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The easternmost part of the Nankai accretionary complex (Tokai area) is presently underthrust by a large basement ridge going into subduction and known as the Paleo-Zenisu ridge. As a consequence, the upper margin has recorded a large finite compressional deformation with broad folding of the forearc basin as well as localized active faults known as Enshu fault, Kodaiba fault and Tokai thrust. These faults are located above the locked part of the subduction megathrust and are likely splay faults of the seismogenic zone.

In this presentation, we combine the existing geophysical data together with the most recent results of the French-Japanese "SFJ" seismic cruise to define the geometry of the Paleo-Zenisu indenter and of the splay faults. The Tokai thrust is the closest to the indenter. It also corresponds to the limit between the Plio-Quaternary accretionary wedge and the Miocene-to-Quaternary uplifted forearc basin domain. This structure is laterally continuous westward and follows the wedge/forearc limit. Enshu fault, the closest to the coast, has a right-lateral strike slip component and dies out westward in Kumano basin. It may thus in part result from shear partitioning in a locally oblique convergence setting. Kodaiba fault is now identified as an oblique thrust fault with a moderate dip angle and evidence for fast hanging wall uplift is found at the intersection with Tenryu canyon. Kodaiba is not laterally continuous but terminates westward in en-echelon fold system

We conclude that the initial structure of the Tokai margin was similar to that Kumano transect and that the current structure of the margin is the consequence of cyclic ridge subduction. We propose the deformation sequence during ridge subduction starts with a long wavelength folding of the whole forearc area and is followed by localization of the deformation along discrete faults and rupture within backstop. In this sequence, Kodaiba fault would be the most recent structure.

T52F MC: 135 Friday 1330h

Multidisciplinary Insights from Seismic Tomography, Mantle Dynamics, Geological Origins, and Evolution III *(joint with S, V, DI, MR)*

Presiding: **D Zhao,** Dept. of Earth Plantary Sciences**; K Hirose,** Tokyo Insitute of Techonology

T52F-01 1330h

Degree 16 model of S-wave heterogeneity in the upper mantle determined by the Direct Solution Method

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We determine degree 16 model of S-wave heterogeneity in the upper mantle by waveform inversion of long period surface wave data. We use the Direct Solution Method (DSM. Hara et al., [1991]) for theoretical calculations. Although the high accuracy of the DSM can improve the accuracy of earth models (Hara and Geller [2000]), the resolution of the model is still limited due to its heavy computational requirements (e.g., Hara and Geller [2000] obtained an degree 8 model of the upper mantle S-wave velocity). It is necessary to improve the DSM computational efficiency to raise the model resolution. Recently, Hara [2000] implemented the DSM codes on vector-parallel supercomputer to find that the improvement of@computational efficiency is almost proportional to the number of processing elements. In the present study, we apply these codes to analyses of surface wave data in the frequency band 2-4mHz. The upper mantle is divided into three layers (11-216 km, 216-421 km, and 421-671 km), and the lateral heterogeneity is expanded using spherical harmonics up to degree 16. Long wavelength features of this new model are similar to the model of Hara and Geller [2000]. There is a good correlation between low velocities and hot spot distributions in the shallow upper mantle (11-216 km). There are low velocities in the transition zone under some hot spots (e.g., south Pacific), which suggests that it is possible to trace temperature and/or chemical heterogeneities related to hot spots by surface wave studies.

T52F-02 1345h

3D upper mantle Q structure from waveform inversion and its interpretation

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We present a degree 8 model of attenuation in the upper mantle obtained by iterative inversion of three component long period seismic waveforms for elastic and anelastic structure. The main features of this model are stable and present interesting relations to corresponding elastic 3D tomographic models (obtained separately for SH and SV). In general, this model confirms the main features of our previous QR19 model, derived in a completely different manner and with lower resolution.

In the first 200-250 km of the upper mantle, we confirm the correlation of low Q with ridges and back arcs as well as high Q with the main shield regions. A feature not seen in SH, but present to some extent in the elastic SV model, is a zone of low Q spanning from Alaska to the south Pacific superswell. At greater depth and continuing into the transition zone, the correlation with tectonics and the low Q under Hawaii fade out, and the most prominent features of the Q model are two low Q minima centered in the Pacific and under Africa (the latter less well resolved). These low Q regions include most of the hotspots, correlate with low velocities in the elastic models, and, strikingly, are positioned above the two "superplumes" documented in the lowermost mantle from elastic tomography. This suggests a continuity in the rising currents associated with these superplumes up through the 670 km discontinuity and the upper mantle transition zone, and a strong thermal component to these plumes. When reaching the lithosphere, these currents are then deflected towards mid-ocean ridges. In particular, the presence of a low velocity region in the central Pacific in the SV model but not the SH model at depths around 200 km, associated with low Q supports the idea that the anisotropy previously documented in this region is related to a major upwelling which changes direction from vertical to horizontal in the uppermost mantle.

