We have applied our method to modeling of one-dimensional seismic wave velocity profiles of the mantle in various tectonic regimes, including old and young ocean, and shields. We compute the equilibrium phase assemglage and its seismic wave velocities along geotherms that account for lithospheric cooling and, in the case of shields, radioactive heat production. Seismologically determined shear velocity profiles are characterized by a distinct minimum in velocity at depths of 100-200 km. Comparison with our computed seismic wave profiles quantify the influence of attenuation and dispersion of seismic wave velocities in this depth range, which is found to be large and comparable to the influence of mantle composition (difference between basalt and harzburgite). Isochemical mantle compositions do not show a G discontinuity, as observed seismically in oceanic regions. We explore the possibility that this feature is caused by variations with depth in bulk composition, possibly due to basalt extraction.

MR11A MCC: 274 Monday 0830h

Elasticity and Constitution of the Earth's Interior IV *(joint with S, T, V, DI)*

Presiding: **G D Price,** University College London**; P J Tackley,** University of California, Los Angeles

MR11A-01 0830h INVITED

Birch's Mantle

Don L Anderson (626 395 6901; dla@gps.caltech.edu)

California Institute of Technology, Seismology Lab-M/C 252-21, Pasadena, CA 91125, United States

Francis Birch's 1952 paper started the sciences of mineral physics and physics of the Earth's interior. Birch stressed the importance of pressure , compressive strain and volume in mantle physics. Although this may seem to be an obvious lesson many modern paradoxes in the internal constitution of the Earth and mantle dynamics can be traced to a lack of appreciation for the role of compression. The effect of pressure on thermal properties such as expansivity can gravitational stratify the Earth irreversibly during accretion and can keep it chemically stratified. The widespread use of the Boussinesq approximation in mantle geodynamics is the antithesis of Birchian physics. Birch pointed out that eclogite was likely to be an important component of the upper mantle. Plate tectonic recycling and the bouyancy of oceanic crust at midmantle depths gives credence to this suggestion. Although peridotite dominates the upper mantle, variations in eclogite-content may be responsible for melting- or fertility-spots. Birch called attention to the Repetti Discontinuity near 900 km depth as an important geodynamic boundary. This may be the chemical interface between the upper and lower mantles. Recent work in geodynamics and seismology has confirmed the importance of this region of the mantle as a possible barrier. Birch regarded the transition region (TR ; 400 to 1000 km) as the key to many problems in Earth sciences. The TR contains two major discontinuities (near 410 and 650 km) and their depths are a good mantle thermometer which is now being exploited to suggest that much of plate tectonics is confined to the upper mantle (in Birch's terminology, the mantle above 1000 km depth). The lower mantle is homogeneous and different from the upper mantle. Density and seismic velocity are very insensitive to temperature there , consistent with tomography. A final key to the operation of the mantle is Birch's suggestion that radioactivities were stripped out of the deeper parts of Earth and placed in the crust and upper mantle. This resolves the lower mantle overheating paradox but the stratified mantle slows down the cooling of the Earth. A completely thermodynamically self-consistent treatment of mantle dynamics, with volume and temperature-dependent parameters has not yet been attempted but the essence of this approach is contained in the 1952 paper, which is must reading for all students of Earth's interior. One implication of this paper is that lower mantle structures should be gigantic and long-lived, a prediction spectacularly confirmed by modern seismic tomography.

MR11A-02 0845h INVITED

Challenging the Standard Model: Equation of State of Natural Peridotite at Lower-Mantle Conditions

Raymond Jeanloz[1] (jeanloz@uclink.berkeley.edu)

Kanani K. M. Lee[1] (leeka@uclink.berkeley.edu)

Sang-Heon Shim[1] (sangshim@seismo.berkeley.edu)

[1]Department of Earth and Planetary Science, University of California, Berkeley, CA 94720-4767

High-resolution x-ray diffraction of natural peridotite, before and after (subsolidus) laser heating at pressures as high as 107 GPa, yields results challenging the paradigm that the Earths mantle is a homogeneously mixed layer having the bulk composition of pyrolite.

The starting material for the experiments is representative of fertile upper mantle, and is indistinguishable from Ringwood's pyrolite compositions. It transforms to an assemblage of 76 (2)% $(Mg_{0.88}Fe_{0.06}Al_{0.12}Si_{0.94})O_3$ orthorhombic perovskite (opv) by volume at zero pressure, 17 (2)% $(Mg_{0.80}Fe_{0.20})O$ magnesiowstite (mw) and 7 (1)% $CaSiO_3$ perovskite (cpv), and room-temperature isotherms for each phase within the assemblage are in good agreement with past results on the individual mineral phases. Different measurement techniques yield reproducible results, with the observed scatter being well explained by the (small) compositional variations within the mineral phases of the natural starting material. We find values of the opv/mw Fe/Mg partition coefficient consistent with prior results, 0.20 (0.10) with no evidence of any pressure dependence, and recent work on $CaSiO_3$ perovskite shows that its structure exhibits slight tetragonal distortion at lower-mantle pressures.

