S11F-0361 0830h POSTER

Usage of Fractal Model of Elastic and Electrical Properties of Porous Rock for Recognition of Liquid-Saturated Pore Zones From Collocated Seismic and Magnetotelluric Experiments: Deep Extension of Nagamachi-Rifu Fault Case

Hisao Ito[1] (81-298-61-3757; hisao.itou@aist.go.jp)

Marina Pervukhina[1] (81-298-61-3757; marina-pervuhkina@aist.go.jp)

Yasuto Kawahara[1] (81-298-61-3757; y-kuwahara@aist.go.jp)

[1]National Institute of Advanced Industrial Science and Technology (AIST), Geological Survey of Japan (GSJ), Central 7, 1-1-1 Higashi, Tsukuba 305-8567, Japan

A theoretical model was involved for quantitative joint analysis of collocated seismic velocity tomography and electromagnetic experiments. The main advantage of the present model against other theoretical models is possibility to describe both elastic and electrical properties of rock with a single model for a wide range of microstructures including 3D grain and pore anisotropy and different interconnection extend from isolated to interconnected pores. Based on the developed model, an attempt have been made to elaborate a quantitative method for solving the problem whether the variation of resistivity and seismic velocities in a region can be attributed to presence of liquid only or whether another assumption should be involved. The suggested method was applied for analyzing a collocated seismic velocity tomography and MT experiment carried out across the active Nagamachi-Rifu fault running through Sendai city, Northeastern Japan. Several zones, where the perturbation of both velocity and resistivity can be explained with several percentage of liquid fraction, were recognized in the region, namely, a caldera and a deep extension of the Nagamachi-Rifu fault. In the caldera region at the shallow depth of 3 km, the reduction of the seismic velocities up to 10% and the low resistivity about several ohm were explained by about 3% of porosity. At the depth of 15 km a zone of the low velocity of 5-10% decrease and of the low resistivity about tens of ohm were explained by about 2% of porosity and interpreted as the deep extension of the Nagamachi-Rifu fault. The developed model allows involving in quantitative analysis of 3 independent parameters: compressional and shear velocities and resistivity and can be used for parameterization of a joint MT and seismic inverse problem in a variety of geological settings.

S11F-0362 0830h POSTER

Application of Fractal Model of Electrical and Elastic Properties of Porous Rock to Hirabayashi Borehole Data

Yasuto Kuwahara[1] (81-298-61-3757; y-kuwahara@aist.go.jp)

Marina Pervukhina[1] (81-298-61-3757; marina-pervuhkina@aist.go.jp)

Hisao Ito[1] (81-298-61-3757; hisao.itou@aist.go.jp)

[1]National Institute of Advanced Industrial Science and Technology (AIST), Geological Survey of Japan (GSJ), Central 7, 1-1-1 Higashi, Tsukuba 305-8567

To investigate microstructure of fault core and damaged zones, a fractal model for elastic and electrical properties of porous rock was applied to logging data of the Hirabayashi borehole, a 746 m deep borehole penetrating the Nojima fault, the main fault responsible for the Kobe earthquake at 1995. The main advantage of the present model against other theoretical models is possibility to describe both elastic and electrical properties of rock with a single model for a wide range of microstructures including 3D grains and pore anisotropy and various degrees of pore interconnection. Dependencies of the conductivity and the seismic velocities against the porosity were successfully simulated for all zones detected by core analysis: from the outside fault zone (152-426 m) to the upper and lower damaged zones (426-611 m and 641-746 m respectively) and the fault core zone (611-641 m). An interesting feature is that while the number of fractures observed by Fullbore Formation MicroImager (FMI) in the outside fault zone (4.2 fracture/meter) is 2-5% more than in the upper damaged and core zones (3.99 and 4.08) and only 12.5% less than in the outside fault zone (4.8 fracture/meter), the resistivity and seismic velocities in the fault zone are remarkably lower. This seeming discrepancy was explained by increasing number of microcracks that might be not detected by FMI. The seismic velocities and resistivity measured by logging at the depth 152-426 m were successfully simulated under assumption, that porosity of microcracks does not exceed 0.73%, the lowest porosity throughout the depths. At upper and lower damaged zones the experimental data were effectively simulated with porosity of microcrackes of 2.28%. These results are in a good agreement with the porosity measurements of core analysis, namely, 0.67% for the samples taken from the outside fault zone and 2.29% for the samples from the upper and lower damaged zones. The application of the fractal model of electrical and elastic properties of porous rock is demonstrated to be useful for recognizing a rock microstructure using porosity, resistivity and seismic velocities, which are measured in boreholes.