T52F-03 1400h

Observations of the Lehmann discontinuity and lower mantle reflectors using SS-precursors

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The upper mantle of the Earth is separated from the lower mantle by two globally confirmed discontinuities at 410 and 660 km depth. We performed a global search for additional mantle discontinuities by making use of regional stacks of precursors to the SS-phase. A bootstrap resampling algorithm is employed to determine robust reflectors (within the 95 % confidence level) and we have sought correlations with features in tomographic models, e.g. subduction- and plume-related features. These observations can be used as a probe for mantle composition and temperature.

The largest number of reflections comes from depths of 200-230 km which we associate with the Lehmann discontinuity. The global stacks show higher amplitudes for the Lehmann discontinuity beneath continental regions and much lower amplitudes beneath the oceans. The regional stacks show reflections where other techniques have shown a 220 km discontinuity, i.e. in the North American craton (Lehmann, 1959) and the Indonesian subduction zone (Revenaugh & Jordan, 1991). We also show new evidence for a Lehmann discontinuity beneath the oceans, where the depth and amplitude are much more variable than below the continents. There are also clear reflections from a depth range of 260-310 km, which correlate with observations of the X-discontinuity by previous investigators.

The stacks also show evidence for reflections from the lower mantle for a range of depths. We do not find one global lower mantle discontinuity, but local reflectors in certain regions. For example in the Indonesian subduction zone region these appear to confirm the 'mid mantle discontinuity' at 1050 km as suggested by Niu & Kawakatsu, 1997.

T52F-04 1415h

Evidence for a Regional Nature of the Lehmann Discontinuity

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The Lehmann ($\sim$220 km) discontinuity is one of the elusive features of upper mantle structure. It is a sharp discontinuity in the PREM model, but it is one of the features of this model that is criticized most often. Also, 220 km does not correspond to any phase transformation predicted for common minerals of the upper mantle. There is little question that it is not a global feature, unless it has a very large topography, because it would be seen as a precursor in stacks of seismograms, such as those presented by Shearer (1990). Taking advantage of a large body of data gathered to study global topography of the transition zone discontinuities, we perform a global survey for the presence of the Lehmann discontinuity using $\sim$20,000 long-period, transverse component waveforms containing the *SS* phase and its precursors. We stack seismograms with reflection points within spherical caps of 10° radius. This data set is strongly sensitive to upper mantle reflectors and the coverage is more complete than in earlier studies. Our survey indicates that the Lehmann discontinuity is a regional feature that is observed under continents more than twice as often as it is observed under oceans. We observe significant variations in travel times and waveforms associated with this shallow mantle reflector, indicating its complexity and lateral depth variations. Little signal is detected on the continent-scale stacks of the *SS* precursors, which provides further evidence for the localized and variable nature of the Lehmann discontinuity. For example, the discontinuity is always detected in Eastern North America, but it is absent in the West. Also, its detection is more common in the stable part of Asia.

T52F-05 1430h

Density Structure of the Upper Mantle under North America

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We present a new high-resolution density model for the lithosphere and upper mantle of North America and analyse its geodynamic and tectonic implications. This model is based on an integrated analysis of gravity, seismic refraction, seismic tomography, drill-hole, and geological data. The thickness of sedimentary cover was determined from geological maps, and the average density-depth relationship was estimated for each specific basin from published data. The density model of the consolidated crust (including Moho variations) is derived from seismic determinations. By removing the effect of the crust we calculate the residual mantle gravity anomalies and the residual topography which are due to density inhomogeneities in the upper mantle. A joint analysis of these results with seismic tomography data (Van der Lee et al., 2000) leads to a construction of a 3D density model of the upper mantle under North America that is consistent with the residual gravity and produces the dynamic topography which is close to the residual one. The obtained density variations in the upper mantle under North America change significantly with depth. We conclude that they can not be explained solely by variations in temperature (Goes and Van der Lee, 2001) but also by compositional differences. Under Canadian Shield this difference is negative and is equal on the average to -$40 \pm 5 kg/m^3$ which corresponds to 1.2% depletion. The opposite compositional anomaly is found in the southern part of North America adjoining to Gulf of Mexico, it exceeds 30 kg/m^3. The origin of this anomaly is in dispute.

