U

U41C MCC: 3001-3003 Thursday 1020h

The Core-Mantle Boundary: Theoretical, Experimental, and Observational Constraints II

Presiding: **A Kavner,** University of California, Los Angeles**; B Buffett,** University of Chicago

U41C-01 1020h INVITED

D": The Enigmatic Magmatic Boundary Layer

Quentin Williams (quentw@emerald.ucsc.edu)

Dept. of Earth Sciences, U. of California, Santa Cruz, CA 95064, United States

The structures and dynamics of the basal region of Earth's mantle lie at the crux of a broad suite of geophysical questions. These include: how Earth's silicate mantle and iron-rich core interact; how volcanic hot spots are generated; how (and at what rate) heat is transported from Earth's deepest interior; and how the Earth's silicate mantle has differentiated through time. The seismically anomalous lowermost 200-300 km of Earth's mantle are characterized by both small or negative changes in velocity with depth, and seismic discontinuities about 250 km above the core-mantle boundary (CMB), and 5-40 km directly above the core. The origin of the former discontinuity remains unclear, but it is likely that it marks the top of the anomalous region at the base of the mantle. The latter discontinuity, characterized by decreases in compressional wave velocity of about -10 percent and changes in shear velocity of about -30 percent (the Ultra-Low Velocity Zone, or ULVZ), is most readily explained by the presence of 5-30 percent partial melt in this zone. The key issue associated with the presence of partial melt at the absolute base of Earth's mantle is not why there is melt present at this depth–this is simply a natural consequence of intercepting the solidus of the basal material–but rather why the melt has not segregated from the coexisting solids into a pure melt layer. The apparent maintenance of a mixture of solid and liquid at the base of Earth's mantle strongly implies that the density difference between melt and solid under these conditions is vanishingly small, and that the solid and liquid compositions have evolved to the point where they coexist at the same depth. Moreover, the partially molten slurry is unlikely to be completely confined to the base of the mantle. The negative shear velocity and small compressional velocity gradients throughout the bulk of D", when coupled with the probable small values of the temperature derivatives of the elastic properties of minerals at the pressures of the core-mantle boundary, are most readily explained by the ubiquitous presence of a small fraction of partial melt (less than 1 percent) distributed throughout the lowermost 200-300 km of the mantle. Seismic evidence indicates that some of this melt may be confined within lamellae distributed at variable depths within D".This ubiquity of melt within the bottom boundary layer of Earth's mantle implies that the geodynamics of the bottom of the mantle is unlikely to be dominated by the solid-state convective circulation present within the bulk of Earth's mantle, but instead by classical magmatic processes: magma ascent and re-equilibration, fractional crystallization, and ubiquitous dissolution and reprecipitation.

U41C-02 1035h

Determining Shear Velocity Structure of ULVZs Using Stacked ScS Data

Megan S. Avants[1] (831-459-4426; mavants@es.ucsc.edu)

Thorne Lay[1] (831-459-4426; thorne@es.ucsc.edu)

Edward J. Garnero[2] (480-965-7653; garnero@asu.edu)

[1]University of California, Santa Cruz, Department of Earth Sciences 1156 High Street, Santa Cruz, CA 95064, United States

[2]Arizona State University, Department of Geological Sciences Box 871404, Tempe, AZ 85287, United States

