A-02 1345h

Admittance Functions for Axisymmetric Loading of a Viscous Layered Lithosphere

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Direct detection of small-scale convection beneath the continental lithosphere is difficult because the amplitude of measurable anomalies produced by the convection is likely to be small relative to those caused by internal lithospheric structure. Even for a simple lithospheric structure, the convection signature is filtered and possibly attenuated by the overlying lithosphere. The response of an elastic lithosphere to external loading is relatively simple, and is well understood in principle. The layered lithosphere can deform only by flexure, and the resulting surface elevation and gravity anomalies are simply expressed in terms of horizontal wavenumber. The amplitude of deflection in the wavenumber domain may be expressed either as the convolution of the impulse response and the load function, or as a filter that acts on the load function in the wavenumber domain. For an elastic layer the important parameter is the flexural rigidity, proportional to elastic modulus and to layer thickness to the third power. In some circumstances, however, the lithosphere demonstrates a viscous response as well as an elastic response. Vertical loading then produces a response that drives the relaxation of internal density interfaces such as the Moho and the upper surface. For each interface the relaxation may be described as exponential decay for a pure harmonic initial deflection, assuming that the stratification is stable and viscosity is Newtonian. Typically, the deflection function includes a broad harmonic content, and the responses from multiple internal interfaces interfere, so that surface response and gravity signal may show complex time dependence. Using a 2D finite element method, numerical solutions can be obtained for the response of a viscous layered medium to axisymmetric loading. Admittance functions (ratio of gravity to topography in the wavenumber domain) are widely used to infer elastic properties of the lithosphere, but may also be defined for a viscous lithosphere. In this paper we examine the variation of viscous admittance functions for the case of axisymmetric loading by normal stress at the base of a viscous lithosphere, and contrast these with the widely used admittance functions for top and bottom loading of an elastic lithosphere.

T23A-03 1400h INVITED

Flow Down Below: Mantle Deformation in Supra-Slab Wedges Sensed with Birefringent Shear Waves

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Studies of seismic anisotropy indicators have become a standard part of efforts to understand the dynamics of the upper mantle. Among various techniques that can sense seismic anisotropy at depth the shear wave birefringence method stands out due to its apparent simplicity, both in terms of performing measurements, and interpreting the results. A common logical pathway for an observed shear wave to associates an estimate of its fast polarization direction with the lattice-preferred orientation of olivine crystals along the wave's path, leading to conclusions about mantle flow direction. However, as the data base of shear wave birefringence measurements has grown, pitfalls in common interpretations have emerged. In this presentation we re-examine the relationship between birefringence and the flow pattern in the supra-slab mantle wedge. Computer simulations of *S* waves in a corner-flow deformation pattern confirm the expected similarity between the flow direction and the fast shear polarization. Important caveats emerge, however, regarding the robustness of measurements in a region close