T52F-06 1445h

Insights into the tectonics of the British Isles from seismic tomography

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A number of major tectonic events have shaped the British Isles, including the opening and closure of the Atlantic. To gain insights into the role of the mantle in such processes we have inverted teleseismic P-wave delay times have to obtain images of the upper-mantle structure beneath the the UK. The inversion uses data recorded by a short-period seismic network of nearly 140 stations operated by the British Geological Survey. Around 10,000 relative arrival times have been picked, for nearly 100 events occurring from 1994 - 2001, using a multichannel cross-correlation technique. The model is parameterised by splines under tension over a dense grid of knots. The nonlinearity of the inverse problem is addressed by alternately performing 3D ray-tracing and linear inversion. Resolution tests performed using a synthetic 'checkerboard' model and various models of discrete anomalies have shown that the resolution across the British Isles, and down to 600 km is excellent.

The resulting tomographic images reveal the presence of significant velocity structure to depths of around 400 km. Slow velocity anomalies in Scotland and in NE Wales show evidence of continental rifting which occurred during the breakup of Pangaea and the formation of the Atlantic Ocean. Fast velocity anomalies in Northern Scotland are interpreted as signatures of Pre-Caledonian subduction, and in central and southern England to the presence of a microcraton which has remained relatively undeformed throughout the Caledonian and Variscan orogenies.

T52F-07 1520h

Tomographic Model for the AAD Region From Waveform Inversion of Rayleigh Waves and Multiscale Parameterization

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The Australian-Antarctic Discordance (AAD)is a region on the Southeast Indian Ridge that is characterized by anomously deep and rugged axial valley and a relatively high seismicity. Global tomographic models suggest the presence of a long-wavelength depression in shear velocity over the AAD; regional studies reveal the high velocity nature of the AAD upper mantle and of the corridor extending northward. Most of these results are based on analysis of dispersion of fundamental mode surface waves, and the waveform information of a multimode seismogram has not been fully explored as a constraint on the upper mantle structure. We employ the waveform modeling technique of Cara and Leveque (1987) to invert for shear velocity structure along the path of the Rayleigh waves from ridge events recorded by GSN and Skippy stations in Australia. The method takes advantage of the definition of some secondary observables extracted from the real and synthetic seismograms prior to inversion. This leads to a stable inversion process for both the amplitude and phase of a multimode Rayleigh wave seismogram. Various tomographic schemes, including the wavelet-based, multiscale technique, are employed to invert path-average shear velocity to the 3-D model. The preliminary model reveals that the deviation from average ridge-axis velocity peaks at the depth of 120-150 km beneath AAD.

T52F-08 1535h

Evidence for a Thin Lithospheric Root Beneath the Tanzanian Craton From Rayleigh Waves

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The Archean Tanzanian craton is nestled between the Eastern and Western branches of the East African rift system. Is the cratonic lithospheric uncommonly thin? Has its root been eroded by rifting or impingement of a mantle plume? We improve the resolution of velocity structure for the cratonic lithosphere by inverting Rayleigh wave data at periods from 20 - 143 s from the regional array of stations of the Tanzanian Broadband Experiment. We perform inversions for phase velocity where pertubations to the wavefield are assumed to be generated by external heterogeneities and are represented by the interference effects of two incoming plane waves. The high density of raypaths yield unusually precise determinations of velocity within the craton, as well as less precise velocities in the two rift branches. Phase velocities for periods greater than 50 s in the craton are significantly lower than in other Archean cratons. Inversion for three-dimensional shear wave velocities show that high velocities beneath the Tanzanian craton are observed to depths of 130 $\pm$20 km while the lowest velocities are observed beneath the rifts at depths of 150 $\pm$20 km. In the craton region below 130 km the velocity decreases sharply, reaching a minimium of $\beta = 4.20 \pm 0.05$ km/s at a depth of $\sim$250 km. The anomalously low velocities below the craton are comparable to those found beneath young oceanic lithosphere indicating high temperatures and the presence of partial melt. At depths greater than 200 km, shear wave velocities are low compared to upper mantle velocities of *ak135*, and support hypotheses for the presence of a plume beneath the craton. Our results are remarkably consistent with a change to younger, more fertile asthenospheric mantle beginning at $\sim$140 km reported for peridotite xenoliths from the Labait volcano at the eastern edge of the craton. Beneath the southeast corner of the craton where rifting appears to crosscut the original craton boundary, we find that velocities at depths below $\sim$70 km are further reduced. Thus, ancient cratonic lithosphere is vulnerable to erosion by rifting processes and may indicate mantle plume activity.

