subduction zone through our anisotropic models along similar travel paths as those observed by Wookey et al. We find that the magnitude of the generated shear-wave splitting is significantly dependant on the mantle viscosity structure. A subduction model with viscosity increases at 410km and 660km generates up to 6 seconds of shear-wave splitting from a source placed at 660km depth and rays traced to epicentral distances of 25°-65°. The magnitude of this shear-wave splitting is similar to the Wookey et al observations. A sensitivity analysis of shear-wave splitting to mantle viscosity structure requires a 10-fold viscosity increase at 410km and 660km depth and supports a viscosity structure similar to that proposed by Steinberger (2000). Observations of topmost lower mantle shear-wave splitting have the potential to constrain mantle viscosity structure.

T32B-0936 1330h POSTER

Self-Consistent Formation of a low Viscosity Zone

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The role of a low viscosity zone in stabilizing plate motion has been proposed by convection models in which a low viscosity zone (LVZ) below the surface has been prescribed. In this case a plastic yield stress serving as deformation mechanism for the stiff surface is combined with a viscosity drop below the thermal boundary layer. As a result regions of constant velocity and continuous motion was observed.In contrast to models that prescribe the formation of the LVZ, we combine a three-dimensional numerical mantle convection model with a temperature-, stress- and pressure-dependent rheology. The additional variation of viscosity with pressure yields the self-consistent formation of a low viscosity zone. However in pressure-dependent viscosity convection not automatically a low viscosity zone forms. The LVZ only appears under a certain parameter combination. Depending on the parameter combination different regimes of convection arise. A stagnant lid type of convection prevails at high yield stresses and a mobile lid type at low yield stresses. In between an episodic regime occurs in which regions of constant velocity are observed on short timescales. These regimes have already been discussed in studies considering a temperature and stress dependence. But for additional pressure dependence of the viscosity a further regime results. In this regime a plate-like (i.e. rigidly moving) surface is observed and plate motion is stable on long timescales. The variation of viscosity with pressure thus is of capital importance in the generation of the LVZ, but furthermore the interaction of all rheological parameters is relevant. In none of the regimes apart from that showing stable plates a viscosity drop beneath the surface was observed even though a pressure dependence was assumed. Thus the existence of continuously moving plates and the presence of a low viscosity zone are two coupled phenomena.

T32B-0937 1330h POSTER

3D Postglacial Rebound With Lateral Rheological Heterogeneities

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We study the Earth response to the melting of the Pleistocene ice sheets by a numerical 3D FE approach. Starting from a reference spherically symmetric Earth model, which has been successfully benchmarked with available solutions based on the viscoelastic normal modes, we include laterally varying structures to discriminate which kind of heterogeneities can be revealed by relative sealevel and geodetic datasets. We focus on the lateral variations in the lithosphere and upper mantle, and we assume a viscoelastic Maxwell linear rheology in all of our computations. In the lithosphere we include a global regionalization which accounts for oceanic, continental and cratonic provinces, whereas in the upper mantle the main feature studied is a low-viscosity region beneath the oceanic plates. Since a high-resolution analysis is not possible due to the huge computer requirements of the FE model, our present analysis is adequate to the study of the effects of the long-wavelength mantle heterogeneities. Our preliminary results suggests that the departure from the spherical symmetry can affect both the predicted relative sealevel curves and the present-day rates of deformation measured by geodetic methods.

T32C MCC: 3005 Wednesday 1340h

Mantle Dynamics and Continent-Mantle Interaction II *(joint with S, V, MR, DI)*

Presiding: **L Moresi,** Monash Cluster Computing, Monash University**; C Jaupart,** Institut de Physique du Globe de Paris

T32C-01 1340h

Effects of Model Geometry on the Dynamics of Mantle Plumes

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Mantle upwelling plumes are derived from thermal boundary layer instabilities at the bottom boundary of convective mantle. They play an important role in cooling the core and producing hot-spot volcanism. Most previous studies of plume dynamics have employed either 2D or 3D Cartesian models. In this study, we formulated models in Cartesian and spherical geometries to investigate the effects of model geometry on the plume dynamics. For each type of models, we explored a large parameter space of Rayleigh number and temperature-dependent viscosity. From the modeling, we determined scalings for the number and radius of plumes and spacing between plumes. We also determined the heat transferred through upwelling plumes or plume buoyancy flux. We found that plume dynamics are sensitive to model geometry. In 2D Cartesian models, the sensitivity of the number of plumes to Rayleigh number appears different from that in 3D models. This is mainly because that in the 2D models, upwelling plumes have a sheet-like structure, while they display quasi-cylindrical structure in the 3D models. For the same Rayleigh number, upwelling plumes are more vigorous in 3D spherical models than in 3D Cartesian models. This results from the fact that with different surface areas between the top and bottom boundaries in spherical models, the temperature difference across the bottom thermal boundary layer in spherical models needs to be significantly larger than that across the top thermal boundary layer and that in Cartesian models, leading to more unstable bottom thermal boundary layer in the spherical models. As a result, upwelling plumes in spherical models transfer a significantly larger fraction of the core-mantle heat flux than those in Cartesian models do.

