T52D-07 1510h

A Collaborative Approach for Providing Low-Cost ELF Monitoring from Ground and Space

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This paper describes a collaborative effort among several groups, including a small business (QuakeFinder,LLC), dozens of high schools in northern California, several universities (Stanford and Cal Poly SLO), and Lockheed Martin in Sunnyvale to build a combined ground-based and space-based ELF monitoring system. The goal is to monitor and characterize the raw RF spectrum in the ELF band, and to look for pre- and post-earthquake signatures. Previous attempts at monitoring ELF signals associated with earthquakes have always been summarized with the statement, **more data is needed**. QuakeFinder is a small business that approached the problem with a different strategy. Rather than deploy a few, expensive, commercial high sensitivity, AC magnetometers on the ground, a collaboration was formed with high school physics classes to build a large number of medium sensitivity magnetometers from partially-assembled kits, and to deploy these sensors in a close spacing along the major California earthquake faults. The strategy was to have a 3-axis ELF ground monitor within 15 km of any large (>M5) quake– before, during, and after the event. To date, 34 sites have been deployed (out of 50 planned), and they now collect and display daily averages from these 3-axis monitors on a web site (www.earthquaketracker.com).
Likewise, satellite-based monitoring is severely restricted by the high cost of building and flying space-based ELF monitors. QuakeFinder formed a collaboration between Stanford Space System Development Laboratory and Lockheed Martin to design and build a nano-satellite (4.5 kg) whose mission was to collect ELF background signatures. QuakeFinder built and donated a single axis ELF (1-1000Hz) magnetometer payload and provided integration and a launch opportunity for “QuakeSat I”. The satellite was launched on June 30, 2003 into a 820 km circular polar orbit, and has recorded natural signals (lightning, whistlers, auroral noise, and several unidentified signatures) as well as man-made (radar) signals. At this writing, it is early in the project, and more signal analysis and statistics are needed to determine if earthquake-related signals are present. The paper will report on the result of QuakeSat tasking over epicenters of >M6 earthquakes for post seismic correlations, and over seismically active areas worldwide for pre-seismic correlations of increasing ELF signals.

T52D-08 1525h

integrated Search for Taiwan Earthquake Precursors (iSTEP)

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Taiwan is located in an active part of the Circum-Pacific seismic belt. Due to intense collision between the Philippine Sea and Eurasian plates, Taiwan experienced many disastrous earthquakes in the past. The incessant plate collision means that we will inevitably face earthquake hazards in the future. Unfortunately, occurrence of earthquakes still cannot be forecast, much of this is due to lack of predictive capability. The problem of earthquake prediction has been under intensive investigations for nearly forty years in Japan, China, and the U.S. Yet relatively little progress is made thus far. Our frustration over the surprising difficulty of earthquake prediction problem has recently led to a serious debate within the seismological community on predictability of earthquakes. At the heart of the debate is the question on whether there are recognizable precursors of earthquakes? What could be precursors of impending earthquakes? A multitude has been suggested, but it is not clear which, if any, may become reliable. To search possible seismo-precursors and take into account the strength of our research team we decide to undertake this overall project, called Research on Seismo-Electromagnetic Precursors of Earthquakes (or integrated Search for Taiwan Earthquake Precursors (iSTEP) during April 2002 - March 2006. It consists of five inter-related sub-projects covering the following precursor topics: Sub-project I - A Study of seismological variations; Sub-project II - variations of the geomagnetic and gravity fields; Sub-project III - Radar interferometry for detection of surface deformation; Sub-project IV - Ionosospheric variations; and Sub-project V - Statistical studies of earthquake precursors. We then correlate the observed precursors by our sub-projects, as well as by other research organizations, with existing earthquake preparation models to (i) identify any possible, yet reliable precursory phenomena of earthquakes, including seismological, geodetic, geomagnetic, and ionospheric changes, and others, (ii) characterize feasible mechanisms behind the identified precursory phenomena in order to give quantitative physical interpretations and (iii) correlate the identified precursory phenomena with existing or emerging earthquake preparation models in order to lay foundation for future earthquake prediction. In this paper we report the current status and some latest results of the iSTEP.

