Seismology

S11A MCC: 2002-2004 Monday 0800h

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

Presiding: **R Jeanloz,** University of California, Berkeley**; M Ishii,** Harvard University

S11A-01 0800h INVITED

Speculations on Some Problems of Continental Evolution

Thomas H. Jordan (213-821-1237; tjordan@usc.edu)

Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089-0740

Don Anderson is a true student of T. C. Chamberlin, who in his famous 1890 paper (probably as an unstated response to Kelvin's unrealistic bound on the age of the Earth) cautioned how "a working hypothesis may with the utmost ease degenerate into a ruling theory." Questioning the ruling theory has been a specialty of Don's—a skill he has recently demonstrated in his vigorous critique of the hypothesis-cum-ruling-theory that deep mantle plumes are a dominant mechanism for anomalous volcanism in the continents and oceans. Though he was my teacher, I have rarely had the occasion to agree with an Andersonian view of the world, even in the multiplicity of its working hypotheses, so I appreciate this opportunity to support his notion that the instabilities responsible for certain types of anomalous volcanism—in particular continental flood basalts—arise in the upper, not lower, mantle. The subject of my presentation will be the evolution of the continental tectosphere. For some time my thinking has been based on the idea that the chemistry and temperature of the deep (sublithospheric) tectosphere are mutually regulated by the dynamic requirement of isopycnic balance. Current data on the substructure of the cratons seem to support this hypothesis, at least as a first approximation, but it places severe constraints on continental formation that have not yet been reconciled with salient aspects of geologic history. The transition sometime in the early to mid Proterozoic from thick to relatively thin tectosphere can plausibly be explained by the exhaustion of mantle peridotitites with magnesium numbers in excess of 92 that were depleted prior to 4 Ga, but the long history of intracratonic volcanism, as evidenced by pervasive dyke swarms and episodes of basaltic flooding, remains a puzzle. I will therefore explore the possibility that the *magmatic* stabilization of the cratons proceeded during an extended interval following their *tectonic* stabilization by supercontinent collisions. According to this line of thinking, remnants of oceanic (i.e., formerly convecting) upper mantle trapped within the accreting cratons conductively cooled, subsided to form sedimentary basins, and eventually became unstable in basin inversion events that produced large volumes of basaltic magma by decompression melting. The resulting depletion led to the stabilization of these tectospheric "flaws", although their existence remains evident as regions of lower Mg numbers and higher temperatures (and thus lower seismic velocities) in near-isopycnic balance with the surrounding tectosphere. Data from southern Africa supporting this speculative model will be discussed.

S11A-02 0825h INVITED

Mineral Physics and Mantle Evolution

Robert C Liebermann[1] (631-632-1968; Robert.Liebermann@stonybrook.edu)

Jay D Bass[2] (217-333-1018; jaybass@uiuc.edu)

Donald J Weidner[3] (631-632-8211; Donald.Weidner@stonybrook.edu)

[1] COMPRES, ESS Building Stony Brook University, Stony Brook, NY 11794-2100, United States

[2] University of Illinois at Urbana-Champaign, Department of Geology, Urbana, IL 61801, United States

[3] Stony Brook University, Department of Geosciences and Mineral Physics Institute, Stony Brook, NY 11794-2100, United States

Don Anderson has been a steadfast patron and constructive critic of mineral physics for more than 40 years. Although he has never actually done an experiment himself [except for perhaps some early work on ice when he was working in Greenland], he has nurtured and supported two generations of experimental mineral physicists throughout the U.S. His role and influence have been especially evident in studies of the elasticity and anelasticity of minerals and the use of such data for interpretation of seismic models of the Earth's mantle. In the 1960s, such acoustic experiments required specimens of centimeter dimensions and could achieve elevated conditions of less than 1 Gigapascal in pressure and a few hundred degrees of Celsius temperature. Today, one can perform such experiments on specimens only a fraction of a milimeter in size and reach pressures of tens of GPa and temperatures in excess of two thousand degrees C. In addition, Anderson's contributions to organized scientific endeavors have extended far beyond his founding role in IRIS to include advising on the establishment of the new Consortium for Materials Properties Research in Earth Sciences [COMPRES]. We ilustrate his remarkable contributions to mineral physics with examples of our own research, some of it done in collaboration with Anderson.

S11A-03 0850h

Origin of the Low Velocity Zone in Oceanic and Continental Regions

Lars Stixrude[1] (stixrude@umich.edu)

Carolina Lithgow-Bertelloni[1] (crlb@umich.edu)