T52F-09 1550h

Plastic Instabilities as a Possible Physical Mechanism Causing Intermediate-Depth and Deep-Focus Earthquakes

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It has been suggested that the occurence of plastic instabilities in the deeper portion of subducting slabs is the responsible mechanism for the generation of deep-focus earthquakes. Similarly, heat generation during viscous deformation providing a positive feedback to creep and eventually faulting under high pressures, could be responsible too for the occurence of intermediate-depth earthquakes within portions of the mantle lithosphere, where mechanisms involving dehydration or phase transformations do not apply. Recent detailed receiver function images of the structure of the Japan subduction zone seem to provide support for this notion. First, there is no indication of an existing metastable olivine wedge. Second, the intermediate-depth seismicity seems to be located in the strong and colder portions of the downgoing slab, about 30 km below the oceanic Moho. This suggests that instead of dehydration or phase transformation triggered events, ductile faulting is its predominating cause.

We show that, under certain conditions, a general local criterion for plastic instability can be met for nonlinear power-law creep (dislocation creep) of olivine resp. spinel (below 410 km discontinuity), so that the existence of metastable olivine in the deeper portion of a slab (below 500 km) is not a necessary condition for the generation of deep-focus earthquakes.

In addition, we have studied numerically the time evolution of an nucleated instability in the mantle lithosphere on the basis of a cellular block-slider model, but with an included viscous relaxation process.

T52F-10 1605h

Thermal Diffusivity Measurements of Olivine, Wadsleyite, and Ringwoodite to 20 GPa

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Heat-transport properties of mantle minerals are essential tounderstanding and modeling thermal regimes in Earth's mantle. Although these properties have been measured for olivine at ambient and high pressures and temperatures, they are lacking for the high-pressure polymorphs wadsleyite and ringwoodite. We have now performed thermal diffusivity measurements in a 5000 tonne, 6-8 type multi-anvil apparatus up to 20 GPa and 1400 K using the periodic temperature wave method. The sample volume in this apparatus is larger by at least a factor of 10 compared with sample volumes in conventional multianvil systems. Measurements were performed on 2.5 mm diameter cylindrical samples of San Carlos olivine (Fo90) and on wadsleyite and ringwoodite that were previously synthesized from San Carlos olivine of the same composition. The samples were all polycrystalline and single phase, and their purity and microstructures were characterized by X-ray diffraction and TEM. Our results show that the thermal diffusivity of wadsleyite measured at 14 GPa is significantly higher than that of olivine as extrapolated to conditions at the 410 km discontinuity (13.5 GPa, 1400° C). At this point thermal diffusivity increases by about 27% when olivine transforms to wadsleyite. The thermal diffusivity of ringwoodite, measured at 20 GPa, is slightly higher than that of wadsleyite at 14 GPa. However, their thermal diffusivities might be similar at the same pressure. Thermal conductivities calculated from densities and heat capacities agree with or are slightly lower than other published values, as is the jump at the olivine-wadsleyite transition. Part of the discrepancy may result from a higher fayalite component compared to forsterite (the presence of Fe decreases thermal diffusivity from that of Mg-end member samples, as observed for various silicates).