The thermal equation of state of the high-pressure assemblage, described in terms of the Debye temperature, Gruneisen parameter and its volume dependence, is well determined if past measurements at high pressures and temperatures are reanalysed in terms of internally-consistent calibration standards. In particular, one model for the thermal equation of state of gold that has been used to calibrate several key experiments is faulty and yields biased results. Our reanalysis shows that all experiments point to relatively high values for the thermal expansion of opv (hence of the entire high-pressure assemblage), compatible with earlier rather than more recent analyses.

The resulting high-pressure, high-temperature bulk modulus of the high-pressure assemblage is constrained to about 5% at lower-mantle conditions, and is expected to be relatively insensitive to Fe abundance. Minimum temperatures of about 2000 K at 700 km depth rising to about 3000 K at 2500 km depth are required for the bulk modulus of the high-pressure assemblage to match the seismologically observed bulk modulus of the lower mantle. These values of temperature are in good accord with current estimates. The density of the pyrolite-composition high-pressure assemblage is then found to be at least 2 (1)%, (and plausibly 4 (2)%) lower than the seismologically determined density at corresponding depths. The density mismatch is partly attributable to the effect of Al on the volume of opv, as also found by others. Uncertainties in the measurements and analysis appear to be well constrained, and rule out pyrolite as a viable bulk composition for the preponderance of the mantle.

MR11A-03 0900h

A New Perspective on Seismic Constraints for 3D Mantle Density Suggests Strong Variations in Iron Content.

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

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

[1]University Utrecht, Earth Sciences Faculty Budapestlaan 4, Utrecht 3508 TA, Netherlands

We have used model space mapping to produce probability distributions for various characteristics of long wavelength models of v_s, v_p, ρ, and boundary topography in the mantle. This is a new approach to translating the global seismic inverse problem into constraints on geodynamic and geochemical modeling. Our distributions reveal that typical results for velocity-density correlation and scaling from seismic inversions are neither robust nor representative of the true nature of the seismic constraints. The data clearly favor density perturbations in most of the mantle that are uncorrelated or negatively correlated with velocity heterogeneity and have amplitudes several times larger (yielding $\delta \ln v_s / \delta \ln \rho < 1.0$) than damped seismic inversions usually allow. These characteristics are most pronounced in the upper mantle transition zone and the top and bottom of the lower mantle. This is strong seismic evidence for broad regions of elevated chemical heterogeneity in the deep mantle, and suggests that variable iron content is a dominant component of such heterogeneity.

MR11A-04 0915h INVITED

Fluid Mechanics and the Dynamics of the Earth's Interior

Richard J. O'Connell (617-495-2532; oconnell@geophysics.harvard.edu)

Harvard University, 20 Oxford St, Cambridge, MA 02138, United States

Flow in the Earth's mantle is directly inferred from the motion of lithospheric plates on the surface. The rheology of the mantle has been directly estimated from observations of postglacial rebound. However, it was the determination of lateral variations of seismic velocities and their interpretation as density anomalies that has allowed the modelling of density driven convective flow in the mantle. Matching the geoid has allowed depth variations of rheological structure to be better inferred. Current models of mantle flow can account for plate motions and observed polar wander reasonably well. Flow in the mantle distorts and moves mantle plumes, which provides a test of the plume origin for hotspots, as well as predictions of hotspot motion. Rheological models based on rebound, the geoid and hotspot motion all show an increase in effective viscosity in the lower mantle, which should diminish convection there. Models of isotopic evolution require a range of reservoirs that have been separate for geologically long times. Flow and stirring rates in a convecting mantle will allow chemical heterogeneity to persist over geologic times, especially if rheologic heterogeneities exist. The determination of the nature and location of geochemical heterogeneity and reservoirs remains one of the outstanding problems in understanding the dynamics and evolution of the mantle, although recent models have illuminated new approaches to the problem.

MR11A-05 0930h

STRUCTURE, ELASTICITY, AND WAVE-VELOCITIES OF MgSiO3-PEROVSKITE AT LOWER MANTLE CONDITIONS

Renata M Wentzcovitch[1,2] (612 625 6345; wentzcov@cems.umn.edu)

Bijaya B karki[1] (612 625 1313; karki@cems.umn.edu)

Matteo Coccocioni[2] (93 040 3787411; matteo@sissa.it)

[1]Department of Chemical Ungineering and Materials Science, University of Minneaota, 421 Washington Ave SE, MInneapolis, MN 55455, United States

[2]International School for Asdvanced Studies, Via Beirut 4, Trieste, TS 34014, Italy

The crystal structure, elastic constants, and wave-velocities of MgSiO3-perovskite (Mg-pv) have been determined throughout the lower mantle's (LM) pressure/temperature (P,T) regime by means of first principles computations of its vibrational density of states at various strained configurations and free energy calculations within the quasi-harmonic-approximation (QHA). The latter is tested "a posteriori" and shown to be valid at expected conditions. This completes the series of calculations on the thermoelastic properties of Mg-pv that are necessary to 1) narrow down constraints on LM's composition and thermal state, 2) shed light on the relative role of temperature on 3D velocity structures, and 3)on the anisotropy of this phase.

