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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 is 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

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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?

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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

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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

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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 $G - H(1, 1)$ diagrams 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

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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 because large-scale 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 tantalizing 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

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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 magnetic 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?

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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

happens during a reversal? Geologically speaking, the field takes very little time to reverse, 1 to 10 kyr as generally inferred from sedimentary records, and the various rock magnetic recorders are imperfect. Thus, paleomagnetic records are always incomplete and give only lower bounds on how rapidly changing and complex the behavior of the reversing field may have been. What we know with greatest certainty is that the field intensity is much reduced during a reversal, usually falling as low as 10-20% of the average value it had during full polarity. In most other regards, reversal records exhibit great variety. The intensity decrease may lead or accompany the departure of direction from full polarity, and its recovery may accompany or lag reestablishment of full polarity. Although the change in field direction might be relatively simple and progressive during some reversals, several of the highest resolution records suggest complex behavior with episodes of rapid directional oscillations. It seems reasonable that the boundary conditions imposed by the lowermost mantle on the core could confer some regularity on the transitional field morphology, but whether they do and to what degree is debated. The transitional field is almost certainly much more multipolar in character than is the full polarity field, but the equatorial dipole may nonetheless exert considerable influence on directional systematics at the earth's surface during some reversals. Prominent non-dipole field features during a transition could cause records of the same reversal at different places to start and finish at different times, making the global duration of a reversal significantly longer than the local duration. Increasingly accurate radiometric dating of transitional lava flows is beginning to suggest this to be true for some reversals, and sophisticated geodynamo simulations also exhibit reversals that vary greatly from one to another and possess many of the above-described characteristics. Is the field starting to reverse? Today we are indeed witnessing a pronounced decrease in field strength. From a broad maximum about 40% higher than today, intensity experiments on archeological materials of fired clay and on young lava flows show that the dipole field has been weakening monotonically for the past 2 kyr. Direct measurements during the modern era confirm that the field is diminishing and indicate that the decay is accelerating: from 5.5% per century from 1850-1950, to 6.8% per century from 1945-1995, to 8.0% per century from 1965 to 1995. However, paleomagnetic records show that the geomagnetic intensity has dropped dramatically many times in the past and recovered without reversing, so that an actual reversal this time is far from certain. The more important societal question is whether the field intensity will continue to diminish down to very low values comparable to the transitional field, or instead turn around uneventfully. Since the last reversal we know that it has decreased to very low values quite a number of times, often accompanied by large excursions of field direction. The environmental effects of such an excursion would likely be very similar to that of a successful reversal.

U42A-06 1510h

Do The Paleomagnetic Records Tell Us Something About The Next Occurrence of a Field Reversal?

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It has been occasionally repeated that the present collapse of the geomagnetic field would predict the future occurrence of a field reversal. The historical field variations represent a very short period of time but the archeomagnetic records tell us that a more or less regular decrease of the field has effectively been going on over the past 1 kyr. Yet this feature depends on the geographical location as a result of the competitive effects of the dipole and non dipole components. Prior to this period (roughly from 1500 to 1000yr BP) there was a field recovery which occurred more or less at a similar rate. Further back in time the field intensity changes revealed by the sedimentary records seem to exhibit large amplitude variations with time scales of a few thousand years. The closest major collapse of the field occurred 38-40 ka ago during the Laschamp event but the most detailed records indicate that other large fluctuations followed until the present period. The last major and worldwide field reversal occurred 780 kyrs ago. In this case as for other reversals, the paleomagnetic records converge to indicate a long-term decrease of the dipole prior to the transition. However this process does not appear to be regular and all detailed records (from sediments as well as from volcanics) show the existence of short-term fluctuations occurring on the millennial scale. In addition the rate of changes appears to be faster during the field recovery which immediately follows the reversals than during the preceding decrease of the dipole. In other words, it is evidently necessary to deal with a long time sequence (at least a few tens of thousand years) to ascertain the issue of

the collapse. Thus the existing database for the archeomagnetic and paleomagnetic field tells us that no prediction can be made regarding the next occurrence of a geomagnetic reversal from the present collapse of the field.

U42A-07 1525h

Field Behavior During the Next Geomagnetic Event: Clues From Paleomagnetic and Geomagnetic Data

