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The nature and origin of the concentrated deformation zone along the Japan Sea coast (NKTZ: Niigata-Kobe Tectonic Zone) was investigated by carefully analyzing the GPS data and qualitatively modeling the lower crust in NKTZ. It was concluded that this deformation zone is not a plate boundary between the Amurian plate (AMU) and the North America plate but is rather an internal deformation zone near the eastern margin of AMU. The data previously obtained on the conductivity anomalies in the lower crust and the 3He/4He ratios suggest that the concentrated deformation in NKTZ results from the lower crust in NKTZ being weakened by a high water content. The high water content is thought to result from the dehydration of subducting slabs.

T51A-07 0945h

Pacific-North America plate boundary deformation in the greater Salton Trough area, southern California, USA

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The general kinematic nature of the Pacific-North American plate boundary in southern California is well described by long-term geologic fault slip-rate estimates and short-term geodetic measurements of surface displacement rates. In general, these data sets agree, often through simple kinematic models. There are, however, interesting differences in the greater Salton Trough/Imperial valley (a sedimentary basin). Geologic estimates of slip-rate on the block-bounding faults (e.g., the southern San Andreas, San Jacinto, Imperial, etc.) favor the San Andreas as the major plate-boundary fault. Recent geodetic strain estimates suggest the San Jacinto fault accommodates as much, or more, strain than the San Andreas fault. These discrepancies could reflect the disparate time scales over which geology and geodesy measure crustal deformation. Also, significant lateral and vertical variations in crustal rheology (elastic properties such as shear strength), which thus far have not been included in kinematic models of geodetic data in this area, may have important effects on interpretation of geodetic displacement rates. We present preliminary results of a finite element model driven by well-known far-field plate motions to test the influence of variations in crustal rheology on observed geodetic displacements. Crustal elastic properties are calculated from seismic velocity estimates from the SCEC 3D velocity model. Model surface displacement rates are compared to the SCEC crustal motion map.

T51B MCC: 3005 Friday 0800h

Structure and Dynamics of the Oceanic Upper Mantle II *(joint with OS, S, V)*

Presiding: **J Gaherty,** Georgia Institute of Technology**; J Korenaga,** Yale University

T51B-01 0800h INVITED

Cooling history of the Pacific lithosphere

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Plate tectonics is expressed most simply in oceanic plates where a thermal boundary layer or lithosphere forms as the plate cools during its journey away from mid-ocean ridges. Based on a seismic model of the Pacific upper mantle inferred from a new compilation of seismic surface wave dispersion measurements, we show that, on average, the Pacific lithosphere has experienced a punctuated cooling history, cooling diffusively for its first 70 Ma and then reheating in the Central Pacific between ages of 70 and 100 Ma predominantly at depths between 70 and 150 km. From 100 Ma to about 135 Ma, the processes of reheating are substantially weaker than in the Central Pacific, on average, and the lithosphere undergoes a second phase of diffusive cooling. The cause of the reheating in the Central Pacific remains unclear, although thermal plumes at a number of length scales are probably important, particularly to modulate thermal boundary layer instabilities (TBI). We argue, however, that TBI forms naturally as the plate cools. We present the results of simulations that show that, with the right rheology, TBI can explain the average characteristics of the observed cooling history of the Pacific plate. To explain the variability within age ranges observed across the Pacific, however, may require additional physical processes not included in our simulations, such as variations in the conditions of formation of the lithosphere or the effects of deeper seated thermal plumes.