The Ultra-Low Velocity Zone (ULVZ) is an intermittent, thin (5-40 km thick) layer or mound of greatly reduced P and S velocities located just above the core-mantle boundary (CMB). ULVZs have been detected in numerous regions using stacks of high-frequency P-waves or SPdiffKS phases. Such observations indicate that ULVZ patches have P-wave velocity reductions of at least 4 to 10%. S wave velocity reductions are more difficult to determine, and are typically based on secondary sensitivity of PcP precursors to combinations of P and S velocity that control the reflection coefficient. The ULVZ is generally regarded as a region of partial melt, based on estimates of a 3:1 S- to P-wave velocity reduction, with the ratio of velocities being a critical, but poorly constrained parameter. A direct measurement of S velocity in the ULVZ, independent of the P velocity is needed to better constrain ULVZ properties. One approach is to examine wide-angle transverse component ScS reflections for evidence of precursors generated by ULVZ structure. We explore this possibility by stacking transverse component ScS wave data from sources in the Tonga-Fiji and South American regions, recorded by dense broadband seismic networks in western North America. The lower mantle regions sampled both provide evidence for low P velocity ULVZ structures. Large numbers of seismograms from events in each source region are stacked after deconvolving source wavelets in order to equalize the signals and to extend the bandwidth. ScS phases reflecting from the CMB beneath the central Pacific show opposite polarity precursors, which can be modeled well by strong reductions (8-10%) in shear velocity in the ULVZ. Spatial variations in the ULVZ shear velocity structure are examined by binning the data, with some evidence for variation in structure over intermediate scale lengths of a few hundred km. Data reflecting from the CMB beneath the Cocos Plate do not show clear evidence of ScS precursors, and we seek to bound admissible S velocity structures. We also explore the sensitivity of our ScS precursor approach to ULVZ density, thickness, and shear velocity contrasts.

U41C-03 1050h

Seismic evidence for a diffuse ultra-low velocity zone in the CMB region beneath North America.

Stephane Rondenay[1] (rondenay@mit.edu)

Karen M. Fischer[2] (Karen_Fischer@brown.edu)

[1]MIT Department of Earth, Atmospheric and Planetary Sciences, 77 Massachusetts Ave, Cambridge, MA 02139, United States

[2]Brown University Department of Geological Sciences, Box 1846, Providence, RI 02912, United States

In recent years, a wide range of geophysical results has offered evidence that Earth's lowermost mantle is characterized by strong lateral variations in material properties. Among the structures of particular interest are intermittent ultra-low velocity zones (ULVZ's), located directly above the CMB, which were inferred originally from the distortion of teleseismic *SPdKS* phases. ULVZ's have been modelled as layers with sharp boundaries and seismic velocity reductions ≥10%, and interpreted as regions of partial melt. In this study, we further constrain local ULVZ structure beneath North America by signal processing and waveform modelling of the *SKS*-coda recorded at broadband seismic arrays. Secondary phases in the *SKS*-coda are effectively isolated by eigenimage processing. Residual (i.e., *SKS*-less) data sections from various western Pacific events display clear *SPdKS* arrivals, followed by a secondary phase whose timing and slowness are consistent with CMB origins. One-dimensional modelling of these phases by reflectivity and generalized ray synthetics favours an asymmetric model, with ULVZ present at only one of the CMB-intercepts. The preferred ULVZ is characterized by reductions in P and S velocities of 18% and 50%, respectively, and a diffuse upper boundary. These characteristics are interpreted in the context of local production and gravitational sinking of dense (i.e., iron rich) partial melt above the CMB. We postulate that a gradational ULVZ beneath North America may mark a lateral transition domain between regions of mantle upwelling, where more uniform ULVZ's exist, and regions of downwelling, where ULVZ's are either nonexistent or imperceptibly thin. The broader existence of such diffuse ULVZ's beyond the portion of the CMB investigated in this study may explain why, in some regions, ULVZ's are detected by *SPdKS* phases but not by *PcP*/*ScP* precursors.

