GEOL540: The Mantle System

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Times Two $\times$ 1.5 hours, 3 units

Objective This graduate class discusses the structure, dynamics, and evolution of Earth's deep interior with focus on the mantle system. The convective evolution of the mantle determines, through fractionation, how continents have formed and regulates Earth evolution by controlling the rate and style of heat loss. In this way, the mantle system encompasses lithospheric dynamics and connects surface geology to processes at the core mantle boundary, as well as core dynamics, including the generation of the magnetic field. We review structural constraints from seismology, focusing on different imaging methods, and discuss a range of dynamic constraints from mineral physics, geochemistry, and geodynamical studies on components of the system, and the system as a whole.

The class targets graduate students from the Earth sciences, and consists of lectures and student discussion of key research papers. Grading is based on a mid term, a final exam, and class participation. GEOL540 provides a continuation of the introductory geodynamics class GEOL534 which focuses on the dynamics of the lithosphere and crust.

Recommended preparation GEOL440, GEOL534.

Grading

- 40% mid term (take home, open book)
- 45% final exam (take home, open book).
- 15% class participation

Syllabus

Week 1 Introduction to the mantle system. Broad scale, thermo-mechanical structure of the mantle. Thermal state and compositional structure of the Earth and mantle.

Reading: Tackley (2000a); Bercovici et al. (2000)

Week 2 Global structural constraints from body waves, surface waves, and normal modes. Detection of discontinuities, scattering. Phase transitions.

Reading: Dziewoński and Anderson (1981); Niu et al. (2003); Ohtani and Sakai (2008)

Week 3 Seismic tomography. Wave propagation. Inverse theory. Damping and regularization.

Reading: Boschi and Dziewoński (1999); Romanowicz (2003); Montagner (2007)

Week 4 Asthenospheric imaging: Attenuation, volatiles, and melt.

Reading: Stixrude and Lithgow-Bertelloni (2005); Hirschmann (2006)

Week 5 Constraining mantle flow from seismic anisotropy.

Reading: Montagner (2007); Mainprice (2007); Long and Becker (2010)

Week 6 Fluid dynamics and thermal convection. Fundamental equations, Rayleigh number. Heat transport and budget of the Earth.

Reading: Davies and Richards (1992); Ricard (2007); Jaupart et al. (2007)

Week 7 Rheology and complexities of thermal convection with lateral viscosity variations.

Reading: Hirth and Kohlstedt (2004); Christensen (1984)

Week 8 Global mantle flow modeling and large scale constraints. The geoid and dynamic topography. Inferences on radial viscosity structure. Crustal stress and mantle flow.

Reading: Hager and Clayton (1989); Forte (2007)

Week 9 The top boundary layer: Oceanic lithosphere and subduction dynamics. Plate driving forces. Slabs and seismicity.

Reading: Billen (2008); Becker and Faccenna (2009)

Week 10 The bottom boundary layer: D". Core-mantle interactions. Chemical heterogeneity of the core-mantle boundary region. Post-perovskite. Core heat flow.

Reading: Garnero (2004); Garnero and McNamara (2008); Lay et al. (2008)

Week 11 Mantle plumes and geochemical reservoirs. Fluid dynamical modeling of plumes.

Reading: Sleep (2006); Ito and van Keken (2007)

Week 12 Generation of plate tectonics from mantle convection.

Reading: Tackley (2000b); Bercovici (2003)

Week 13 Super-continental cycles, whole mantle convection, and thermal evolution of the Earth.

Reading: Christensen (1985); Zhong et al. (2007); Korenaga (2008)

Week 14 Geochemical geodynamics. Isotopic signatures of MORBS and OIBs. Fractionation models.

Reading: Zindler and Hart (1986); Hofmann (1997); Tackley (2007)

Week 15 Core dynamics and generation of the magnetic field.

Reading: Buffett (2000); Glatzmaier (2002)

Textbooks

No text book is required, but the first two strongly recommended.

- Turcotte, D. and Schubert, G. Geodynamics. Cambridge University Press, 2nd edition, 2001. (Update of a classic, standard text.)
- Ranalli, G. Rheology of the Earth. Chapman & Hall, 1995. (Somewhat out of date but highly useful, PDF may be available.)
- Schubert, G. Turcotte, D. and Olson, P.: Mantle convection in the Earth and Planets, Cambridge University Press, 2001. (More comprehensive treatment of convection with all the equations you'll ever need.)
- Davies, G. F., Dynamic Earth: Plates, plumes, mantle convection, Cambridge University Press, 1999. (Nice narrative of one of the traditional views on mantle dynamics.)
- Malvern, L. E., Introduction to the mechanics of a continuous medium, Prentice Hall, Inc., 1969. (Classic continuum mechanics text, very useful for more comprehensive background reading.)
- Rogers, N. (ed). An Introduction to our Dynamic Planet, Cambridge University Press, 2008. (A unique, undergraduate text that provides a compelling interdisciplinary treatment of geodynamics.)
- Karato, S.-i., Deformation of Earth Materials, Cambridge University Press, 2008. (Somewhat of an update of Ranalli with a slightly different angle.)
- Kennett, B. and Bunge, H.-P., Geophysical continua, Cambridge University Press, 2008. (General treatment of seismology and geodynamics based on the premise that both are an application of continuum mechanics.)

Statement for Students with Disabilities

Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m.5:00 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.

Statement on Academic Integrity

USC seeks to maintain an optimal learning environment. General principles of academic honesty include the concept of respect for the intellectual property of others, the expectation that individual work will be submitted unless otherwise allowed by an instructor, and the obligations both to

protect one's own academic work from misuse by others as well as to avoid using another's work as one's own. All students are expected to understand and abide by these principles. Scampus, the Student Guidebook, contains the Student Conduct Code in Section 11.00, while the recommended sanctions are located in Appendix A: `http://www.usc.edu/dept/publications/SCAMPUS/gov/`. Students will be referred to the Office of Student Judicial Affairs and Community Standards for further review, should there be any suspicion of academic dishonesty. The Review process can be found at: `http://www.usc.edu/student-affairs/SJACS/`.

References

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Billen, M. I. (2008). Modeling the dynamics of subducting slabs. *Ann. Rev. Earth Planet. Sci.*, 36:325–356.

Boschi, L. and Dziewoński, A. M. (1999). 'High' and 'low' resolution images of the Earth's mantle – Implications of different approaches to tomographic modeling. *J. Geophys. Res.*, 104:25567–25594.

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