MR11A-06 0945h INVITED

Geochemistry and Mantle Structure: Still Crazy After All These Years

Donald J DePaolo (510-643-5064; depaolo@eps.berkeley.edu)

U C Berkeley, Department of Earth and Planetary Science, Berkeley, CA 94720-4767, United States

Geochemical evidence suggests that the modern mantle is layered, or at least zoned, such that the uppermost mantle is more depleted in incompatible elements than the deeper parts of the mantle. The inference of vertical stratification is based largely on the idea that volcanism associated with passive upwelling at mid-ocean ridges provides a sampling of the shallow mantle, while plumes that support volcanism at hot spots provide a sampling of the deep mantle. This geochemical evidence has so far been difficult to reconcile with what is currently understood about mantle convection and seismic structure. Numerical convection models show little indication that stratification can be preserved, or that the upper and lower mantle differ much in terms of mixing efficiency. Seismic and mineral physics data suggest that there may be no barriers to radial flow. Progress has been made in defining problems, but in many ways the issues facing the community now differ little from the situation in 1982.

The mid-ocean ridge basalt (MORB)ocean island basalt (OIB) dichotomy may or may not fairly represent the current geochemical state of the mantle. The degree to which it does is an important issue to resolve. The apparent layering, if not an illusion, may be either a longstanding feature of the deep earth or something more like a dynamically maintained steady state. What we can assume is: (a) chemically fractionated material (continental crust and oceanic crust) has been extracted from the mantle in a semi-continuous way over the entire history of the earth, leaving domains in the mantle with complementary depletions; (b) continental material, as well as ocean floor, is currently being

continuously subducted, and thus returns to the mantle, (presumably) with isotopic and chemical signatures betraying its time near the earths surface; (c) mantle plumes (exist and) come from fairly deep in the mantle, if not from the bottom; (d) the largest mantle plumes carry He that looks primordial; (e) the mantle material that melts to form MORB cannot represent more than a fraction of the total mantle; (f) mantle convection causes stirring of all of the components generated by partial melting and subduction (delamination) such that heterogeneities generated by different means can be juxtaposed as well as attenuated over time.

A model that accounts for all or most of these observations and reasonable assumptions has been elusive. How to model the processes is a subject of considerable debate. Nevertheless a consensus model is needed, if only as a benchmark for further research. A better synthesis of existing capabilities for modeling deep earth chemistry would be a start. A committee meeting might even be useful. Concurrent modeling of the petrology, chemistry, and fluid dynamics of mantle evolution, and volcanism itself, are still at an early stage. There is cause for hope and reason to stay tuned.

MR11A-07 1020h

Constraining the "African Anomaly" Using Geodynamical and Seismological Observations

Lianxing Wen (631-632-1726; Lianxing.Wen@sunysb.edu)

State University of New York at Stony Brook, Dept. of Geosciences, Stony Brook, NY 11794, United States

Seismic results have consistently shown a significant low-velocity anomaly in the lower mantle beneath Africa. This "African anomaly" has a broad base near the core-mantle boundary, extending from the south Atlantic ocean to the Indian ocean [Wen et al., 2001; Wen, 2001, 2002, Wang and Wen, this meeting]. The basal layer has steeply dipping edges, rapidly varying thicknesses (0-300 km) and geometries, and anomalously low shear wave velocities decreasing from -2% at 300 km above the core-mantle boundary to -9% to -12% at the core-mantle boundary. The structural features and velocity characteristics of the basal layer unambiguously suggest that it is a compositional anomaly. It is also suggested that the seismic characteristics associated with this basal layer can be best explained by partial melt driven by a compositional change produced early in the Earth's history. Such a suggestion implies a denser basal layer of the "African anomaly". In this presentation, I first discuss the seismic results and then use the observations of surface uplift and geoid to gain some insights into the density structure of the "African anomaly" in the mid-lower mantle. I assume that the observed surface uplift in southern Africa is caused by the "African anomaly" in the lower mantle. It is perceived that, if the surface uplift is caused by the "African anomaly" in the lower mantle, it would require that the top portion of the "African anomaly" is less denser. In this case, it would imply that the top part of the anomaly is unstable, and may have a different origin from its base. This conclusion, however, is only true under the assumption of whole mantle flow. If we assume a layered mantle flow and no viscosity jump from the upper to the lower mantle, a denser, rather than a buoyant, "African anomaly" would be required to explain the surface uplift. Such a layered model is attractive beneath Africa, as an elevated temperature or partial melt inside the anomaly would significantly reduce its internal viscosity, producing a locally weak lower mantle. I will discuss how these various flow and density models perform in consistently explaining the geoid, as well as implications to the origin of the "African anomaly".