U41C-04 1105h INVITED

Seismological Characterization of the Boundary Layers at the Core-Mantle Boundary

Thorne Lay[1] (831-459-3164; tlay@es.ucsc.edu)

Edward J. Garnero[2] (480-965-7653; garnero@asu.edu)

[1]University of California, Santa Cruz, Earth Sciences Department 1156 High Street, Santa Cruz, CA 95064, United States

[2]Arizona State University, Department of Geological Sciences Box 871404, Tempe, AZ 85287-1404, United States

The spatial resolution of seismological structure near the core-mantle boundary (CMB) is improving steadily as the numbers of broadband and high frequency array data increase. The improved spatial resolution is revealing new complexity of the boundary layer at the base of the mantle, and possibly even in the boundary layer in the outermost core. While large-scale seismic tomography has established the predominance of long wavelength heterogeneities in the D" region of the lowermost mantle, the nature of these large provinces can only be assessed by high resolution imaging, which typically involves waveform modeling and array processing of data. Large-scale low velocity provinces in D" have been revealed to have very strong lateral and radial gradients into the low velocity material, challenging the interpretation of these as simple thermal anomalies and bolstering the case for chemical or partial melting contributions to the heterogeneity. A vast region beneath southern Africa, the south Atlantic, and the south Indian Ocean has S velocity reductions of 3 to 5 percent in a 200-300 km thick region with some evidence for an increase in thickness to 800 km below Africa. Margins of the large Pacific anomaly have strong ULVZs and a bumpy S wave discontinuity 230 km above the CMB. Large-scale high velocity provinces in D" have been revealed to have laterally coherent S velocity discontinuities 200-300 km above the CMB, with array processing revealing remarkable topography (or lumpiness) of the discontinuity involving 100 km depth variations over 250 km horizontal scales. Shear wave splitting occurs in these regions, again over large lateral scales, with most data consistent with vertical transverse isotropy or symmetry axes slightly tilted from the vertical. A few localized patches of the outermost core may have finite rigidity or fuzzy transitions with scales of hundreds of meters at the CMB and there still remains a possibility of anomalous global core structure in the outermost 50 km of the core.

U41C-05 1120h

Global Lower Mantle Velocity, Attenuation, and Anisotropy from Differential *ScS-S* Analysis

Tracy R Portle[1] (314 935-6619; tportle1@ithaca.edu)

Jesse Fisher Lawrence[1] (314 322-6277; jfisher@levee.wustl.edu)

Michael E Wysession[1] (314 935-5625; michael@mantle.edu)

[1]Earth and Planetary Sciences Washington University, Campus Box 1169 One Brookings Drive, St Louis, MO 63130, United States

We obtained more than 40,000 high-quality radial and tangential *ScS-S* differential travel-time and attenuation residuals. This examination used broadband seismic station data from both permanent global networks (e.g. GSN) for broad sampling and temporary Passcal-style networks for fine resolution of isolate regions between 1990 and 2001. We used these results to explore the elastic and anelastic behavior of the lowermost mantle. Travel-time and attenuation anomalies are often anisotropic and/or correlated, indicating complex structures on various spatial scales. We inverted for seismic velocity and quality factor anomalies on global and regional scales. Resultant models may help differentiate between chemical, thermal, and structural anomalies. The observed mean global differential attenuation varies with epicentral distance, and could only be modeled by adding highly attenuating material at the core-mantle boundary (CMB). Significant deviations from mean lower mantle quality factor and velocity are required to account for the observed seismic anomalies. Observed correlation between seismic velocity and quality factor may indicate regional thermal anomalies. Alternatively, the lack of attenuation variation in the presence of seismic velocity anomalies may indicate chemical or phase variations. Other areas are strongly anisotropic with the absence of strong isotropic velocity and attenuation variations, indicating possible flow or fabric variations. We examine the pattern of velocity, quality factor, and anisotropy to obtain an improved image of the lowermost mantle. Simultaneous examination of the elastic and anelastic characteristics of the lowermost mantle helps differentiate between types of anomalies. Examination of lateral variations on the global scale is consistent with whole-cell convection, while regional examinations provide evidence for isolated small-scale anomalies, which may indicate plume-like activity.