T52E MCC: 3005 Friday 1340h

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

Presiding: **J Korenaga,** Yale University**; S Zhong,** University of Colorado

T52E-01 1340h

Mantle Flow Beneath Slow-Spreading Ridges Constrained by Seismic Anisotropy in Atlantic Lithosphere

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Seismic anisotropy within the oceanic lithosphere provides one of the most direct means to study deformation associated with convection in the mantle. Advection beneath a mid-ocean ridge spreading center deforms the mantle rocks, and as the rocks cool to produce the oceanic lithosphere, they retain a record of this deformation in the form of lattice-preferred orientation (LPO) of olivine grains. LPO direction and strength can be estimated from directional and/or polarization dependence (anisotropy) of seismic wave speeds, and mid-ocean ridge mantle flow properties can be inferred. Mantle flow beneath the slow-spreading Mid-Atlantic Ridge (MAR) is suspected to be strongly three-dimensional due to the influence of hotspots and other thermal variations, and this thermal heterogeneity may be related to buoyancy-driven flow beneath the ridge. This notion is supported by two analyses of lithospheric anisotropy in the Atlantic, which until recently had not been well characterized. Radial anisotropy imaged near the hotspot-influenced Reykjanes Ridge implies a quasi-vertical (rather than horizontal) orientation of the lithospheric fabric. Azimuthal anisotropy within a narrow swatch of western Atlantic lithosphere that was formed via ultra-slow spreading is weaker than that found in the Pacific by a factor of two. Both can be interpreted in terms of buoyancy-driven flow beneath the MAR. Here we extend these results using regional surface-wave analyses of the Atlantic basin. Earthquakes from Atlantic source regions recorded at broad-band seismic instruments located on Atlantic islands and the surrounding margins provide excellent sensitivity to oceanic lithosphere structure, without contamination by continental heterogeneity. By characterizing such structure in both hotspot-influenced (e.g. Azores) and normal slow-spreading lithosphere, and comparing these structures to the Pacific, we evaluate the degree to which spreading rate and/or mantle source temperature control fabric and mantle flow beneath mid-ocean ridges.

T52E-02 1355h

Cause and Effect: Seismic Anisotropy Measurements Using Full Wavefield Simulations in Realistic Mantle Flow Models.

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The supra-slab mantle wedge is a site of relatively small-scale flow of mantle material. Wedge flow is controlled by the rate, angle and direction of slab descent, the shape of the subducting slab and the nature and behavior of the overriding plate. The simplest geodynamic model for the mantle wedge is a 2-D corner flow driven by the shear coupling to the down-going plate. An upper mantle wedge at a convergent margin that deforms in corner flow should develop a trench-normal olivine LPO texture detectable by seismic anisotropy studies. It is considerable concern therefore that most studies of seismic anisotropy within supraslab wedges do not conform to expectations from this simple 2-D corner flow regime. We perform a systematic exploration of seismic anisotropy indicators expected in a subduction zone. Our primary goal is to separate effects of ”true” anisotropy from other contributions to the complexity of S waveforms, like propagation in complex 3D structure, specific biases of individual measurement techniques, frequency content of the wavefields etc. We use models composed of the mantle, the slab, the supraslab wedge and the crust. Anisotropy may be prescribed in one or more regions of the model. In particular, in the supraslab wedge we prescribe flow lines, and an associated pattern of anisotropic seismic velocities. Our wave propagation code allows for 3D heterogeneity in (anisotropic) velocity structure (crust, slab, subslab mantle, supraslab mantle) plus tilt for alignment with flow fields of any geometry. The code uses a finite difference solution of the elastic wave equation and allows for both point sources and upcoming plane waves of any back-azimuth and inclination (Okaya and McEvily, 2003). We compute S wavefields for a range of incidence parameters, and perform measurements of anisotropy as we would if these were real data. To evaluate resulting birefringence, we use two commonly used techniques for estimating shear wave splitting. The first method seeks a rotation of observed seismograms that would yield waveforms on two components that are most similar, and then evaluate the delay between them via cross-correlation. The second method seeks a combination of a rotation and a delay which, once it is used to correct for the effect of anisotropy, would minimize one of the components of motion. We also use a recently developed algorithm of Menke and Levin (2003) that is based on explicit wavefield comparison of ”observed” and ”predicted” wavefields, and allows to search for group solutions using multiple observations. Preliminary results show that the combined influence of effects other then anisotropy cause significant ”deviations” of seismic anisotropy parameters recovered by standard measurement techniques from the ”true” flow patterns in the model mantle. Of particular importance is the geometry of the wave propagation relative to the flow pattern.