T51B-02 0820h

Seismic Structure of the Mantle Beneath Western Pacific Using 3D Fréchet Kernels

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Two decades of seismic tomography studies have yielded earth models with three-dimensional (3D) velocity heterogeneities in the mantle on both global and regional scales. We have developed a tomography technique which uses 3D Fréchet kernels in setting up the linearized inverse problem. We present a 3D model of the shear-speed structure for the mantle beneath the Western Pacific Ocean. Over 1600 three-component recordings of earthquakes (Mw > 5.5) from the seismic zones around the western Pacific rim were processed to obtain ~30,000 frequency-dependent phase delays for various of seismic waves, including S, SS, upper-mantle guided and surface waves, and ScS reverberations. The 3D Fréchet kernels for these delay times are computed by the coupled normal mode theory described by Zhao, Jordan, and Chapman (2000), and the measurements were inverted for a 3D radially anisotropic shear-speed model. The model parameters include shear-speed variations throughout the mantle and perturbations to radial shear-wave anisotropy in the uppermost mantle. The resolving power has been investigated through a series of inversion tests, which indicate that the horizontal and vertical resolving lengths are about 750 km and 250 km, respectively, in the upper mantle. Our results for the large-scale variations in the isotropic shear speeds are generally consistent with published global tomographic models. Comparison of inversion results using 2D and 3D Fréchet kernels shows a good correlation between 2D and 3D inversion, and somewhat lower amplitude in 3D inversion. Our model reveals greater lateral heterogeneity than the global models, especially in the 200-400 km depth range, suggesting a complex 3D mantle flow in the western Pacific upper mantle.

T51B-03 0835h

The Origin of the Low Velocity Zone: Laboratory Constraints

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One of the most prominent features of oceanic upper mantle is a minimum in shear wave velocity usually observed at a depth between 100 and 200 km. Partial melting is most commonly invoked as an explanation, but a change in deformation mechanism and the presence of water have also been suggested. An important observation is that the depth of the low velocity zone varies with age of the oceanic lithosphere, implying a relationship with the thermal structure rather than a process occurring at a fixed depth. We have measured shear modulus and attenuation of polycrystalline olivine as a function of temperature at seismic periods. The data from five samples ranging in mean grain size by more than an order of magnitude have been fitted to an extended Burgers model that allows extrapolation of our measurements to the larger grain sizes expected in the upper mantle. An important experimental observation is that polycrystalline olivine behaves nearly elastically at temperatures below $\sim 900^\circ$C and seismic periods. Above this temperature anelastic processes cause attenuation and shear modulus reduction, resulting in much larger and period-dependent modulus variation relative to lower temperatures. We have calculated shear wave velocities for oceanic upper mantle from the fit to our experimental data and a conductively cooling half-space model commonly invoked to explain the age dependent structure of oceanic lithosphere. In addition to the temperature sensitivity, pressure dependence also is taken into account by an activation volume and anharmonic pressure derivative of the shear modulus. When the shear wave velocity is calculated as a function of depth, a pronounced velocity reduction occurs where the temperature first exceeds $\sim 900^\circ$C, corresponding to the onset of anelastic behavior. As long as the temperature increases rapidly along the conductive part of the geotherm, the velocity continues to decrease. Once the geotherm joins the adiabat, the increase in temperature with depth is much more modest and the pressure dependence becomes dominant, causing an increase in velocity. This combination of temperature and pressure dependence therefore results in a velocity minimum that is age dependent for oceanic lithosphere less then 100 Myr old. When comparing our calculated velocity profiles with those observed seismologically we find that our calculations match the observations fairly well-both with respect to the magnitude of the calculated velocities and the age dependent depth of the velocity minimum. The calculated attenuation is also consistent with seismic observations, with the least well constrained parameter being the activation volume. Comparison of calculated zero-age velocities with velocities determined by the MELT Seismic Team suggests the presence of melt beneath the East Pacific Rise.