URL: http://geophysics.geo.sunysb.edu/wen/

MR11A-08 1035h

On the Mechanisms of Solution of Al_2O_3 in $MgSiO_3$ Perovskite at Lower Mantle Pressures and Temperatures

Sofia Akber-Knutson[1] ((510) 642-9532; sofia@eps.berkeley.edu)

Mark S.T. Bukowinski[1] ((510) 642-0977; markb@socrates.berkeley.edu)

[1]Department of Earth and Planetary Science, 307 McCone Hall UC Berkeley, Berkeley, CA 94720, United States

Experiments and calculations suggest that $MgSiO_3$ perovskite, believed to be the most abundant mineral in the Earth's lower mantle, absorbs some amount of aluminum, via substitution into the Mg and/or Si sites. The substitution mechanism can significantly affect the properties of perovskite, so knowledge of which ones can actually take place can increase our understanding of the composition and evolution of the earth.

We consider two substitution mechanisms of Al into $MgSiO_3$ perovskite: 1) the charge coupled mechanism in which Al enters the Mg and Si sites equally and 2) the oxygen vacancy forming substitution mechanism, in which Al enters only the Si sites and charge balance is maintained with oxygen vacancies. Previous theoretical studies, based on 0 Kelvin, static computations on $MgSiO_3$ perovskite with an Al cation concentration of 25%, treat the two substitution mechanisms as mutually exclusive and suggest that Al is incorporated into the lattice via oxygen vacancy formation at low pressures and via charge coupled substitution at higher pressures (Brodholt 2000).

However, at equilibrium the solution of Al into perovskite is a thermodynamic process, in which it is possible for the two substitution mechanisms to coexist. We considered two separate reactions for the formation of the two types of aluminous perovskite. Using lattice dynamics with various parametrized pair potentials, that give reasonable equations of state for a large class of minerals, we examine the effects of temperature (0-2000 K), pressure (25-125 GPa), and Al concentration (3.125-12.5%) on these reactions. Regardless of the substitution mechanism, at T=300 K and P=0 GPa, and for an Al cation concentration of 6.25%, the predicted volume is slightly larger (by less than 1%) and the bulk modulus is smaller (by 4 and 7%, for charged coupled and oxygen vacancy forming substitutions, respectively), consistent with the results of Zhang and Weidner (1999) and Daniel et al. (2001).

An examination of the Gibbs free energies of reaction, ΔG, including estimates of configurational entropies, indicates that the two substitution mechanisms indeed coexist. At the pressures and temperatures corresponding to conditions at the top of the Earth's lower mantle, $\Delta G_{CHARGE-COUPLED}$ is negative and yields an Al cation concentration of at least 3.5% in $MgSiO_3$ perovskite. Pressure further decreases $\Delta G_{CHARGE-COUPLED}$ and hence increases Al solubility. In contrast, the calculated $\Delta G_{VACANCY}$ is positive at the top of the lower mantle. However, its magnitude ($\approx$ 9.7 kJ/mol) is small enough so that at equilibrium some amount of oxygen vacancies will be present. Furthermore, we find that $\Delta G_{VACANCY}$ increases with pressure, rendering the charge coupled substitution mechanism increasingly dominant with depth in the lower mantle.

MR11A-09 1050h INVITED

Seismological constraints on deep mantle structure: recent results

Jeroen E Ritsema (626 395-6937; jeroen@gps.caltech.edu)

Seismological Laboratory, 252–21 , California Institute of Technology, Pasadena, CA 91125, United States

Thanks to the development of global seismic networks, especially in the past two decades when digital broadband ground motion sensors were employed, full waveform analysis has led to the development of three-dimensional models of the structure of Earth's interior. Yet, many of the new models confirm a number of critical conclusions that F. Birch drew in his seminal 1952 JGR paper. For example, he envisioned that the upper mantle transition zone plays a prominent role in mantle circulation and he emphasized the significant effect of pressure on thermodynamic parameters. Indeed, a large number of seismic studies of the transition zone indicate that the descent of slabs of former oceanic lithosphere is, with few exceptions, impeded by the 660–km discontinuity. Furthermore, the observation of predominantly broad seismic velocity structures in the lower mantle (> 1500 km depth) may reflect sluggish convection, due to reduced thermal expansivity.