URL: http://epsc.wustl.edu/seismology/jfisher/DDP

U41C-06 1135h

Lateral variations in the structure of the thermal boundary layer at the base of the mantle from the dispersion of core-diffracted waves

Michael E Wysession[1] (314-935-5625; michael@wucore.wustl.edu)

Ghassan I Aleqabi[1] (314-935-5817; ghassan@ocean@wustl.edu)

Patrick J Shore[1] (314-935-7357; patrick@wups.wustl.edu)

Jesse Fisher Lawrence[1] (314-935-6619; jfisher@levee.wustl.edu)

Karen M Fischer[2] (401-863-1360; Karen_Fischer@Brown.edu)

[1]Washington University, Department of Earth and Planetary Sciences, St. Louis, MO 63130, United States

[2]Brown University, Department of Geological Sciences, Providence, RI 02912, United States

The thermal boundary layer at the bottom of the mantle (D") plays an extremely important role in controlling the dynamics of Earth's interior. However, very little a actually known of its vertical structure and lateral variations. The lateral and vertical variations in the thermal boundary layer at the top of the mantle (the lithosphere) have been largely mapped by the dispersion of surface waves. We perform a similar study for D", using the dispersion of core-diffracted Pdiff waves, which can propagate for great distances along the core-mantle boundary. Pdiff dispersion is not nearly as great as for surface Rayleigh waves, but in the right circumstances, it can be used to forward-model velocity structures in D". Using the linear arrays MOMA (Missouri-to-Massachusetts) and FLED (Florida-to-Edmonton), we examine the dispersion of Pdiff waves across the arrays in order to model regional variations in the vertical structure of D". Good results were obtained with 12 earthquakes recorded at MOMA for Pdiff, and 5 earthquakes for the surface-reflected pPdiff. The dispersion curves are generated by measuring the varying ray parameter values across the array at a discrete number of bandpass intervals ranging from 0.005 and 0.2 Hz. Many regions are well-modeled by a PREM-type structure (essentially zero velocity gradient) or models with a mild negative velocity gradient. Unfortunately, this method can not reliably distinguish between a thermal boundary layer structure with a negative velocity gradient, and a structure with a zero gradient but lower than average value. There are certain regions, however, that are best modeled by a discontinuous increase in velocity at the top of D", underlain by a negative velocity gradient. This kind of structure has been inferred from precursors to core-reflected body waves, but the support of such models by such a radically different type of data lends significant validation to their existence.

U41C-07 1150h INVITED

Effects of Thermal Core-Mantle Coupling on the Geodynamo

Peter Olson[1] (410-516-4659; olson@jhu.edu)

Ulrich Christensen[2] (49-5556-979-542; christensen@linmpi.mpg.de)

[1]Peter Olson, Earth & Planetary Sciences Johns Hopkins University 3400 North Charles St, Baltimore, MD 21218, United States

[2]Ulrich. R. Christensen, Max Plank Institute for Aeronomy, Katlenburg-Lindau 37191, Germany

The response of the geodynamo to thermal core-mantle coupling is investigated using numerical dynamo models with nonuniform boundary heat flow. Small variations in boundary heat flow slightly perturb the geocentric axial dipole magnetic field, whereas large variations tend to kill the dynamo. Intermediate levels of boundary heat flow heterogeneity produce a variety of observable effects, including long-term departures from the geocentric axial dipole, azimuthal differences in secular variation, longitudinal bias during polarity changes, and azimuthal heterogeneity at the inner core boundary. We focus on dynamo models with boundary heat flow heterogeneity derived from the pattern of lower-mantle seismic tomography. These models offer explanations for several of the observed characteristics of the geomagnetic and paleomagnetic fields, including intense magnetic flux patches at high latitudes, westward drift below the Atlantic and weak secular variation beneath the Pacific, and non-random pole paths during polarity reversals.

U41C-08 1205h INVITED

Decadal variations in length of day: a probe of the CMB?