T51B-04 0850h INVITED

Modeling seismic anisotropy in 3D mantle flow beneath Hawaii

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Large-scale measurements of azimuthal anisotropy in the Pacific ocean show a global alignment of fast directions with the motion of the plate. However, significant disturbances occur around the Hawaii hotspot. Direct geodynamical modeling of seismic anisotropy can be used to extract information about mantle flow from these observations. The steady flow field around a thermal plume interacting with a moving lithosphere is determined using a 3-D variable-viscosity convection code. Next, the lattice preferred orientation of olivine and enstatite at each grid point is determined by along-streamline integration of the evolution equations of Kaminski and Ribe (Earth Planet. Sci. Lett., 2001) which account for plastic deformation of the crystals and for dynamic recrystallization by nucleation and grain boundary migration. Finally, the full elastic tensor at each grid point is calculated using a Voigt average. The anisotropy is strongest around the plume conduit and in the depth range 80-150 km where the hot plume material spreads laterally, and its orientation varies substantially as a function of both lateral position and depth. To apply our results to the Hawaiian region, we calculate synthetic anisotropic phase velocity maps at different depths and compare them with maps inferred from seismic observations. We will also present preliminary calculations of synthetic seismic observables, using the spectral element code of Komatitsch and Tromp (Geophys. J. Int., 2002) and a simplified version of our model in which the full elastic tensor at each point is replaced by the best-fitting hexagonal approximation.

URL: http://www.ipgp.jussieu.fr/~kaminski

T51B-05 0910h

Evidence for Upper Mantle Flow Associated with the African Superplume

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The presence of a large-scale, low seismic velocity anomaly in the mid to lower mantle beneath Africa is a robust feature of global tomographic models. Assuming the low velocities are associated with warm, less dense material, the African seismic anomaly has been ascribed to a long-lived thermal upwelling from the lower mantle. Such large-scale upwelling should exert significant driving forces on the surrounding plates and affect the regional horizontal mantle flow field. To test this model we compare seismic anisotropy inferred from shear wave splitting measurements with instantaneous flow calculations that incorporate mantle density structure derived from seismic tomography. We calculate splitting parameters at 12 ocean island stations surrounding Africa. Splitting measurements from island stations are ideal for interpreting anisotropy induced by asthenospheric flow due to the lack a thick overlying lithosphere. The observed fast polarization directions are used to investigate the following hypotheses regarding mantle flow. First, we tested for a possible lithospheric contribution by comparing the splitting measurements to fossil spreading directions and found that they are a poor fit to the data at stations located >500 km from the ridge axis. Thus, we conclude that the observed anisotropy is dominated by asthenospheric flow. We then considered several models with varying assumptions about the velocity at the base of the asthenosphere: that it is 1) stationary below plates moving in the no-net-rotation (NNR) and hotspot reference frames, 2) driven by plate motion at the Earth's surface, and 3) driven by a combination of plate-motion and mantle density heterogeneity inferred from seismic tomography. We find that the best-fitting flow field is one that includes density heterogeneity associated with large-scale upwelling originating in the lower-mantle beneath southern Africa, and is manifest as a radial pattern of flow at the base of the asthenosphere. The resulting sub-asthenospheric flow field is characterized by velocities of 0-3 cm/yr, and an asthenospheric viscosity of $1\text{-}3\cdot10^{19}$ Pa·s is found to be most consistent with the regional anisotropy, geoid height, and dynamic topography.