T52E-03 1410h

Trapped Heat in the Mantle: The Origin for Topographic Flattening at Old Seafloor.

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It is well known that the rates at which seafloor topography and heat flux vary with age are greatly reduced at old seafloor (i.e., flattening), compared with the predictions from the half space cooling model. The origin for the reduced rates remains unresolved. In the conventional plate model, plate cooling is arrested at old seafloor through sublithospheric small-scale convection (SSC) that removes the bottom part of lithosphere and homogenizes it with the underlying mantle, leading to a constant lithospheric thickness at old seafloor and reduced rates of variations in topography and heat flux with age. While recent surface-wave tomography studies in the Pacific provide evidence for SSC and its associated lithospheric structure, it has been long debated whether SSC leads to topographic flattening or deepening, given that SSC could cool the mantle more efficiently to give rise to a even colder mantle below old seafloor than that without SSC. We have formulated numerical models to examine the effects of SSC under a mobile plate on the seafloor topography. In models with flow-through boundary conditions that best mimic the cooling of initially hot flow and isolate the effects of SSC, We found over a large parameter space for mantle rheology and plate motion that SSC has little influence on the topography which undulates around but closely follows the prediction from the half-space cooling model. However, in more realistic models with significant internal heating in a closed box, we found that heat tends to accumulate below old lithosphere, leading to topographic flattening. The heat accumulation below old lithosphere occurs because the thick lithosphere results in less efficient heat transfer than that at young seafloor. When SSC is absent, the accumulated heat is distributed over a large depth range. However, SSC brings the heat to shallow depths below the thinned lithosphere and causes largely uniform temperature in the underlying mantle.

T52E-04 1425h

Texture Evolution and Visco-Elasticity in Mantle Convection

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A novel class of nonlinear, visco-elastic rheologies has recently been developed by Mühlhaus et al (see web page). The theory has originally been developed for the simulation of large deformation processes including folding and kinking in multi-layered visco-elastic rock . The orientation of the layer surfaces or slip planes in the context of crystallographic slip is determined by the normal vector-the so called director-of these surfaces. Here the model is generalized to include thermal effects; it is shown that in 2D steady states the director is given by the gradient of the flow potential. The model is applied to anisotropic simple shear where the directors are initially parallel to the shear direction. The relative effects of textural hardening and thermal softening are demonstrated. Turning to natural convection we compare the time evolution and approximately steady states of isotropic and anisotropic convection for a Rayleigh number Ra =5.64 x 10E5. The isotropic case has a simple steady state solution, whereas the orthotropic convection model produces a continuously evolving patterning in the core of the convection cell which makes only a near-steady condition possible. The direct simulation of anisotropic mantle flow has been a very specialized area with very few publications since the original paper of Christensen (Geophys.J.R.astr. Soc. 91;711-736) In general it has instead been assumed that the instantaneous flow patterns predicted by convection simulations can be mapped immediately to seismic anisotropy. However, the results of Simons et al http://quake.mit.edu/ fjsimons/azimuthal.html and many others show the observations to be far more advanced than this simplistic modeling assumption. Advanced models should include feedback processes between large-scale flow, director miss-alignment and the drive towards flow alignment. A step in this direction is illustrated in finite element simulations of anisotropic simple shear and anisotropic natural convection.