S11G MCC: 2002-2004 Monday 1020h

Theories of Earth's Interior II *(joint with T, V)*

Presiding: **L Kellogg,** University of California, Davis**; T Lay,** University of California, Santa Cruz

S11G-01 1020h

Subduction Drive of Plate Tectonics

Warren B. Hamilton (whamilto@mines.edu)

Dept. of Geophysics, Colorado School of Mines, Golden, CO 80401, United States

Don Anderson emphasizes that plate tectonics is self-organizing and is driven by subduction, which rights the density inversion generated as oceanic lithosphere forms by cooling of asthenosphere from the top. The following synthesis owes much to many discussions with him. Hinge rollback is the key to kinematics, and, like the rest of actual plate behavior, is incompatible with bottom-up convection drive. Subduction hinges (which are under, not in front of, thin leading parts of arcs and overriding plates) roll back into subducting plates. The Pacific shrinks because bounding hinges roll back into it. Colliding arcs, increasing arc curvatures, back-arc spreading, and advance of small arcs into large plates also require rollback. Forearcs of overriding plates commonly bear basins which preclude shortening of thin plate fronts throughout periods recorded by basin strata (100 Ma for Cretaceous and Paleogene California). This requires subequal rates of advance and rollback, and control of both by subduction. Convergence rate is equal to rates of rollback and advance in many systems but is greater in others. Plate-related circulation probably is closed above 650 km. Despite the popularity of concepts of plumes from, and subduction into, lower mantle, there is no convincing evidence for, and much evidence against, penetration of the 650 in either direction. That barrier not only has a crossing-inhibiting negative Clapeyron slope but also is a compositional boundary between fractionated (not "primitive"), sluggish lower mantle and fertile, mobile upper mantle. Slabs sink more steeply than they dip. Slabs older than about 60 Ma when their subduction began sink to, and lie down on and depress, the 650-km discontinuity, and are overpassed, whereas younger slabs become neutrally buoyant in mid-upper mantle, into which they are mixed as they too are overpassed. Broadside-sinking old slabs push all upper mantle, from base of oceanic lithosphere down to the 650, back under shrinking oceans, forcing rapid Pacific spreading. Slabs suck forward overriding arcs and continental lithosphere, plus most subjacent mantle above the transition zone. Changes in sizes of oceans result primarily from transfer of oceanic lithosphere, so backarcs and expanding oceans spread only slowly. Lithosphere parked in, or displaced from, the transition zone, or mixed into mid-upper mantle, is ultimately recycled, and regional variations in age of that submerged lithosphere may account for some regional contrasts in MORB. Plate motions make no kinematic sense in either the "hotspot" reference frame (HS; the notion of fixed plumes is easily disproved) or the no-net-rotation frame (NNR) In both, for example, many hinges roll forward, impossible with gravity drive. Subduction-drive predictions are fulfilled, and paleomagnetic data are satisfied (as they are not in HS and NNR), in the alternative framework of propulsionless Antarctica fixed relative to sluggish lower mantle. Passive ridges migrate away from Antarctica on all sides, and migration of these and other ridges permits tapping fresh asthenosphere. (HS and NNR tend to fix ridges). Ridge migration and spreading rates accord with subduction drive. All trenches roll back when allowance is made for back-arc spreading and intracontinental deformation. Africa rotates slowly toward subduction systems in the NE, instead of moving rapidly E as in HS and NNR. Stable NW Eurasia is nearly stationary, instead of also moving rapidly, and S and E Eurasian deformation relates to subduction and rollback. The Americas move Pacificward at almost the full spreading rates of passive ridges behind them. Lithosphere has a slow net westward drift. Reference: W.B. Hamilton, An alternative Earth, GSA Today, in press.

S11G-02 1035h

Stability of Subduction Zones in Numerical Models of Mantle Convection With Plate Tectonics

Sandrine Quere[1,2] (squere@sca.uqam.ca)

Alessandro Forte[1,2] (forte.alessandro@uqam.ca)

[1]Universite du Quebec A Montreal, Centre GEOTOP, C.P. 8888, Succ. Centre-Ville, Montreal, QC H3C 3P8, Canada

[2]Dept. of Earth Sciences, University of Western Ontario, London, ON N6A 5B7, Canada