Richard Holme (441517945254; holme@liv.ac.uk)

Richard Holme, Deptartment of Earth and Ocean Sciences, University of Liverpool 4 Brownlow St, Liverpool L69 3GP, United Kingdom

Decadal variations in length of day are believed to result from the exchange of angular momentum between the fluid core and the solid mantle. Based on the theory of torsional oscillations, a good match has been found between modelled changes in core angular momentum and observed Earth rotation, at least for the period 1900-1990. However, the mechanism by which angular momentum is exchanged is still not clear. I discuss the difficulties with using geomagnetic observations to constrain this process, and consider what information on the CMB region may be gleaned. I reconsider the period prior to 1900, to see what can be constrained from this period. Recent dedicated magnetic satellites have resulted in high resolution models of the geomagnetic field and its temporal variation for the current epoch. I consider what these models can tell us about core processes, both now and in the future.

U42A MCC: 3001-3003 Thursday 1340h

Earth's Collapsing Dipole I

Presiding: **J Tarduno,** University of Rochester**; C Constable,** Institute of Geophysics and Planetary Physics, SIO, University of California, San Diego

U42A-01 1340h INVITED

Investigating the Nature of the Current Decrease of the Earth's Magnetic Dipole Moment

Gauthier Hulot[1,2] (301 614 6494; hulot@kasei.gsfc.nasa.gov, gh@ipgp.jussieu.fr)

Benoit Langlais[1] (301 614 6455; langlais@ltpmail.gsfc.nasa.gov)

[1]NAS/NRC at GSFC/NASA, Geodynamics Branch, Code 921, Greenbelt, MD 20771, United States

[2]IPGP/CNRS, 4, Place Jussieu, BP89, Paris 75005, France

The Earth's dipole moment is currently decreasing fast, at a much faster pace than the one it would experience were this pace due to a free diffusive dipole decay mode. This suggests that an active process is going on that is responsible for this current decay. In this paper we will briefly review various aspects of the present field behavior, which could be related to this fast decay of the dipole and which could thus provide us with some information about the processes that could be responsible for it. Of particular interest is the fact that both the field and its secular variation display a strong hemispheric Pacific/Atlantic asymmetry. Also of interest is the amount of diffusion involved in the process. All those issues will be discussed in view of recent satellite data.

U42A-02 1400h

Trends of the Geomagnetic Dipole from Observations Over the Last Three Centuries

David T. Mozzoni[1] (850-644-4014; cyric@geomag.gfdi.fsu.edu)

Joseph C Cain[1] (850-644-4014; cain@geomag.gfdi.fsu.edu)

[1]GFDI and CSIT Florida State University, 18 Keene Bldg, Tallahassee, FL 32306-4360, United States

A review is made of published geomagnetic models utilizing data from the 18th century when absolute measurements were first introduced and those created with angular data back to the 15th century, through those using spacecraft surveys such as POGO, Magsat, Ørsted and CHAMP. The more detailed variations since 1900 of the strength of the centered dipole are viewed to evaluate whether the apparent ~ 60 year periodicity in the average 5% decay per century is a valid feature of the observed poloidal field or a result of the irregular distribution of data used prior to full global coverage by spacecraft. Simulated data using distributions for past epochs computed with recent global models were analyzed. The results indicate that whereas the higher components are suspect for early and mid 20th century, the variations seen in the dipole itself are likely valid. No acceleration of dipole decay over the average century–long rate is indicated from these studies provided this periodicity is taken into account. The energy being lost by the dipole continues to be fed into that of the $n = 2$ and $n = 3$ terms as originally noted by Verosub and Cox, though there is excess loss presumably being converted to heat. The direction of the dipole axis has continued to slowly drift on a clockwise path (westward) as represented by $G - H(1, 1)$ dialgrams since 1690, with the absolute value of that non–axial contribution decreasing at least since the middle of the 19th century.