URL: http://www.ned.dem.csiro.au/research/ solidmech/Publications/

T52E-05 1440h

Deep Continental Lithosphere Keels as Impediments to Asthenosphere Flow and Cause of Ocean Crust Depth Anomalies

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The Australian-Antarctic Discordance (AAD) lies directly in the wake of a deep keel of 2.5 billion year old Australian lithosphere that severed from and moved northward in the hot spot reference frame from a near-stationary Antarctica. Adopting the model of a plume-fed sub-ocean asthenosphere (Morgan, 1971,1972; Phipps Morgan,et al, 1995), this keel, like others of similar ancient age beneath South Africa and Laurentia could have served as a dam to isolate different pools of asthenosphere and thus allow each pool to evolve independently from their supplying plumes. A NSF-funded Antarctic database effort has allowed us to digitize a large set of seismic reflection profiles, map sediment thickness and remove the subsidence caused by sediment load. This effort confirms not only that the ocean crust between the keels of Australia and Antarctica was always manufactured at an anomalously deep spreading center, but the depth anomaly was greatest right after continental separation, and the crust beneath the faster moving Australian plate is deeper for all ages than counterparts on the Antarctic Plate. The same depth asymmetry and a similar geoid anomaly are observed in the South Atlantic where South America is traveling faster than Africa relative to the mantle. Upon separation of the continents, asthenosphere from both sides of the keel flows into the wake of the moving continent to replenish the void created by the initial dam. The Pacific asthenosphere, with its distinct geochemical composition, is currently observed to be propagating into the AAD. Since asthenosphere is consumed as it is frozen onto the diverging oceanic lithosphere, a dammed region with a limited asthenosphere supply might act as a brake, or governor, for seafloor spreading. We point out that spreading started very slowly upon the breakup of Australia and Antarctica, the aborted spreading center in the Labrador Sea occurs in a narrow ocean between very ancient cratons, and the boundary between the geochemical distinct Indian and Atlantic mid-ocean ridges occur where deep continental keels were severed.

T52E-06 1455h

Constraints on Asthenospheric Flow From the Depth of Oceanic Spreading Centers

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The near constancy of the depth of mid-ocean ridges away from hotspots has led to the view that such ridge depths reflect a globally averaged density and pressure structure. New analysis of data on ridge depths combined with a simple model of mantle flow leads us to assert that ridge depths depend on the thickness of underlying low-density asthenosphere. The asthenosphere thickness and related isostatic ridge depth depends primarily on the divergence rate of a spreading center and also on the distance to subduction boundaries according to a thin-layer asthenospheric flow model. We assume that the asthenosphere layer is lower in density than the mesosphere by about 10 kg/m3. Following Phipps-Morgan et al., (1995) the asthenosphere is sourced from below, though we assume a uniform distribution of sources. The ridge is a sink where 100 km thick rigid lithosphere is formed from flowing asthenosphere. The mean depth of the Southern East Pacific Rise (EPR) is consistently close to 3100 m while the consistent mean depth along the Pacific-Antarctic Rise (PAR) is closer to 2700 m. For a 10,000 km by 10,000 km area of Pacific asthenosphere overlain by idealized lithospheric plates representing parts of the Pacific, Nazca and Antarctic plates the model predicts nearly constant, but different depths for the model EPR and PAR. The faster divergence rate of 15 cm/yr for the model EPR compared to 9 cm/yr for the adjacent PAR can produce a 400 m greater mean ridge depth (i.e. average within 30 km of the axis) for the EPR for a viscosity of just over 1019 Pas and regionally averaged asthenosphere thickness near 300 km. Predicted asthenospheric strains are broadly consistent with shear wave splitting measurements. The deepest stretch of the world's mid-ocean ridges is the Austrailian Antarctic Discordance (AAD). The mean depth of the AAD is greater than 3500 m in places and there is evidence that the crustal thickness there is much less than for normal ridges. There is also evidence that the along-ridge length of the discordance is shrinking with time. We apply the asthenospheric flow model to this region under the assumption that the lithopsheric roots of the Austrailian and Antarctic continents extend to greater depths than the base of the thickest asthenosphere. The divergence of the model roots combind with the asthonspheric sink of the spreading center leaves a "wake" of zero asthenospheric thickness along a section of the model spreading axis. The length of the section of little or no asthenosphere shortens in time as asthenosphere flows parallel to the axis. If the near axis upwelling of hotter or more fertile asthenosphere produces more melt than would result from melting of mesosphere then the model can explain both the depth anomalies and thin crust observed at the AAD. For model parameters similar to that assumed for the EPR-PAR model and for a spreading history based on the AAD region we predict the present day AAD length.