During geological time, the Earth's surface has been marked by several cycles of opening-closing of oceans and collision-breakup of continents related to mantle dynamics and location of subduction zones.
indent Here we present a 3-D spherical model of mantle convection which incorporates surface surface tectonic plates which are dynamically coupled to the buoyancy-driven mantle flow. The formalism used to take into account the plates is the same as the one used by Monnereau and Quéré (2001). These time-dependent convection models reveal a cyclical re-organization of the subduction zones, alternating between two stable configurations. The principal input to this convection model is a multi-layer viscosity profile, with a low-viscosity channel at the bottom of the upper mantle, inferred by Forte and Mitrovica (2003) from simultaneous inversions of convection and glacial isostatic adjustment (GIA) data.
indent In these numerical convection simulations, the cycling between the two stable subduction zone configurations is characterized by a period between 500 and 700 Ma. This periodic behaviour is manifested in a relatively restricted range of model parameter space. For example, we have also used the same viscosity profile with differing internal and bottom heating inputs and we found that the cyclical behaviour was suppressed or entirely absent. For these alternative heating configurations, the convection simulations instead yielded a classical polygonal cell pattern usually obtained in free-slip models with upwellings surrounded by cold downwellings. It appears that the configuration of the mantle (e.g., relative importance between internal and bottom heating at the core-mantle boundary) plays a role in determining the appearance of steady, periodic variations in subduction zone configuration. Oscillations in bottom heat flux will enable the convective process to cycle back and forth between its two stable plate subduction patterns. We speculate that geological inferences of periodic variations in subduction zone configuration may provide a possible constraint on the style of mantle convection and in particular on viscosity structure and/or heating configuration.

S11G-03 1050h

Understanding the Mantle Through the Curious Topography on the 410 Discontinuity

Christine Reif[1] (858-534-8119; creif@ucsd.edu)

Guy Masters[1] (guy@igpp.ucsd.edu)

Megan Flanagan[2] (flanagan5@llnl.gov)

Peter Shearer[1] (pshearer@ucsd.edu)

[1]University of California San Diego SIO-IGPP, 9500 Gilman Drive MS-0225, La Jolla, CA 92093, United States

[2]Lawrence Livermore National Laboratory Earth Sciences Division, EES, Bldg.1404, Room 105 PO Box 808, L-205, Livermore, CA 94551, United States

Our understanding of the 410 km and 660 km seismic discontinuities has grown tremendously over the past 15 years. The debate regarding whether the seismic discontinuities arise from chemical or phase changes seemingly has been put to rest by the multitude of seismic and mineralogical evidence supporting phase transformations in the olivine component at these depths. Assuming that the discontinuities are indeed due to mineral phase transformations, there is much that can be learned about the composition and dynamics of the mantle. The depth and sharpness of the discontinuities depends on composition, temperature, water content, and attenuation. The Clapeyron slopes (the gradient of the phase boundary in pressure/temperature space) of the olivine to wadsleyite transition at the 410 and the ringwoodite to perovskite and magnesiowüstite transition at the 660 are similar in magnitude but opposite in sign. Therefore, the topography of the two discontinuities should be anti-correlated in the presence of vertically coherent thermal anomalies. While this is observed in some subduction zones and hot spots, many global and regional studies do not observe the expected anti-correlation of topography. This lack of anti-correlation can be explained in some instances where the subducting slab broadens at the 660, causing a more extensive thermal anomaly

S

than is present when the slab encounters the 410. However in areas where this is not the case, other explanations are necessary. We use an updated SS-S410S and SS-S660S (SS precursor) dataset that is nearly double the size of the Flanagan and Shearer (1998) dataset. Unlike previous studies that bin the SS precursor data from all azimuths to determine cap averages of topography, we are able to make SS precursor summary rays and correct for 3D velocity structure. However, we are best able to constrain the thickness of the region between the 410 and 660 (the transition zone thickness) since their differential times are not dependent on the upper mantle velocity model. While the transition zone thickness is dominated by the slab signature of the 660 topography, it is clear that the 410 topography is more often positively rather than negatively correlated with 660 topography. We find that this correlation is not an artifact of the modeling and therefore indicates either non-thermal effects or the presence of thermal anomalies that are not coherent between the two discontinuities.

S11G-04 1105h

Robust Compositional Heterogeneity Throughout the Mantle Inferred from Probabilistic Tomography

Jeannot Trampert[1] (jeannot@geo.uu.nl)

Frederic Deschamps[1] (deschamp@geo.uu.nl)

Joseph Resovsky[1] (resosvky@geo.uu.nl)

David Yuen[2] (davey@krissy.geo.umn.edu)

[1]Department of Earth Sciences, Utrecht University, PO BOX 80021, Utrecht 3508 TA, Netherlands