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

By virtue of its intermediate position between the upper thermal boundary layer and the nearly adiabatic interior, the low velocity zone holds important clues to the relationship between plate tectonics and the earth's internal dynamics and to the origin of the crust. Forty years after its discovery, the origin of this region is still debated. Some have argued that the presence of small amounts of partial melt are needed to explain the extremely low shear wave velocities observed, while others have argued that no partial melt is required by seismological observations. The question is complicated by the importance of attenuation and anisotropy in the low velocity zone, and, perhaps most importantly, the limited information we have had until recently of the elastic properties and phase equilibria of relevant mantle assemblages. We apply a new method to the construction of one-dimensional models of the low velocity zone in a number of tectonic settings, which allow direct comparison with seismological observations. The method is based on a thermodynamic formulation that allows us to predict phase equilibria, density, and compressional and shear wave velocities of multi-component, multi-phase mantle assemblages self-consistently. Such an approach is important because many phase transformations occur over the upper few hundred km of the mantle including plagioclase=spinel=garnet, and the gradual pyroxene to garnet transition, and because the phases involved have very different elastic properties. To extrapolate experimental data that is often still limited, we use an anisotropic generalization of the Mie-Gruneisen-Debye theory modified after Davies (1974), which is expected to capture much better the behavior of elastic constants at high pressure-temperature conditions than polynomial expansions that have sometimes been used in the past. We find that no partial melt is required to account for the low velocity zone in oceanic regions. Along half-space cooling geotherms, the low velocity zone is pronounced even in the elastic limit: the low velocity zone becomes more pronounced and moves to shallwer depths as age decreases. These age dependent features are seen in many models of the low velocity zone. The only feature of the low velocity zone that is not captured by the elastic limit is the magnitude of the velocity anomaly. However, the lowest velocities are readily accounted for by plausible values of attenuation and attendant dispersion without invoking partial melt. One-dimensional shear and compressional velocity profiles that include plausible Q models agree well with published one-dimensional seismological models over a range of lithospheric age. We will report on extensions of our work to continental areas and to the more direct comparison with seismological observations via the computation of phase velocities.

S11A-04 0905h

An explanation for the surface area of continents versus oceans

Adrian Lenardic[1] (713 348 4883; adrian@esci.rice.edu)

Louis Moresi[2]

A. Mark Jellinek[3]

Michael Manga[4]

[1] Rice University, Department of Earth Science - MS 126, Houston, TX 77251-1892, United States

[2] Monash University, School of Mathematical Sciences, Building 8, Victoria 3800, Australia

[3] University of Toronto, Department of Physics, 60 St. George St., Toronto, Ont M5S 1A7, Canada

[4] University of California, Department of Earth and Planetary Science, 307 McCone Hall, MC 4767, Berkeley, CA 94720-4767, United States

The Earth's surface is approximately 40 percent continental and 60 percent oceanic. We present a theory of the Earth's internal heat loss that provides a thermal explanation for the 40-60 split. The theory, which is shown to be consistent with numerical simulations and laboratory experiments, couples oceanic and continental heat transfer modes and predicts that the observed surface area of continental lithosphere is near optimal in the sense that it maximizes the Earth's global heat flow. It also predicts the surface area that would maximize heat flow in the geologic past when the Earth had more internal heat to lose. This allows a continental growth curve to be constructed that maximizes global heat flow over geologic time. The theoretical curve is consistent with growth curves based on geochemical observation.

S11A-05 0920h

29 years of surprises from hotspots: A personal perspective

. Students of EAO[1]

Emile A Okal[1] (emile@earth.nwu.edu)

[1] Northwestern Univ., Locy Hall, Evanston, IL 60208, United States

I arrived at Caltech on 26 August 1974, to begin my graduate studies at the Seismo Lab, then under the Directorship of Don L. Anderson. These were the days, among other topics, of Don's famous multilingual footnote on the "definition..., antecedents..., supporters and detractors" of the concept of "plume" [GSA Bull., 86, p. 1593, 1975], and even though I was not to set foot on a hotspot island until my first trip to Tahiti in December 1977 (those stopovers at Keflavik on the 199-dollar Loftleidir runs did not really count), I quickly acquired a mild form of Don's contagious fascination for the activity and structure of hotspots. As a tribute to Don, I have chosen to recap here a few surprising results obtained, with the help of my students, past and present, over several decades of work on the seismological sources and structures in the neighborhood of hotspot islands.

S11A-06 0935h INVITED

Thermal evolution of the Earth, plate tectonics, and chemical geodynamics

Jun Korenaga (jun.korenaga@yale.edu)

Department of Geology and Geophysics, Yale University, PO Box 208109, New Haven, CT 06520, United States

A heat-flow scaling law for mantle convection has been playing a fundamental role in modeling the thermal evolution of the Earth. The sensitivity of surface heat flux to a change in mantle temperature is usually considered to be positive; the Archean Earth is characterized by hotter mantle, more vigorous plate tectonics, and thus higher heat flow. This positive sensitivity is surprisingly robust - isoviscous convection, stagnant-lid convection, and plate-tectonic convection all show essentially the same positive sensitivity. The generation of oceanic plate at mid-ocean ridges, however, involves decompressional mantle melting, which have a strong influence on the subsequent evolution of the top boundary layer in mantle convection. Global energetics of mantle convection, incorporating this interaction between chemical differentiation and mantle dynamics, exhibits an inverse relationship between mantle temperature and surface heat flux. This suggests that plate tectonics may have been more sluggish in the past than present. The new heat-flow scaling law has a number of intriguing implications for the heat budget of the Earth, the style of mantle convection, the thermal history of the core, and the chemical evolution of the Earth. Critical issues relevant to future research directions will be discussed.