I will review several recent seismological studies of the deep mantle and place them in the context of Birch's paper. In particular, I will discuss surprising new findings in the deep mantle beneath Africa, which is especially well studied with data from recent African deployments. Furthermore, I will show results of the application of a new 3D waveform modeling technique that may prove invaluable in future seismological studies of the deep mantle.

MR11A-10 1105h

Effects of the compositional heterogeneity on the thermal evolution of the convecting mantle and core

Takashi Nakagawa[1] (takashi@ess.ucla.edu)

Paul J Tackley[1] (ptackley@ess.ucla.edu)

[1]Department of Earth and Space Sciences, University of California, Los Angeles, 595 Charles Young Drive East, BOX 951567, Los Angeles, CA 90095-1567, United States

A dynamical model for the thermal evolution of the convecting mantle and core is here used to investigate heat transfer in a compositionally heterogeneous mantle and its influence on the thermal evolution of the mantle and the core. Although parameterized convection is a powerful tool for understanding the thermal history of the mantle, such a model cannot treat lateral variations in thickness (including the possibility of discontinuous piles of material) of a potential compositional boundary in the deep lower mantle. Dynamical models have not previously focused on cases that include a compositionally heterogeneous mantle and the heat balance in the core.

The mantle convection model treats thermo-chemical convection in an extended Boussinesq and infinite Prandtl number fluid that includes an endothermic phase transition at 660km depth, and with volume averaged temperature-dependent viscosity in a two-dimensional cylindrical shell with cylindrical-spherical rescaling [van Keken, 2001]. The heat balance in the core is based on Stevenson et al.[1983], which includes treatment of latent heat and gravitational energy release during the inner core growth.

Seven cases, namely: isochemical with no phase transition, compositionally-heterogeneous mantle (thick layering and thin layering), compositionally-heterogeneous mantle with excess heat sources in the dense material (thick and thin layering), and completely layered convection bounded at the depth of 1600 km and 2500km, are tested using such a model. The scaling law of heat transfer in the surface and core-mantle boundary region, cooling rate of the mantle and core, and the possibility of existence of the inner core will be discussed in this presentation.

MR11A-11 1120h

Elasticity of Mantle Minerals and their High-Pressure Polymorphs at High Pressures and Temperatures

Robert C Liebermann[1] (33-5-61-55-80-27; Robert.Liebermann@sunysb.edu)

Baosheng Li[1] (Baosheng.Li@sunysb.edu)

Jennifer Kung[1] (Jennifer.kung@sunysb.edu)

Donald J Weidner[1] (DWEIDNER@sunysb.edu)

[1]Department of Geosciences/Mineral Physics Institute , ESS buliding Stony Brook University, Stony Brook, NY 11790, United States

In his 1952 paper, Francis Birch concluded "New phases are required to account for the high elasticity of the deeper part of the mantle (below 900 km), and it is suggested that, beginning at about 200 to 300 km, there is a gradual shift toward high-pressure modifications of the ferro-magnesian silicates, probably close-packed oxides, with the transition complete at about 800 to 900 km."

In the subsequent quarter century, experimental evidence for such transitions to high-pressure polymorphs emerged in laboratories around the world, most notably in those of Akimoto in Japan and Ringwood in Australia; these studies confirmed the existence of stable silicate phases with the wadsleyite, ringwoodite, majorite, ilmenite [now akimotoite], and perovskite structures. In the 1970s and 1980s, single crystal and polycrystalline specimens of these high-pressure phases were synthesized, thereby enabling studies of their elastic properties in the laboratory at ambient conditions [see Brillouin studies of the Weidner and Bassett laboratories, and ultrasonic studies by Mizutani and Fujisawa in Japan and Liebermann and colleagues in Australia]. This work often started with experiments on crystal chemical analogues of mantle silicates, following the original suggestions of Goldschmidt and Bernal in the 1930s (repeated by Birch in 1952), and then moved on to the real mantle compositions.

Prior to 1988, most of these acoustic experiments were conducted versus presssure at room temperature or versus temperature at room presssure; these conditions fell far short of those achieved in the Earth's mantle. Substantial progress has been made in the past decade, making it feasible to perform acoustic experiments at conditions approaching those for the transition zone (at depths greater than 400 km); this progress has been achieved in many laboratories, including those at the University of Washington, Geophysical Laboratory, Bayreuth Geoinstitut, Nagoya University, Australian National University, and Stony Brook.

Recent experiments have vastly expanded our knowledge of the elasticity of the high-pressure phases of mantle silicates, whose existence Birch foreshadowed 50 years ago. We summarize and discuss the new data for the olivine, wadsleyite and ringwoodite phases of (Mg,Fe)2SiO4, pyrope-majorite garnets with pyroxene stoichiometry, the coesite and stishovite phases of SiO2, ferropericlase, and silicate perovskites, and the implications of these data for interpretations of seismic models of the Earths interior.