T32C-02 1355h

Thermal Perturbations Caused by Large Impacts and Consequences for Mantle Convection

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We consider the manner in which large impacts, with projectile radii in the range of 50-500 km and incident velocities of 10-20 km/s, may perturb circulation in the mantles of solid planets with dimensions comparable to those of the Earth and Mars. In particular, we address the possibility that such impacts may initiate or disrupt deep mantle plumes. We consider three mechanisms whereby these impacts may initiate instabilities in a thermal boundary layer (TBL) at the core-mantle boundary (CMB) and lead to the formation of plumes: (1) direct heating of the CMB-TBL; (2) the lifting of TBL isotherms by relaxation of impact-related thermal perturbation; and (3) local or global disruption of circulation patterns in the CMB-TBL, causing motion to slow or stagnate and instabilities to grow. In order to evaluate the merits of mechanism (1), we first determine under what circumstances the CMB-TBL is heated significantly by large impacts. The projectiles are assumed to impinge upon a chemically homogeneous layer with an STP-centered shock equation-of-state (EOS) that is reasonable for lower-mantle materials in the Earth and Mars. We make several estimates of waste heat with increasing distance from the impact's isobaric core, using a range of peak-pressure decay laws, and also considering the effects of gravity: i.e., of increasing density and pressure with depth. The consequences of gravity are addressed by calculating re-centered Hugoniots and impedance match solutions for a shock wave propagating through a stack of layers whose densities and interface pressures increase with depth. The consequences of adding a chemically distinct upper-mantle layer with a different shock EOS is also considered. In order to complete our evaluation of mechanism (1) and in order to assess the merits of (2) and (3), we estimate the two-dimensional structure of thermal perturbations caused by large impacts, and add these to the temperature-field solutions of 2-D finite-element calculations of mantle convection. We then use this code to simulate the subsequent evolution. Our perturbations have the geometry of a squashed inverted hemisphere with a two-fold structure: (i) an inner hemisphere of partial melt; and (ii) an outer region characterized by the power-law decay of shock-related temperatures. The subsequent evolution may be summarized as follows: (a) the volume affected by the perturbation relaxes by rising and flattening; (b) the lateral motion of this relaxation locally stabilizes the mantle-lithosphere, inhibiting the initiation of downwellings and disrupting the local circulation pattern; and (c) the relaxation stalls and a new pattern is established. For the models considered, plume initiation by mechanism (3) appears to be far more important than (1) and (2). We find a range of Rayleigh numbers and impact energies for which the pattern reorganizes significantly, causing the extinction and initiation of plumes and even periods of chaotic global reorganization during which volcanism may intensify dramatically.

T32C-03 1410h

Conversion of Poloidal Energy in the Mantle to Toroidal Motions of Surface Plates - A Numerical Investigation

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Equal partition of poloidal and toroidal energies of surface plates has been reported by many investigators. It has also been pointed out that convection within a constant viscosity mantle is unable to produce toroidal motions at the surface. Thus, surface plate rotation remains a problem of considerable interests in the theory of plate tectonics. Several investigators have suggested subsequently that lateral viscosity variations can excite toroidal motions. Because mantle viscosity is strongly temperature-dependent and lateral temperature variation is the main driving mechanism of mantle dynamics, a source to produce toroidal energies appears readily available in the mantle. Unfortunately, numerical simulations of convection with strong temperature-dependent viscosity show that the amount of toroidal energy produced can only reach about 20% of the poloidal energy using a viscosity contrast of 5 orders of magnitude. Simulations with greater viscosity contrasts are computationally difficult at present. Here, instead of treating the mantle and the lithosphere as a single system, we decide to model the lithosphere as a rigid lid resting on a dynamic mantle. We seek to study the interactions between a circular solid top and a cylindrical impinging plume. In addition, we also wish to examine the effects of a solid lid with bottom topographic variations to the generation of rotational motions at the surface. Our results indicate that rotational torques of a rigid lid is dependent on the separation between the center of mass of the lid and the stagnation point of the impinging plume. If a plume impinges at the center of mass of a rigid lid and if the lid possesses a plane of symmetry that goes through its center of mass, no net torque is produced. Thus, as long as up-welling and down-going currents of the mantle occur away from the center of mass of a surface plate, net torques can be realized to produce plate rotation and show toroidal motions at the surface.