[2]Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, United States

To date, the most compelling evidence for compositional heterogeneity comes from several observations of regions with high ratios of relative S to P velocity heterogeneity and a general anti-correlation between bulk-sound and shear wave speed in the lowermost mantle. No clear picture has yet emerged, since the inferences are clearly study dependent, most likely due to the inherent non-uniqueness of the associated inverse problem. To identify all possible models compatible with seismic data (fundamental mode and overtone phase velocity data and normal mode splitting functions), we employed a full model search technique to the tomographic problem. We used Sambridge's Neighbourhood Algorithm. There is no need to employ ad hoc damping parameters, the algorithm is easy to tune, and most importantly, it converts the solutions into probability density functions for long wavelength models (spherical harmonic degree 2, 4 and 6) of bulk-sound and shear wave speed, density and boundary topography in the mantle. Using appropriate sensitivities (which take into account our ignorance on the thermodynamic reference state and the published range of mineral physics data), we convert the results from probabilistic tomography into likelihoods of variations in temperature, perovskite and iron content throughout the lower mantle. Several robust features emerge which shed a new light on the nature of the lower mantle. Throughout the mantle temperature variations are much weaker than classically inferred from shear wave speed alone. Compositional variations are essential to explain the seismic data. In most places, the inferences are robust, i.e. the amplitudes of chemical variations are much larger than the uncertainties inferred from the width of the likelihoods. Below 2000 km, the correlation between relative shear wave speed variations and temperature is quite low. In particular, we find that the much debated superplumes beneath the Pacific and Africa are due to an enrichment in perovskite and iron. This makes these features denser than the surrounding mantle and hence not buoyant. Slabs can be thought of as sinking cold oceanic lithosphere, in the lower mantle they should then correspond to regions colder than average and depleted in perovskite. Robust mapping of places of lower temperatures and perovskite depletion do not generally correspond to where we would expect slabs.

S11G-05 1120h

Effect of variable heat production on the thermal evolution of the mantle

Louise H. Kellogg[1] (kellogg@geology.ucdavis.edu)

Sylvaine Ferrachat[1] (sylvaine.ferrachat@wanadoo.fr)

Conjeepuram S. Natarajan[1] (nsconjeepuram@ucdavis.edu)

[1]University of California, Davis, Geology Department, 1 Shields Avenue, Davis, CA 95616, United States

The Earth currently loses heat at about 44 TW; this reflects both cooling and radioactive decay. From cosmochemical models, the bulk silicate earth budgets of uranium, thorium, and potassium are thought to produce about 20 TW. Thermal history models, which balance the rate of heat loss against the resulting temperatures in the mantle, yield a slightly higher value of about 30 TW. This heat production is distributed among the continental and oceanic crust, mantle, and core. The total heat production in the depleted mantle (the MORB source), plus the crust, may total between 9.6 and 17 TW, leaving a substantial amount of heat unaccounted for (at least 3 to 10.4 TW, assuming that the cosmochemical models correctly estimate the bulk silicate earth.) The most likely reservoir for the excess is either in the deep mantle or in the core. We investigate the several models for the distribution of the excess heat within the mantle, using numerical models of convection. Our goal is to assess the effects on Earth's thermal history of a mantle reservoir of excess heat production. Such a reservoir could be formed, for example, by incomplete differentiation of the crust and mantle, or by separation and isolation of recycled oceanic crust. We concentrated on models with a moderate amount of excess heat production in a lower layer, while remaining within the constraints required above. The excess heat must be low enough to prevent an excessive temperature increase across any internal boundary layers. In models with two strictly isolated layers and equivalent total heat production, the temperature-dependent viscosity adjusts to maintain an equivalent temperature drop across the layers, regardless of the thickness of the layers. The regulation of viscosity by temperature is consistent with the results of earlier parameterized models of two-layered convection by a number of researchers. Using a double-diffusive model of two-component convection to relax the mass transfer constraint across the interface, we observe substantial topography on the boundary. We will discuss the effect of fully dynamical layering on the thermal evolution.

S11G-06 1135h

Towards a Physical Understanding of the Effects of Depth-dependent Rheology on Mantle Convection

Mark Richards[1] (510-642-5872; markr@seismo.berkeley.edu)

Stephen Morris[2] (morris@newton.berkeley.edu)

Friedrich Busse[3] (Friedrich.Busse@uni-bayreuth.de)

Adrian Lenardic[4] (adrian@esci.rice.edu)

[1]Dept. of Earth and Planetary Science, University of California, Berkeley, CA 94707, United States

[2]Dept. of Mechanical Engineering, University of California, Berkeley, CA 94707, United States