T51B-06 0925h

Upper Mantle Structure Beneath the East Pacific Rise

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Depth extent and characteristics of low velocity zones under spreading centers have long been debated. Evidence from recent global and regional surface wave studies suggests considerable shear velocity variations at depths possibly as large as 300 km. The upper mantle beneath midocean ridges are also known to exhibit highly anisotropic behaviors, especially in the top 200 km. In this study we combine regional observations with global constraints to investigate shear velocity structure (both isotropic and anisotropic) and mantle discontinuities under the East Pacific Rise (EPR). The data set consists of intermediate-period (15-35 sec) records from ocean-bottom seismometers (OBS) deployed by the TOES (1995) and MELT (1996) experiments, as well as long-period surface (>45 sec) and body waves from on-land, permanent stations worldwide. Our preliminary surface wave (mostly Rayleigh wave) analysis of the OBS recordings shows considerable differences in 1-D isotropic velocities between cross-ridge and along-ridge paths. The presence of a distinct low-velocity zone within the top 100 km is required to fit the observed waveforms. The average velocity for several source-receiver paths in the distance range 8-25 degrees appears to correlate with the path-integrated age of the oceanic lithosphere. A joint inversion for isotropic/anisotropic shear velocity structures reveals a radially anisotropic anomaly (possibly as strong as 2.5%) ~230 km beneath various parts of fast spreading ocean ridges, most notably north EPR. A positive difference between the vertical and horizontal wavespeeds implies near-vertical alignments of olivine fast crystallographic *a* axis at asthenospheric depths. The anomalous nature of the EPR is further evidenced by the presence of a deep (~270 km) reflector in north EPR. This feature could potentially represent a deep Lehmann discontinuity, though the latter is generally associated with major continents. Waveform comparisons between observed S multiples and synthetic calculations suggest either a positive jump that is nearly as strong as the 220-km discontinuity in PREM or, alternatively, a gradient in the V_{SV} wavespeed exists below 200 km. The nature of this anomaly, especially its potential association with anisotropy under ocean ridges, is being investigated.

T51B-07 0940h

A causal relationship between the migration of oceanic spreading centers and the magmatic segmentation of ridges

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The elevation of the world's mid-ocean ridges (MORs) displays pronounced undulations which subdivide the MOR into discrete spreading segments bounded by transform faults and smaller offsets of the axis. These morphological changes have been attributed to spatial variations in the supply of magma from the oceanic mantle but the cause of these variations has not been explained. Shallow and broad ridge segments are believed to reflect enhanced magma supply while deeper, more tectonized segments are believed to be magma-starved. Analysis of morphological changes along the ridge crest in the context of absolute plate motions reveals a simple relationship between the magmatic segmentation of the ridge and ridge migration direction. Currently all spreading centers are migrating relative to the "fixed" hotspot reference frame at a rate and direction determined by the absolute motions of the bounding plates. Along the northern East Pacific Rise (NEPR), where the spreading center migrates to the northwest, depth profiles show that the shallow robust ridge segments are consistently offset in the direction of ridge migration relative to the deeper adjoining segments. This relationship is observed at all transform offsets as well as at smaller discontinuities with offsets typically < 15 km. Analysis of other fast and intermediate spreading portions of the world's MOR reveals changes in topography consistent with the ridge migration direction at the majority of transform faults and second-order discontinuities. We suggest that these variations in ridge morphology may be a consequence of a three-dimensional pattern of melt focussing from a broad zone of mantle upwelling in the presence of a migrating spreading center. In the case of a segmented spreading center, focussing of melts should occur not only from the mantle upwelling zone beneath each ridge segment, but also across ridge axis discontinuities. Indeed, melt may be preferentially entrained across discontinuities where horizontal flow paths are shorter to the adjoining ridge axis leading to extraction of melts at one segment which originated in the upwelling zone of the adjoining segment. Simple kinematic models of mantle upwelling in the presence of a migrating spreading center predict faster mantle upwelling and resultant higher melt production by decompression beneath an advancing plate (Davis and Karsten, 1986; Schouten et al., 1987). A consequence of this asymmetry is that the pattern of mantle upwelling and melt production across discontinuities will depend on ridge geometry with more melt available for lateral entrainment across discontinuities to leading segments than to the trailing segments.

T51C MCC: 3010 Friday 0800h

Brittle Deformation and Faulting of the Earth's Crust: Observations and Models I *(joint with G, S, V)*

Presiding: **G Hayes,** Pennsylvania State University**; C Goldfinger,** Oregon State University

T51C-01 0800h

The Dead Sea Transform Fault: electrical conductivity, other geophysical data, and comparison with the San Andreas Fault