T32C-04 1425h

Is the Wilson Cycle Caused by the Memory Effect of Water?

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Did the Atlantic close and then re-open ? *(Nature, 211, 676-681, 1966)*. John Tuzo Wilson's cyclical event of opening and closing of ocean basins, later found to be a generally applicable, became the "Wilson cycle" *(Dewey, J.F., and Burke, K., Nature, v.249, p.313-316)*.Whilst the cyclical nature appears to be understood what then breaks and consumes the oceans at roughly the same location? Remnant textural anisotropy, structural damage and intra-crystalline water content are means of long-term plate memory (> 500 Myrs). This explains a predetermined breaking point but can these heterogeneities lead to the formation of a lithosphere scale fault allowing the consumption and the opening of oceans? In a self-consistent theory, driven by gravity and thermal-mechanics, only a very narrow parameter range initiates the contraction master fault through feedback of thermal-mechanics and water weakening. We have shown that the water content in olivine must be above 200 ppm H/Si for subduction intiation to be possible *(Science 2001, 294, 578-580)*. Here, we provide a broader context and show that the same criticality exists for the ocean opening phase. We prove that water storage can be the critical ingredient for the whole history of the Wilson cycle. In a worked example we show an exploratory application, to the Atlantic-Iapetus pair. We also look at possible present day seismological observations focusing on the US-Atlantic margin.

T32C-05 1440h

Continents And Mantle Convection: Insulation And Large Scale Flow

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Continents can be seen as passive rafts at the surface of the mantle, while the oceanic lithosphere is continuously recycled through subduction and can be considered as the upper thermal boundary layer for mantle convection. Continents however participate into mantle convection by imposing specific thermal and mechanical boundary conditions. Estimates of mantle heat flow under continental shields can be as low as 10 mW.m^{-2}, while the mean heat flow under oceans is 100 mW.m^{-2}, indicating that continents are thermal insulators for mantle heat loss. Two-dimensional numerical experiments of mantle convection are carried out to study this thermal blanketing effect. Rigid conductive lids are set on top of an isoviscous fluid. These lids which represent continents induce a special pattern of convection, with a set of hot plumes under the lid feeding a large cellular circulation. We show that continental lithospheres, with an estimated thickness between 100 and 400 km, induce a very strong insulating effect that requires mantle heat flow under continents to be less than 25% of the mean oceanic heat flow. A heat flow scaling is proposed, which gives the mean heat flow on the whole mantle surface, the mean oceanic heat flow and the mantle heat flow under the continent, as a function of the Rayleigh number of the mantle, of the width of the convective cells generated by the continent, and of the continent width, thickness and thermal conductivity. The insulating effect of continents on Earth cooling can be ascribed as much on the fact that a low heat flow is the prevailing boundary condition at the base of the continent, as on the long wavelength pattern of convection induced by the continents. It is shown that mantle heat loss cannot be understood without a full description of the wavelength of mantle flow, and therefore both continents and oceanic lithospheric plates are to be considered.

T32C-06 1455h

Length and Time Scales in Continental Drift

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Nonlinear feedback between continents and the mantle through thermal blanketing has long been surmised as a mechanism for continental drift and Wilson cycles. Paleomagnetism provides ample evidence for large scale (10,000 km) continental motion on time scales of several hundred million years, indicative of large scale mantle circulation. While much has been learned about the interactions between continents and mantle flow from analog and numerical modeling studies in two and three dimensions, a rigorous sensitivity study on the effects of continents in high resolution 3D spherical mantle convection models has yet to be pursued. As a result, a quantitative understanding of the scales of continental motion as they relate to relevant fluid dynamic processes is lacking. Here we focus on the effect of continental size. Continents covering 30% of the surface are representative of a supercontinent such as Pangea, smaller continents (10% of Earth's surface) are representative of present day Asia, and still smaller continents (3% of Earth's surface) are similar to present day Antarctica. These continents are introduced into simple end-member mantle flow regimes characterized by combinations of bottom or internal heating and uniform or layered mantle viscosity. We find that large scale mantle structure, and correspondingly the large scale displacement of continents, depends not only on mantle heating mode and radial viscosity structure, but also on continental size. Supercontinents promote heterogeneity on the largest scales (spherical harmonic degree one), especially when combined with strong bottom heating and a high viscosity lower mantle. Degree one heterogeneities in turn drive cyclical continental motion, with continents moving from the hot to the cold hemisphere on time scales of several hundred million years. Smaller continents are unable to initiate degree one convection. As a result, their motion is governed by shorter length and time scales. We apply these insights toward understanding the motion of several continents to study the aggregation and dispersal of continental groups.