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Although it is unclear whether the present weakening of the axial dipole will ultimately result in a geomagnetic event or complete reversal of polarity, particular subsets of paleomagnetic transition data suggest that the pattern of flux emanating from the core today is not so unlike that which dominated transitional fields over the past few million years. We focus first on the Plio-Pleistocene records obtained from lavas erupted at the Society Island hotspot. With the newly-reported record of the 600 ka Big Lost Event exposed on Tahiti, there now exist five reasonably detailed transition records spanning 2.3 myr between 2.9 Ma and 0.6 Ma from the islands of Tahiti and Huahine. All five of these records contain a sequential clustering of virtual geomagnetic poles (VGPs) found near western Australia. The same is the case for several records of the Matuyama-Brunhes transition, the last reversal, from sites about the globe. In order to compare these findings with the modern-day and historic fields, first, at the Society Island hotspot, we removed the axial dipole term from the 1900, 1950, and 2000 IGRF models and found that the three associated "transitional" south VGPs resided within the same Australian patch. Applying these non-axial dipole field models to sites throughout Australasia, we again found the synthetic VGPs to lie along a narrow north-south line through western Australia. In fact, VGPs associated with the modern-day non-dipole field for the same Australasian sites run in a similar fashion through Australia. These findings suggest strongly that the location of the modeled VGPs is not simply fortuitous, due to the current orientation of the geocentric equatorial dipole. Rather they suggest strongly that the flux pattern involved is far more complex, yet stationary, and most likely due to physical variations of the core-mantle boundary region beneath Australasia. Given this correspondence between recorded transitional paleomagnetic data and modeled geomagnetic data, we propose that the onset of an event or reversal attempt involves the near- vanishing of the axial dipole, leaving a residual field whose source is the pattern of flux fixed to the mantle about the surface of the core. Since it appears that the basic features of this pattern are long-lived, serious investigation of global field changes associated with the next geomagnetic event may now be possible.

U42B MCC: 3001-3003 Thursday 1600h

Earth's Collapsing Dipole II

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

U42B-01 1600h

Is the Recent Decrease in the Geomagnetic Dipole a Precursor of a Reversal?

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Given the remarkable decrease observed in the strength of the geomagnetic dipole, two end members scenarios that may develop are (1) the dipole recovers and secular variation continues and (2) the field reverses within several thousand years. An argument for former is that the dipole has fluctuated in strength repeatedly throughout geological time without reversing. To justify advocating the latter scenario, one needs to show that the present behavior is particularly like the behavior of the geomagnetic field in the early stages of a reversal. However, to establish the transition field during reversals has proved very difficult. Efforts have concentrated on the simpler, but still difficult task of determining the VGP distributions during reversals. These distributions will be reviewed and new analyses presented that confirm earlier suggestions of preferred VGP paths during reversals. Models of the transition field will also be presented. From these, it appears that

a region in the southern hemisphere plays an important role in reversals. It has frequently been noted that this is an area that is generating reversed magnetic field at present. Such behavior in the present field might be regarded as indicative of the onset of a reversal, or of an excursion.

U42B-02 1615h

Earth's Collapsing Dipole in the Context of Long-term Geomagnetic Field Behavior

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Over the time interval for which direct geomagnetic field measurements have been made the strength of the geomagnetic dipole has been monotonically decreasing, at the rate of several percent per century. The significance of this decrease (collapse?) must be considered in the light of what is known about geomagnetic field behavior over longer timescales, behavior which includes mean strength, variance, and temporal correlation, in addition to the rates of occurrence of and time taken to accomplish individual geomagnetic reversals. Paleomagnetic data suggest that the decreasing trend has been present at least since 1000 AD, although estimation of the actual dipole moment becomes increasingly difficult as one goes further back in time because of sparse temporal and spatial data coverage. However, it is also abundantly clear from paleomagnetic data that the present dipole is not anomalously low, and that even if it were, extreme DIPs (Decreases in Paleointensity) are not necessarily accompanied by full geomagnetic reversals. Such DIPs may nevertheless have important influences on Earth's immediate magnetic environment. This work adopts a statistical approach in attempting to answer the following questions: Is the next geomagnetic reversal overdue? Is the current rate of decrease of the dipole moment anomalously large? Is the variance in the geomagnetic field related to reversal rate? What does the spectrum of secular variation look like? Paleomagnetic datasets drawn from times that include both low and high reversal rates are evaluated in the context of Gaussian statistical models for paleosecular variation.

U42B-03 1630h

The Long-term Strength of the Geomagnetic Field

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The long-term strength of the geomagnetic field, an essential parameter constraining the nature and history of the geodynamo, has been defined on the basis of Thellier-Thellier paleointensity experiments using igneous whole-rock samples. However, many of the virtual dipole moments derived from the Thellier data are comparable to values that characterize geomagnetic excursions and reversal transitions. The low field stability implied by these values represents a paradox: it is in stark contrast to what is known from the history of paleosecular variation and frequency of geomagnetic reversals. Taken at face value, the paleointensity data imply the field has been extraordinarily energetic during the last 10 million years. Because factors that could change the magnetic field energy are characterized by time scales orders of magnitude longer than this apparent signal, we suggest natural processes that lead to underestimates of field values (natural and experimental alteration) are far more common than is usually supposed (resulting in a bias toward low values in paleointensity databases). Using secular variation as a guide, we conclude that the mean strength of the field since Mesozoic times was probably similar to that of the last 10 million years (7 to 8×10^{22} Am²), except during periods of very low (superchron) and very high (e.g. the Late Jurassic) reversal frequency. Paleointensity estimates for the latter interval are anomalously low relative to all data and, together with Thellier estimates based on analyses of single plagioclase crystals from the Cretaceous Normal Polarity Superchron, suggest that reversal rate and field intensity are inversely related. These interpretations suggest that the modern decay of the dipole should be viewed relative to the "threshold" value of paleointensity, estimated from analyses of sediments. At this threshold value (approximately 1/2 the modern field strength), excursions of field behavior can be expected.