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The more than 1000 km long trans-continental Dead Sea Transform (DST) forms the boundary between the African and Arabian plates in the Middle East. Magnetotelluric (MT) data were recorded at more than 200 sites, focusing on the DST in the Arava valley in Jordan. 2D inversion results of the MT data indicate very clearly that the DST is associated with a strong lateral conductivity contrast. The most prominent feature on the MT image is a conductive half-layer beginning at a depth of approximately 1.5 km, which may be caused by brines in porous sediments. The DST can be identified as a sharp vertical conductivity boundary on the east side of the feature and directly beneath the surface trace. On a coincident high-resolution seismic tomography image of the upper crust, a strong increase of the P wave velocities to values exceeding 5 km/s is observed west of the DST, where the MT model indicates lower conductivities. The seismic velocities are consistent with metamorphic basement rocks; however the observed resistivities (50-250 Ωm) are unusually low for unaltered metamorphic rocks. Fractured metamorphic rocks with interconnected fluid bearing veins could explain both the seismic and MT observations. However, the conductivity model suggests furthermore that the DST acts as an impermeable barrier to cross-fault fluid flow. In stark contrast, a prominent flower structure is observed along the central segment of the SAF and interpreted as evidence of pervasive along-fault fluid flow. Here, the high conductivity is attributed to the circulation of saline fluids within the damage zone of the fault system. The width of the conductive zone (0.5 km) is in the same order of magnitude as the width of a seismic low-velocity zone inferred from fault-zone-guided wave observations, while its depth extent (3 km) coincides with the occurrence of a cluster of small earthquakes. It is possible, that the damage zone of the DST is so narrow that it cannot be resolved even with the dense site spacing of the MT experiment. This observation is supported by preliminary results from geological mapping and a seismic study using fault-guided waves that suggest a very narrow low-velocity waveguide of 3 to 10 m width. The reason for this difference between the DST (very narrow fault zone) and the SAF (wide gouge zone) is not yet clear, but seems to coincide with generally slower slip rates and the relatively low recent seismicity associated with this segment of the DST.

T51C-02 0815h

Turbidite Based Earthquake Record Along the Northern San Andreas Fault

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During June and July, 2002, we collected 60 cores from channel and canyon systems draining the northern California continental margin. The objective of this project is to test the hypothesis that many of the turbidites deposited in these channels result from turbid flows triggered by earthquakes on the northern San Andreas Fault (SAF). Along the northern coast of California between San Francisco and Point Delgada, the San Andreas lies close to the coast or just offshore. No regional stratigraphic datum has yet been found in our cores, however correlation of individual turbidites both along individual channels and across non-connecting channels is robust, providing numerous stratigraphic ties between these systems. We are using Gamma density, high-resolution magnetics, x-ray, and color reflectance data to build a comprehensive regional correlation along the length of the northern San Andreas. That we are able to correlate individual turbidites along channels is not surprising, however correlating turbidites from one channel to another, as much as 300 km away, is surprising. The correlation using patterns in imagery and physical properties suggests that, as we found in Cascadia, many turbid events appear to be recording large earthquakes rather than other possible triggers of these flows. Correlation of events along the margin for large distances suggests an earthquake origin for these turbidites, since other potential triggering mechanisms (except very large storms) operate in only single channels. Such synchronous triggering, only possible with earthquakes, is shown for many events. Channels from separate mineralogic provenances come together at confluences, below which we see either doublets, with no intervening time between them, or bimodal coarse fractions in the turbidites, each peak representing a separate provenance. Perhaps of equal or greater importance, the regional correlation of events implies that the physical property "wiggles" contain information about the earthquakes themselves, since the turbidites located in widely separated and non-communicating channels have, to our knowledge, nothing else in common. Based on initial AMS 14C results, we find that regional correlation is possible for the last 6200 years, and identify 35 events above this datum for the entire region. Of these, 10 events can be correlated along the length of the study region, from the northern limit of the SAF to south of San Francisco. Twelve events correlate along a northern "segment" and nine events correlate along a southern "segment" We find no events that occur clearly in only one channel, and only four events that are found in two and three channels only. These events are in close proximity to the seismically active Mendocino Triple Junction.