T52F-11 1620h

Two types of radiative transfer exist, but only one is relevant to the mantle

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Heat is transported by both contact (phonons) and radiation (photons). The situation is further complicated because radiative transfer occurs via two different mechanisms, termed "diffusive" and either "ballistic" or "direct" (e.g., Blumm et al. 1997, High-T High-P, p.555). This important distinction has largely been overlooked in Earth Science, leading to gross overestimates of thermal conductivity (k) from measurements and spectroscopic calculations. For a diffusive process, the distance over which temperature changes must be large compared to the distance light travels before it is extinguished. This condition is needed to use the sum $k_{rad,diff} + k_{phonon} = k_{tot}$ in Fourier's equation for conduction, or in convection studies (Siegel and Howell, Thermal Radiation Heat Transfer, 1972). Inside the Earth, this diffusive condition is met. Ballistic transport occurs when the light from a hot region reaches a cold region. This is the case for most laboratory measurements of k for geological samples (i.e., 5 mm size minerals have a gradient of circa 500 K, and are partially transparent. New thermal diffusivity techniques and modelling (Hofmann et al 1997, High-T High-P, p. 703; Mehling et al. 1998 Int. J. Thermophys, p. 941) separate out the ballistic component. The resulting k_{tot} for glasses and CaF_2 decreases with T over all T. The earlier measurements which instead showed upturns (where measured k went through a minimum and then increase strongly with T at moderate to high T) are largely heated through a ballistic mechanism. Similar upturns in olivine at high T must also represent undesirable ballistic transport. This process is unique to each experiment and irrelevant to the mantle, but has been viewed as intrinsic mineral behavior. The misunderstanding has persisted because early spectroscopic calculations recapitulated the ballistic upturn. The error lies in assuming that the mean free path of the photons goes as 1/A, where A is the absorption coefficient at each frequency. If A is 0, then k_{rad} is infinite, when it should be nil. Instead of the continuum approach, I assume quantization, and thus the mean free path is $1/A_{max}$ for each peak. The resulting $k_{rad,diff}$ for mantle olivine is $1/10^{th}$ the previous results. The same result [$k_{rad} = -3.95\times10^{-5}$ T $+1.047\times10^{-7}T^2 - 1.632\times10^{-11}T^3$ up to 2500 K] is independently obtained from photon lifetimes which are connected to peak widths through a classical damped harmonic oscillator model. Thus, the radiative mechanism under diffusive conditions is weak compared to contact at all temperatures in the mantle. For this reason, convection dominates heat transport in the Earth. Moreover, variation in Fe content of mineral will not drastically alter k. Structure and degree of solid solution are more important as these control the phonon mechanism (Giesting and Hofmeister, this volume).

T

T52F-12 1635h

The Effect of Water on the 410-km Discontinuity

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The H content of the Earth is one of the most poorly constrained compositional variables for the planet. The nominally anhydrous olivine and spinelloid phases thought to compose the bulk of the upper mantle and transition zone may contain many times the amount of H and O that reside in the hydrosphere. The discontinuity at 410 kilometers corresponds to the olivine-wadsleyite transition with an increase in both density and S-wave velocity of about five percent. Previous experiments and calculations in the anhydrous peridotite system indicate an olivine-wadsleyite two-phase interval that is from 10 to 18 km in width. Calculations indicate that the two-phase region would be significantly broader in a hydrous system.

We have conducted a series of synthesis experiments in the multi-anvil press on hydrous and anhydrous peridotite compositions and characterized the products by electron microprobe and single-crystal X-ray diffraction. Six experiments were conducted in a hydrous peridotite system, and three in an anhydrous system. The results of our synthesis experiments are consistent with the prediction of Wood (1995) that the presence of H_2O extends the stability of wadsleyite to 0.6 to 1.0 GPa lower pressure and would broaden the two-phase loop to as much as 30 km. In the hydrous runs containing both olivine and wadsleyite, there appears a sharp boundary between regions of olivine and regions of wadsleyite. The texture of the run thus does not appear to be a simple chemical equilibrium, but rather a diffusion-controlled boundary. Hydrogen is known to diffuse very rapidly in these materials, raising the possibility that diffusion of H might control the texture and may affect the sharpness of the boundary in the natural system.

Hydrous wadsleyite is about five percent denser than anhydrous olivine. In a hypothetical two-phase region consisting of olivine and wadsleyite plus lesser amounts of garnet and clinopyroxene extending over a depth 20 km in a hydrous system, gravitational equilibrium can be approached by rapid diffusion of H. This would enrich the lower parts of the two-phase region in wadsleyite and the upper part in olivine, thus sharpening the boundary. This mechanism could sharpen the apparent boundary to four kilometers or less as indicated in some seismic studies. This mechanism may allow the transition zone to serve as a trap for H. Compression experiments indicate that H will have a larger effect on velocity than temperature, so that a hydrous 410 will be shallow and slow, whereas a cool, dry 410 will be shallow and fast.

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