T32C-07 1510h

Non-equilibrium temperatures and cooling rates in thick continental lithosphere

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Beneath cratons, the lithosphere probably extends to more than 200km depth, which has important implications for the interpretation of heat flow measurements and xenolith geothermobarometry data. The time-scale for diffusive heat transport in a 200 km thick lid is about 1 Gy, which is smaller than, but comparable to, the half-lives of the main radiogenic isotopes of Uranium, Thorium and Potassium. In this case, the thermal structure of the lithosphere is not in equilibrium with the instantaneous rate of radiogenic heat generation and with the heat supply at the base of the lithosphere. For a given amount and distribution of heat sources, the instantaneous vertical temperature profile exhibits significant curvature and may be hotter than the steady-state prediction by as much as 150K. Comparison of (P,T) data with steady-state thermal models therefore leads to an overestimate of the mantle heat flow. The present-day rate of cooling in deep lithospheric material depends on the values of crustal and mantle heat production and on the rate of heat supply from the convecting mantle. Typical values of the cooling rate are in the range of 50-150 K/Gy, close to values reported by F. Albarede for xenoliths from South African kimberlites (Geophys. Res. Lett. 30, 1015, 10.1029/2002GL016484, 2003). Monte-Carlo calculations have been performed to investigate the range of values for the lithosphere thickness, mantle heat production and basal heat flux which are compatible with xenolith (P,T) arrays and surface heat flow determinations.

T32C-08 1525h

Stability of a Chemical Boundary Layer Within a Convecting Mantle

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Chemical lithosphere can be stabilized from deformation by possessing a higher viscosity and/or a higher plastic yield strength than the convecting mantle. Numerical simulations were conducted to determine the transitions between viscous and localized plastic deformation of a chemical lithosphere within a convecting mantle. Several deformation modes were mapped as were the parameter conditions required for lithosphere stability. The value of the friction coefficient that lead to lithosphere stability was found to be dependent upon the thickness of the chemical lithosphere and the mantle Rayleigh number. The value of the viscosity contrast that lead to stability was found to depend on chemical lithosphere thickness, but only weakly on the mantle Rayleigh number. These results are consistent with simple physical scaling laws. Outside of the stability parameter windows, both localized and distributed deformation modes were observed. Further scaling laws are being developed to help physically explain the parameter space transitions from localized to distributed deformation regimes.

T32D MCC: 3007 Wednesday 1340h

Structure and Tectonics of the Western U.S. and the Gulf of California II *(joint with G, S, V)*

Presiding: **N J McMillan,** New Mexico State University**; C A Shaw,** University of Wisconsin-Eau Claire

T32D-01 1340h

Diffuse Continental Deformation in the Western US: A Preliminary 4D Modeling Effort of the GEON Project

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The GEON (GEOscience Network, www.geongrid.org) is a large NSF/ITR research project for building a national geosciences information cyber-infrastructure that will seamlessly integrate geoscience data and analytic tools. One of the major goals of GEON is to facilitate studies of four-dimensional (4D) evolution of continents. We have developed a suite of 3D finite element models as a pilot study of GEON to address some of the first-order questions of continental deformation in the western US in the past 80 Myr: 1) What caused the Laramide deformation? Was it flat subduction or gravitational spreading of a high-standing Sevier plateau in the western Cordillera? 2) What caused the Tertiary extension in the Cordillera? Did metamorphic core-complex formation directly lead to Basin and Range extension? 3) What is the major driving force for the present crustal deformation in the western US? By exploring the impact of possible changes of tectonic boundary conditions and driving forces with time, we derive a preliminary model of the 4D evolution of diffuse continental deformation in the western US. Through this work we will also show how the multi-scale and multidisciplinary data sets from GEON may be used to help scientific investigations, and the computing resources that will be provided to the geoscience community by the GEON grid.

T32D-02 1355h

Laramide Magmatism in the SW US as a Consequence of Lithospheric Thinning and Thermal Structure Created by Late Jurassic Continental Rifting

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Spatial and temporal patterns of Late Cretaceous-Early Cenozoic magmatism in Arizona, New Mexico, west Texas, and northern Mexico demonstrate that arc-like magmatism was prevalent up to 1000 km east of the Farallon-North America trench. Prior to the Late Cretaceous, Mesozoic magmatism was focused in the Sierra Nevada region, with widespread peraluminous intrusions throughout the Cordilleran interior. As early as 80 Ma, however, magmatism shifted far inboard and persisted as late as 50 Ma. Early models for this phenomenon relate an eastward sweep of magmatism to the progressively decreasing subduction angle of the Farallon plate. This model is no longer tenable, for several reasons. 1) Investigation of shallow-angle subduction worldwide demonstrates that magmatism ceases as the subduction angle decreases; modern shallow-angle subduction zones are nearly devoid of active volcanoes.

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