U42A-03 1415h INVITED

Dipole Decay, Secular Variation and Reversals

Jeremy Bloxham (617 495-9517; jeremy_bloxham@harvard.edu)

Harvard University, 20 Oxford Street, Cambridge, MA 02138, United States

Over the last 160 years, the axial dipole component of the Earth's magnetic field has decayed by almost 10%, a rate of decay roughly an order of magnitude faster than would result from free decay. This decay rate is also characteristic of that required for geomagnetic reversal. Does the present-day dipole decay hold clues as to the mechanism of geomagnetic reversal? To address this question we begin with some simple kinematic and dynamical considerations of possible reversal mechanisms. Two end-member models of the reversal process can be eliminated, namely a purely diffusive reversal in which the dipole is destroyed through free decay and a purely advective reversal in which flux is exchanged between hemispheres. Both end-members would take too long: the first because of the long free-decay time, and the second becuase largescale flow across the geographical equator is extremely weak, owing to tangential geostrophy. Instead, reverse flux must grow in situ. As first shown by Gubbins in 1987, the rapid decay of the dipole over the last 160 years is almost entirely due to changes in the field at the core-mantle boundary beneath the South Atlantic Ocean, a region that is characterized by a large reverse flux patch. How do such reverse flux patches form and grow? One possible mechanism is flux expulsion, a process that involves both advection and diffusion. In a numerical model of the geodynamo, we observe two instabilities leading to flux expulsion, one of which results in mid-latitude reverse flux patches and is associated with reversal in the numerical model. Although this provides a tantalising connection between present-day secular variation and reversals there is no reason to believe that the present-day dipole decay will result in a reversal. We outline a method by which it might prove possible to predict the future behavior of the field.

U42A-04 1435h

Dipole Field Collapse in a Reversing Dynamo Model

Peter Olson[1] (410-516-4659; olson@jhu.edu)

Johannes Wicht[2] (49-5556-979-0; wicht@linmpi.mpg.de)

[1]Peter Olson, Earth & Planetary Sciences Johns Hopkins University 3400 North Charles St., Baltimore, MD 21218, United States

[2]Johannes Wicht, Max Plank Institute for Aeronomy, Katlenburg-Lindau 37191, Germany

We analyze the collapse of the external dipole magnetic field in a three-dimensional numerical dynamo. A dynamo model driven by thermal convection in a rotating spherical fluid shell with an electrically conducting solid inner core exhibits collapse of its external dipole field prior to polarity reversal at Rayleigh number 300, Ekman number 0.01, Prandtl number 1, and Roberts number 20. Helical motion in rising plumes lifts and twists the toroidal magnetic field, producing loops of poloidal magnetic field. Expulsion of these poloidal field loops results in patches of reversed mangetic flux on the core-mantle boundary. The external dipole collapses when the reversed flux patches are transported to the pole by meridional flow. Seen from the surface, polarity change occurs when reversed flux is transported by meridional flow over the whole core-mantle boundary. In this model, reversed magnetic flux on the core-mantle boundary above rising plumes is a precursor to dipole collapse and polarity reversal. Collapse of the external dipole does not, however, indicate a dynamo blackout. Although the external dipole collapses prior to polarity change, both the total magnetic energy and the dipole energy within the core actually increase during a reversal.

U42A-05 1450h INVITED

What can Paleomagnetism Tell us About the Next Reversal?

Robert S Coe (831-459-2393; rcoe@es.ucsc.edu)

Earth Sciences Department, University of California, Santa Cruz, CA 95064, United States

Our sole source of evidence about geomagnetic polarity reversals is the paleomagnetism of rocks. Observations show that the stable magnetization acquired by igneous and sedimentary rocks when they formed possesses reversed polarity almost as frequently as the normal polarity of the field today. Averaged over the past 20 Myr the dipole field has reversed almost five times per million years, though at irregular intervals. The last one occurred 0.78 Myr ago, giving rise to the speculation that we are overdue for a reversal. What