[3]Institute of Physics, University of Bayreuth, Bayreuth D95440, Germany

[4]Dept. of Earth Sciences, Rice University, Houston, TX 77251, United States

It has long been suspected that the presence of a low viscosity zone (LVZ) beneath (at least) the oceanic plates has a major influence on plate tectonics and mantle convection, and there is ample evidence for an LVZ from glacial rebound and geoid studies, seismology, and mineral physics. 3-D numerical studies of mantle convection show that an LVZ is very effective in promoting long-wavelength structure, and that an LVZ facilitates plate-like surface motions when coupled with a lithospheric failure rheology. However, a fluid mechanical understanding of these important effects has been elusive. Referring to an idealized conceptual model that exploits the symmetry of bottom-heated convection with LVZ's at both the top and bottom boundary layers, we have devloped complementary theoretical models that elucidate the numerical results. Straightforward modification of classical boundary layer theory suggests that reduced horizontal shear stresses due to an LVZ should promote long-wavelenth structure. Rigorous scaling analysis can roughly predict the form and amplitude of the dependence of Nusselt number on Rayleigh number and horizontal wavelength, as revealed by 2-D numerical models of thermal convection. Extension of this analysis to non-symmetrical cases with internal heating and a single LVZ should be possible, and may lead to a more fundamental understanding of plate tectonics on Earth, and the lack thereof on Venus and Mars.

S11G-07 1150h

D": A Thermo-Chemical Boundary Layer With Partial Melt

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

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

Quentin Williams[1] (831-459-3132; quentw@es.ucsc.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 boundary layer at the base of the mantle has been shown to have strong seismic heterogeneity, dominated by large scale provinces of higher or lower than average P and S velocities. Most attempts to account for the observations involve a hybrid boundary layer similar to that at the Earth's surface, involving large, enduring chemical heterogeneities embedded in a dynamically mixed boundary layer that participates in overall mantle flow. Thus, high velocity regions are associated with ponds of subducted slabs and low velocity regions are continent-size chemical aggregations that accumulate beneath upwellings. An alternate perspective of the boundary layer that merits consideration is that the lowermost mantle is chemically stratified, a natural consequence of the chemical differentiation of the planet and the proximity to the massive density and compositional change at the core-mantle boundary. It is difficult to account for the observed seismic attributes of D" with such a model unless one allows for the possibility of variable partial melting of the boundary layer. If the eutectic solidus of the chemically distinctive D" region is very close to the CMB temperature, lateral variations in the thermal structure of D" may cause variable degrees of partial melting. Proximity of D" temperatures to the solidus has gained viability by the observation of ultra-low velocity zones with 10 to 30 percent velocity reductions right above the CMB, and the profound affect of even very small amounts of melting on seismic shear velocity provides a means by which to account for large scale variations of +/- 4 percent in shear velocity as observed. Chemical contrasts and melting effects in a stratified thermochemical boundary layer can plausibly account for all of the salient seismological observations about the boundary layer. Testing of this hypothesis, versus the notion of the hybrid boundary layer presents a basic challenge in deep Earth research.

S11G-08 1205h

D" Layer Activation via Tidal Dissipation: A Link Between Non-Hydrostatic Ellipticity, Non-Chondritic Heat Flux, and Non-Plume Head Generation of Flood Basalts

Bradford H Hager[1] (617 253-0126; bhhager@mit.edu)

Erwan Mazarico[1] (mazarico@mit.edu)

Jihad Touma[2] (jt00@aub.edu.lb)

Jack Wisdom[1] (wisdom@mit.edu)

[1]Massachusetts Institute of Technology, 54-622 MIT, Cambridge, MA 02139

[2]American University of Beirut, P.O. Box 11-0236, Beirut 11026, Lebanon

Quantitative understanding of Earth's heat budget has eluded a list of distinguished physicists and geochemists ranging from Lord Kelvin to Don L Anderson. The global heat flux is substantially greater than that generated by the estimated inventory of radioactive heat sources, so simple energy balance considerations demand an additional heat source. Secular cooling is commonly invoked to balance Earth's energy budget, but the required cooling rates are difficult to reconcile with both traditional convection calculations and petrologic estimates of ancient upper mantle temperatures. A non-geochemical heat source seems plausible. Indeed, Tuoma and Wisdom (Astron. J., 122, 2001) showed that tidal dissipation of rotational energy associated with resonant coupling could provide a substantial heat pulse to the CMB. D" Layer Activation (DLA) by dumping of rotational energy could have important geodynamical consequences that we explore here. DLA could lead to a sudden (but modest) increase in the temperature of preexisting plumes, leading to a sudden increase in melt volume without the need for a troublesome plume head. The dissipation depends on non-hydrostatic CMB ellipticity, which itself is a result of mantle convection, leading to the possibility of an important feedback mechanism - DLA would lead to an increase in CMB ellipticity, further increasing the geodynamic importance of DLA.