MR11A-12 1135h

Cation Disorder and Elasticity in $MgSiO_3$ Akimotoite

Boris Kiefer[1] (609-258-3261; bkiefer@princeton.edu)

Lars Stixrude[2] (734-647-9071; stixrude@umich.edu)

[1]Princeton University, Department of Geosciences, Princeton, NJ 08544-1003, United States

MR

[2]University of Michigan, Department of Geological Sciences, Ann Arbor, MI 48109-1063, United States

The earth's transition zone, which extends from 410 and 660 km depth, is characterized by a complex series of polymorphic phase transformations. Akimotoite ($MgSiO_3$-ilmenite) is a high pressure polymorph of enstatite that is thought to be important in cold portions of the deep transition zone. The crystal structure of this mineral has not been determined at mantle conditions. Studies of analog materials indicate that akimotoite may exhibit cation disorder in the mantle, a behavior that would be expected to have an important influence on its stability and physical properties. In order to investigate this issue we performed first principle calculations of the $R\bar{3}$ structure of akimotoite, as observed experimentally at ambient conditions, and a novel structure in which each (001) layer contains equal amounts of Mg and Si. Our studies agree with the experimental finding that the $R\bar{3}$ structure has the lowest energy at low pressure. However, the energy of one of the cation-exchanged structures approaches that of $R\bar{3}$ as pressure is increased and becomes more stable at pressure greater than 40 GPa and zero temperature. The novel structure is 4.6% denser, has a 13.6% higher bulk modulus and a 18.5% larger shear moduls at zero pressure as compared to the $R\bar{3}$ structure.

These preliminary results suggest that order-disorder transitions in akimotoite may occur at mantle temperatures and that a disordered structure ($R\bar{3}c$) or partially disordered structure may be the stable state within the stability field of akimotoite. This behavior may effect the location of the ilmenite/majorite and ilmenite/perovskite phase transitions and may help to reconcile recent first principles computations of the akimotoite to perovskite phase transformation with experiment.

MR11A-13 1150h

Anisotropic Lattice Thermal Conductivity of Upper Mantle Minerals at High Temperature

Michael D Harrell[1] (206-543-0367; mharrell@ess.washington.edu)

J Michael Brown[1] (206-616-6058; brown@ess.washington.edu)

Evan H Abramson[2] (206-616-4388; evan@ess.washington.edu)

[1]Department of Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195, United States

[2]Department of Chemistry, University of Washington, Box 351700, Seattle, WA 98195, United States

The anisotropic lattice thermal diffusivity of three olivines (Fo0, Fo78, and Fo91) and one orthopyroxene (En91) has been measured to high temperatures via impulsive stimulated light scattering, permitting the calculation of the respective lattice thermal diffusivity tensors. Diffusivities have been combined with calculations of density and specific heat to determine the lattice thermal conductivity tensors. Both the diffusivities and conductivities were found to depart significantly from expectations based on a simple inverse-temperature dependence of the phonon mean free path. The observed behavior is explained in terms of a positive lower bound on the phonon mean free path, and the data thereby constrain a model of thermal conductivity at high temperature. The relative contributions of optic and acoustic modes are evaluated from analysis of published dispersion curves.

Several conclusions are reached: The anisotropy of lattice thermal conductivity remains essentially unchanged over the observed range of temperatures, indicating that anisotropy remains significant under upper-mantle conditions, and, in regions displaying preferred alignment, may account for observed lateral variations in the geotherm. Thermal conductivity departs significantly from earlier predictions of its temperature dependence; this may be understood in terms of a minimum phonon mean free path that is a small multiple of the mean interatomic spacing. For olivine, the optic modes have group velocities that are approximately one-third those of the acoustic modes, and do not dominate lattice conduction despite their greater number. Impurity scattering is significant along the olivine Fe-Mg solid solution series, but is not appreciable near the endpoints and therefore likely does not play a major role in the upper mantle. Finally, the historic underestimation of lattice thermal conductivity at temperature has led to an overestimation of radiative conductivity; radiative transport, although significant, plays an even smaller role in the upper mantle than has heretofore been assumed.

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Pan, C., The rotation of ron-rigid Earth, *Eos Trans. AGU, 83*(47), Fall Meet. Suppl., Abstract U41A-05, 2002.

