Meeting of Young Researchers in the Earth Sciences-I

Heat, Helium, Hotspots, and Whole Mantle Convection

La Jolla CA, August 12-15, 2004

Program

- Wednesday, August 11, 2004
  - evening: arrival (ERC dorms, UCSD campus)
  - 7pm: ice breaker (informal) (ERC dorms, UCSD campus)
- Thursday, August 12
  - 9am-6pm: full session (Hubbs Hall, SIO campus)
  - 6:30pm: Scripps sponsored dinner (Surfside, SIO campus)
- Friday, August 13
  - 9am - 5pm: full session (Hubbs Hall, SIO campus)
  - 5pm – 7pm: Tour of the Earth by D. Sandwell (VizCenter, SIO)
  - 8pm: informal poster session in dorm halls (ERC, UCSD campus)
- Saturday, August 14
  - 9am-6pm: full session (Hubbs Hall, SIO campus)
  - 8pm: informal poster session in dorm halls (ERC, UCSD campus)
- Sunday, August 15
  - 9am-6pm: full session (Hubbs Hall, SIO campus)
  - 7pm: Farewell dinner (Munk Lab, IGPP, SIO campus)
- Monday, August 16
  - morning: departure (ERC, UCSD campus)

UCSD: University of California, San Diego, with main campus in La Jolla, CA

ERC: Eleanor Roosevelt College of UCSD

SIO: Scripps Institution of Oceanography (part of UCSD)

IGPP: Institute of Geophysics and Planetary Physics (part of SIO)

Daily program structure

7:30am-8:30am breakfast (ERC college, UCSD)

9:00am – noon **two keynote lectures (SIO)**

- 9am – 10:15am lecture 1
- 10:15am – 10:45am coffee
- 10:45am - noon lecture 2

12:00 - 1:30pm lunch (SIO)

1:30pm - 3:00pm **small group break-out discussion (SIO)**

- focus on questions and create mini presentations for the FORUM
- 2 days by discipline, 2 days mixed discipline
- instructors act a facilitators and keep record of discussion
- someone else from the group presents questions, synthesis to the FORUM

3:00 am- 5:00pm **THE FORUM (SIO)**

open floor discussion, ask questions, discussions

6pm-7pm dinner ERC college (UCSD)

8pm-10pm **informal poster session** (ERC, UCSD; only Aug 13 and 14)

Session order

Please note the links for draft lecture slides in PDF or Microsoft Powerpoint (PPT) format as kindly provided by our keynote speakers. We would like to ask you to inquire before using this material for purposes other than personal education.

- **Mantle Structure (Aug 12)**
  - Frederik Simons (Princeton): *Tomography: Art or Science?* (PPT slides (with animations), PDF slides, recommended reading)
  - Wendy Panero (U Michigan): *Interpreting Geophysical Data for Mantle Dynamics* (PPT or PDF slides, recommended reading)

- **Surface Observables** (Aug 13)
  - Magali Billen (UC Davis): *Constraints on Mantle Structure from Surface Observables* (PPT or PDF slides, recommended reading, glossary of terms)
  - Cin-Ty Lee (Rice U): Composition of the Earth and it's Reservoirs: Geochemical observables (PDF slides)

- **Heat and Mass Flux** (Aug 14)
  - Sujoy Mukhopadhyay (Harvard): Noble gas Constraints on Mantle Structure and Convection (PDF slides, recommended reading)
  - Jie Li (U Illinois): boundary layers, heat & chemical exchange

- **Boundary Layers** (Aug 15)
  - Tine Thomas (Liverpool U): Seismic Constraints on Boundary Layers (syllabus and glossary, PDF slides, recommended reading)
  - Shijie Zhong (CU Boulder): Dynamics of Thermal Boundary Layers and Convective Upwellings (PPT slides, PDF slides, and recommended reading)

Syllabi of lectures

Seismic Tomography: Art or Science
Frederik Simons
In the last two decades, seismologists have contributed detailed images of the wave speed variations in the Earth's interior. Those images have inspired, surprised, and often confused us. Just how are they made? This lecture will be part tutorial, exploring the methodology of seismic tomography in the larger context of scientific inverse problems. We will learn what seismology can tell us about the Earth - and what not. What we're looking for, and how to look at our results. On the way, we will learn what's hot, and what not, and not just when expressed in red and blue.

Interpreting Geophysical Data for Mantle Dynamics
Wendy Panero
The physical properties of earth materials as a function of pressure, temperature and composition are necessary for the interpretation of geophysical observations with respect to possible chemical variations between the upper and lower mantle as well as chemical and thermal lateral heterogeneities. I will discuss experimental and theoretical methods in mineral physics along with the way in which the data are interpreted and quantified. Examples will include the recent debate over the Mg_2SiO_4 to MgO and $MgSiO_3$-perovskite phase boundary, the high-temperature equation of state of $MgSiO_3$ perovskite, and the influence of minor elements on material properties.