T52E-07 1510h

Crustal and Upper Mantle Structure of the Ultra-slow Spreading Gakkel Ridge

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The 1800 km long Gakkel Ridge (Arctic Ocean) shows full spreading rates between 13 mm/yr north of Greenland and 6 mm/yr near its termination in the Laptev Sea. It is the slowest-spreading mid-oceanic ridge worldwide, and therefor plays a key role in understanding melt generation and crustal accretion processes. The joint AMORE expedition investigated the rigde in summer 2001 with the two research icebreakers RV Polarstern and USCGC Healy. Several geophysical and petrological experiments have been conducted including refraction seismic profiling along the rift valley and detailed sampling of the sea floor. Analysis of the rock samples and forward modelling of the wide-angle seismic data resulted in a clear division of the ridge in three parts with completely different structural characteristics. First results of a helicopter-based magnetic survey gave evidence for long-term focused magmatism along some parts of the ridge. The seismic data yielded also an exceptional thin oceanic crust with thicknesses not higher than 3 km and seismic velocities well below 6.4 km/s. Seismic velocities in the upper mantle are with values around 7.8 km/s also very low. The velocity models gave direct constraints for a 3D forward modelling of gravity data based on the 5-minute-grid of the Arctic Gravity Project. The crustal thickness shows only little variations along the rift valley, but perpendicular to the ridge the thickness varies between vanishingly thin and about 6 km. The density models off-axis strongly depend on the assumed temperature structure of the upper mantle. We will present several 3D density models of the oceanic crust and upper mantle to discuss different melt generation processes along the ridge.

T52E-08 1525h

Permeability Constraints From Microstructural and Geochemical Correlations in Dunites

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Trace element compositions, field relationships, and numerical models indicate that dunites represent high porosity conduits for melt transport beneath mid-ocean ridges. In this study we exploit systematic correlations between microstructure, chemical composition, and dunite width in the Oman ophiolite to constrain melt transport processes in the shallow mantle. In detailed transects across dunites of different widths, we observe an increase in Ti content in spinel and decrease in Ni content in olivine, relative to the surrounding harzburgite, as dunite width increases. Mass balance calculations with increased melt-rock ratios in wider dunites fit the measured chemical variations. In the same rocks, we also observe an increase in olivine grain size with increasing dunite width. Grain growth kinetics are sufficiently rapid to allow for the observed coarsening on timescales shorter than the residence time of solid material in the melting region. Depending on the mechanism of coarsening, wider dunites either formed over a longer time than narrow dunites or had a higher melt flux to achieve the larger grain size. But in either case, the increased grain size implies an increased permeability in wider dunites. The observed correlations between chemistry and texture are consistent with dunite formation by reactive porous flow of ascending basalt with the adjacent harzburgite. If dunites grow by reaction at their boundaries, then wider dunites have evolved over longer periods of time, which, coupled with an increase in permeability due to grain coarsening, implies a higher time-integrated melt-rock ratio in wider dunites. Using the power-law size-frequency relationship for dunites in Oman, we can integrate the compositional and microstructural observations into porous flow models to quantify the variations in permeability required to satisfy the observed melt flux at mid-ocean ridges.