Nonlinear Geophysics

NG52A MCC: 103 Friday 1330h

Scaling, Predictability, and Earthquake Fault Models *(joint with G, S, T)*

Presiding: **D L Turcotte,** Cornell University**; V G Kossobokov,** International Institute of Earthquake Prediction Theory**; K F Tiampo,** University of Colorado**; M Glasscoe,** University of California, Davis

NG52A-01 1330h INVITED

Scaling and Correlations in Earthquakes

Luciano Pietronero[1] (+39-06-49913488; luciano@pil.phys.uniroma1.it)

Luigi Ciofi degli Atti[1]

Vittorio Loreto[1] (loreto@pil.phys.uniroma1.it)

[1]Universita degli Studi di Roma "La Sapienza", P.le A. Moro 5, Roma 00185, Italy

Most of the breakdown phenomena of interest show instabilities at all sizes or scales. In this respect they represent an ideal playground to apply and test the novel concepts of critical and self-organized structures that have been developed mostly in physics. The basic idea is that the application of these new concepts should lead to a broader and deeper understanding of these phenomena. In this way it should be possible to cast the concept of predictability within a scientific framework, leading to a new generation of analysis and prediction methods.

It is with this spirit that we have analyzed space-time correlations in real earthquakes catalogs with the aim to define new statistical parameters for a quantitative description of the seismicity. We introduce in particular a method suitable to identify the spatial extension L(m) and the time duration T(m) of the aftershocks series as a function of the main event's magnitude m. It turns out that L(m) and T(m) are multivalued functions: events of the same magnitude may display significant fluctuations in the spatial extensions and durations of the aftershocks series. This method provides a new framework to define declustered catalogs which represent one of the main ingredient of any statistical analysis of the seismicity.

NG52A-02 1345h INVITED

On the short-term earthquake prediction: renormalization algorithm and observational evidence in S. California, E. Mediterranean, and Japan

Vladimir Keilis-Borok[1,2,3] (vkb@ess.ucla.edu)

Peter Shebalin[3] (shebalin@mitp.ru)

Ilya Zaliapin[1,3] (zal@ess.ucla.edu)

Olga Novikova[3] (onovikov@mitp.ru)

Andrei Gabrielov[4] (agabriel@math.purdue.edu)

[1]Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90095, United States

[2]Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095, United States

[3]International Institute for Earthquake Prediction Theory and Mathematical Geophysics, Warshavskoe sh., 79, korp. 2, Moscow 113556, Russian Federation

[4]Departments of Mathematics and Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, United States

Our point of departure is provided by premonitory seismicity patterns found in models and observations. They reflect increase of earthquake correlation range and seismic activity within "intermediate" lead-time of years before a strong earthquake. A combination of these patterns, in renormalized definition, precedes within months eight out of nine strong earthquakes in S. California, E. Mediterranean, and Japan. We suggest on that basis a hypothetical short-term prediction algorithm, to be tested by advance prediction. The algorithm is self-adapting and can be transferred without readaptation from earthquake to earthquake and from area to area. If confirmed, it will have a simple, albeit non-unique, qualitative interpretation. The suggested algorithm is designed to provide a short-term approximation to an intermediate-term prediction. It remains not clear, whether it could be used independently.

URL: http://www.igpp.ucla.edu/mcdonnell

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Discrete Models of Seismicity: A Case Study in Complexity

William I. Newman (310 825 3912; win@ucla.edu)

University of California, Dept. Earth and Space Sciences, Los Angeles, CA 90095, United States

Complexity describes the transition from order to chaos, where nonlinear interactions inextricably link space and time, where the whole is greater than the sum of its parts. Complexity may be seen in patterns that can reproduce at different scales embracing a hierarchy of interactions, where fractal structures are often produced, yet preserving a subtle sensitivity in its detail to its starting point. The seismicity observed in the earth is an example of such a complex system. While the equations of mathematical physics are generally given continuum representations, discrete models offer substantial simplification both in simulations and in their mathematical properties without sacrificing the essential physics. By combining discrete models with features derived from the renormalization group, we can learn much about scalings, cascades, and possibly predictability in application to many geophysical phenomena, including seismicity. We begin with percolation models, focusing on the emergence of criticality and relevance to modeling forest fires and earthquake events. Slider-block models are considered as well as their non-inertial equivalents, so-called "sandbox" models. We present fiber bundle models as a description of hierarchical structure, and then progress to colliding-cascades model for seismicity which have been successful recently in describing all observed scalings present in seismicity but have lead as well to the discovery of new scalings.

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The Fractal Approach to Estimation of the Physical Parameters of Seismicity

Vladimir Smirnov (7-095-9393848; smirnov@phys.msu.su)

Earth Physics Dept., Physics Faculty, Lomonosov Moscow State University, Leninskie Gory, Moscow, RUS 119992, Russian Federation

Modern physical theory of the failure is based on the fault mechanics and the kinetics of the multi-scale defects in the stress field. This theory contains a series of key parameters which define the character of the failure process. That are first of all such parameters, as the durability of a material in the kinetic concept of strength (known in seismology as a period of seismic cycle or earthquake recurrence time) and the critical concentration of cracks in a crack mechanics. The first one represents the intensity of the failure process; second one reflects the degree of crack interaction. Usual information for estimation of these physical parameters for the seismosphere of the Earth is statistics of earthquakes. However, the problem of quantitative comparison of the results of seismic statistics with the deductions of the physical theory lies in the discordance of corresponding spatial sizes. The typical size of the failure physics is the size of area of failure earthquake source size for seismology. Statistical estimates relate to areas containing a set of earthquakes and having, therefore, the size much more then t?? earthquake source. Hence, the transference of statistical estimates in theoretical field is their extrapolation in the space scales. Such extrapolation is correct only under the adequate account of character of the spatial structure of seismicity.