Heat in the Earth's Interior
Jie Li
This lecture will review constraints on the thermal structure and evolution of Earth's deep interior from experimental geochemistry and mineral physics. Topics to be covered include: (1) temperature at the core-mantle boundary and inner-core boundary based on melting point of iron, silicate perovskite, and magnesiowüstite; (2) current estimates on the heat sources in the Earth's interior, and constraints from experimental results on the light element(s) and potassium in the Earth's core; and (3) heat flow paradox (from a different perspective) and the age of inner core.

Inferring Mantle Dynamics and Viscosity Structure from Geophysical Surface Observables
Magali Billen
The surface observables of post-glacial rebound, geoid and dynamic topography have provided first order constraints on the radial viscosity structure of the mantle. Seismic imaging clearly shows significant lateral heterogeneity in the mantle related to temperature and/or composition in the mantle. Based on experimentally determined flow laws, this lateral heterogeneity may also represents strong lateral variations in viscosity. I will: (1) review some of the early research using surface observables to constrain viscosity structure; (2) discuss some of the inherited simplifying assumptions that need to be revisited in light of recent experimental results and current numerical modeling methods; (3) outline limitations in the sensitivity and resolving power of surface observations; and, (4), present a simple example of the effect of lateral variations in

viscosity on surface observations. I aim to give an overview that provides the workshop participants with the background knowledge necessary to critically examine the ability of surface observations to distinguish between different models of mantle structure and dynamics.

Constraints on Mantle Structure and Composition from Geochemical Surface Observables
Cin-Ty Lee
The dynamic evolution of the Earth's interior is manifested by the geochemical differentiation of the Earth into various geochemical heterogeneities. Core-mantle segregation and partial melting at mid-ocean ridges, hotspots, and subduction zones are the dominant processes that lead to "unmixing" of the Earth while mantle convection serves to remix these heterogeneities back into the mantle. Therefore, the Earth is presently in a dynamic state of "mixing" and "unmixing". The goal of this presentation is to outline certain aspects of our current understanding of solid Earth geochemistry, how it bears on understanding the nature of the Earth's convective interior, and what, if any, fundamental questions remain. We will discuss the concepts of geochemical "reservoirs", "heterogeneity", and " observables" (e.g., lavas, xenoliths, and diamond inclusions) and their spatio-temporal evolution. I will review the salient geochemical features of continental crust, oceanic crust, and depleted mantle and proposed geochemical components (e.g., DMM, EM1, EM2, HIMU, SCLM, etc.) I will then compare and
contrast the geochemical characteristics of ocean island basalts (OIBs) and mid-ocean ridge basalts (MORBs).Issues that arise include: How do the current datasets relate to the many models and cartoons that have been proposed for the chemical structure of the mantle? Are there new (geochemical) ways to refute some of these models, or are these models effectively untestable? Other current debates include the question if the mantle possesses a primordial stratification, could this be tested by short-lived lithophile radiogenic systems, such as by the ^{146}Sm-^{142}Nd chronometer? Another knowledge gap is the water content and its variation in the mantle and all its sub-reservoirs as well as the problem of oxygen fugacity of the mantle.

Noble gas constraints on Mantle Convection
Sujoy Mukhopadhyay
The noble gases (He, Ne, Ar, Kr, and Xe) have provided valuable insights into mantle heterogeneities and into the nature of mantle convection. In particular, the noble gases have been used to argue for a primordial reservoir in the Earth's mantle. The existence of a primitive undepleted mantle is apparently at odds with geophysical evidences of slab subduction into the lower mantle and evidences from other geochemical tracers, such as Sr, Nd, and Os isotopic ratios. I will critically review and discuss the distribution of noble gas elemental and isotopic ratios in Mid Ocean Ridge Basalts (MORBs) and Ocean Island Basalts (OIBs). I will then address the geochemical histories of the sources that contribute to volcanism at MORBs and OIBs and the constraints noble
gases place on mantle convection.

Boundary Layers of the Mantle - Seismological Constraints
Christine Thomas

This lecture will review how we can detect seismic boundaries in the mantle using seismic waves together with resolution issues. Discontinuities in the lowermost mantle (core-mantle boundary, D" layer) and the upper mantle (mantle transition zone) will be discussed. Different hypotheses as to the nature of the boundaries and their relation to mantle convection will be presented. Other boundary layers in the mid-mantle, and their absence, respectively, as well as lateral extent of known boundary layers will be examined.

Boundary Layers of the mantle - dynamic constraints
Shijie Zhong
The dynamics of thermal boundary layers is an important part of mantle dynamics. Important physical processes in the mantle including subduction and mantle upwellings are all related to the boundary layer dynamics or instabilities. Although subduction, which results from the instability of the top boundary layer (i.e., lithosphere), is one of the most important processes in mantle dynamics, here we will focus on the dynamics of thermal boundary layer(s) in the deep mantle including the core-mantle boundary that may produce upwelling plumes. We will discuss: (1) the controls and consequences of such instabilities; (2) energy transfer associated with the upwelling plumes and its implications for the seafloor topographic anomalies and the core heat flux; and, (3), plumes in whole/layered mantle convection.