The combination of the fractal approach to the geometry of seismicity and Gutenberg- Richter relation (known as generalized GR relation) allows us to obtain correct estimates of the physical parameters of seismicity. The technique and results of such estimates, their dependence on the earthquake magnitude are discussed for different regions of the World.

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Elastodynamic Simulation of Fault System Dynamics

Peter Mora[1,2] (+61 7 33652128; mora@quakes.uq.edu.au)

Dion Weatherley[1,2] (+61 7 33654853; dion@quakes.uq.edu.au)

[1]QUAKES, The University of Queensland, Brisbane, Qld 4072, Australia

[2]Australian Computational Earth Systems Simulator, The University of Queensland, Brisbane, Qld 4072, Australia

Previous simulations of granular systems subjected to shear with the lattice solid model have exhibited evolution of the stress correlation function in the leadup to large events. While these results provide evidence for a Critical Point-like mechanism in elasto-dynamic systems and the possibility of earthquake forecasting, it remains unclear whether such a mechanism will occur in more realistic models of interacting fault systems or in the real earth. Furthermore, CA simulations suggest that both Self-Organised Critical and Critical Point behaviours are possible depending on the values of tuning parameters. This suggests that even if the the crust does exhibit CP-like behaviour, a given fault system may not depending on the tuning parameters such as fault density, the statistics of fault friction, and dissipation. To progress towards resolving this issue, we develop a 2D fully elasto-dynamic model of parallel interacting faults. Either slip or velocity weakening friction can be defined along faults. Slip weakening friction and a power law distribution of static and dynamic friction coefficients is specified. Numerical shear experiments are conducted in a model with ten parallel interacting faults and fault friction power law exponents of 0.6 and 1.6. The results exhibit a complex evolution of the stress field and a number of interesting features including activity switching between faults and fault segments in the model. The event size distributions are essentially a power law with a slight overabundence of large events. Based upon comparisons with CA simulation results, this suggests the system is in the SOC part of phase space although further analysis is required to confirm this hypothesis. Numerical expriments are now in progress using different fault densities, fault friction statistics and slip weakening distance to study whether or not the model exhibits both critical point and SOC behaviour like the CA models. The model provides a crucial link between CA maps of phase space (e.g. that show regimes of CP or SOC behaviour) and the behaviour of more realistic elasto-dynamic interacting fault system models, and thus, a means to improve understanding of the complex system behaviour of real fault systems and progress towards the goal of a scientific underpinning for earthquake forecasting

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Problems and Challenges in Earthquake Simulations

John B Rundle (530-752-1500; rundle@physics.ucdavis.edu)

Department of Physics University of California, Davis, One Shields Ave., Davis, CA 95616

We describe problems and challenges in constructing topologically realistic simulations of active earthquake fault systems, focusing on 1) Rationales for incorporating successive hierarchies of physical processes and layers of detail; 2) Computational issues associated with performance, efficiency, and optimization of codes; and 3) Knowledge acquisition, related to data mining, visualization, and comparison with theory. Numerical simulations of physical systems are particularly useful for investigating the relationship between observable multi-scale space-time patterns in data and the fundamentally unobservable, underlying multi-scale dynamics that produce them. In general, simulations are designed to provide physical understanding of fault system processes and their influence on factors such as: 1) Seismic activity through time; 2) Surface displacements observable by GPS, strainmeters and InSAR; 3) Relative importance of fault network topology and frictional processes in determining dynamical behavior; and 4) Partitioning of slip and seismic activity among active strike slip faults in California. As an example of how simulations can provide substantial insight into the collection, processing, and interpretation of observational data, we discuss a new result suggesting that surface observations from NASA space geodetic data can be used to construct a new type of fluctuation metric, a Local Ginzburg Criterion. Since earthquakes are now interpreted as generalized phase transitions, techniques can be developed that make use of fluctuation-related phenomena to image the underlying dynamics from data. In particular, the form of our friction equations, which are based on laboratory experiments, suggest that the strain rate should be viewed as an order parameter, whose mean value is high immediate prior to a large earthquake, and jumps discontinuously to a low mean value immediate following the event. From ideas developed in these simulations, we propose a new mapping function, which we call a Local Ginzburg Criterion, that can be used to reveal information about the underlying dynamics using surface strain rate observations on fault systems.