Structure and composition of Earth's interior

(GEO4-1401)

Tentamen – November 4, 2019; 9:00-11:30
Arwen Deuss

The numbers in () indicate the percentage for evaluation. No documents are allowed during the examination. Please write clearly and don't forget to indicate your name. When answering the questions, please give references to the papers we have read and explain why these papers are relevant. A full list of references is attached to the exam paper.

1. Seismic studies show that the Earth's mantle is delineated by seismic discontinuities and observations have been made for almost every depth.
   (a) (10) Describe the main discontinuities in the upper mantle and lower mantle, including how they can be observed using seismic data and what mineralogical causes might explain these discontinuities.
   (b) (10) How can the topography of seismic discontinuities to used to determine if slabs are subducting through the 660-km discontinuity into the lower mantle or not?
   (c) (10) How can observations of seismic discontinuities be used to estimate the temperature in the Earth's mantle transition zone and D"?
2. An important question in studies of the Earth's deep interior is how we can reconcile the geochemical and geophysical data which both constrain the properties and style of convection in the Earth's mantle. In the lectures, we have seen number of papers addressing this problem and a range of models has been proposed.
   −> (a) (10) What are the main geophysical and geochemical data which need to be explained?
   (b) (10) Initially, two end-member models were proposed: (i) layered convection and (ii) whole mantle convection. Which data and observations are in favour of each of these models, and why is it so difficult to reconcile the geochemical and geophysical data?
   (c) (10) Describe the additional convection models that have been proposed by Kellogg et al (1999), Helffrich & Wood (2001) and Davies (2009). How do these models try to reconcile geophysical and geochemical data and why do they reach either similar, or different conclusions?
   (d) (10) Which is your preferred model and why? Or do you have your own ideas on how to reconcile the geophysical and geochemical data? Give references to the papers we have read.

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3. It is relatively straightforward to make tomographic models of 3D variations in shear wave velocity and compressional velocity, but models of 3D variations in density are much more difficult to make.

   (a) (10) In the lowermost mantle, seismic tomography shows that the ratio R of relative variations in shear wave velocity (dV_s/V_s to variations in compressional velocity (dV_p/V_p) becomes larger than three. How do Karato & Karki (2001) explain these large values of R?

   (b) (10) Describe the different methods that have been used to map 3D density variations in the Earth's mantle and what are the main findings of these studies? How can the different results on 3D variations in density be interpreted using Karato & Karki (2001)?

   (c) (10) We need density models in order to obtain constraints on viscosity. How can we constrain the viscosity structure of the Earth's mantle and what are the main findings of these studies?

1. Hager et al, Lower mantle heterogeneity and the geoid, *Nature*, **313**, p. 541–545, 1985.

2. Phipps-Morgan & Shearer, Seismic constraints on mantle flow and topography of the 660-km discontinuity: evidence for whole mantle convection, *Nature*, **365**, p. 506–511, 1993.

3. van der Hilst et al, Evidence for deep mantle circulation from global tomography, *Nature*, **386**, p. 578–584, 1997.

4. Kellogg et al, Compositional stratification in the deep mantle, *Science*, **283**, p.1881–1884, 1999.

5. Ishii & Tromp, Normal-mode and Free-Air gravity constraints on lateral variations in velocity and density of Earth's mantle, *Science*, **285**, p. 1231–1236, 1999.

6. Forte & Mitrovica, Deep-mantle high-viscosity flow and thermochemical structure inferred from seismic and geodynamic data, *Nature*, **410**, p. 1049–1056, 2001.

7. Karato & Karki, Origin of lateral variations of seismic wave velocities and density in the deep mantle, *J. Geophys. Res.*, **106**, p. 21,771–21,783, 2001.

8. Helffrich & Wood, The Earth's mantle, *Nature*, **412**, p. 501–507, 2001.

9. Davies, Reconciling the geophysical and geochemical mantles: Plume flows, heterogeneities, and disequilibrium, *G-cubed*, **10**, p.1-19, 2009.

10. Hernlund et al, A doubling of the post-perovskite phase boundary and structure of the Earth's lowermost mantle, *Nature*, **434**, p. 882–886, 2005.

11. Lau et al, Tidal tomography constrains Earth's deep-mantle buoyancy, *Nature*, **551**, p. 321–326, 2017.

12. Song & Richards, Seismological evidence for differential rotation of the Earth's inner core, *Nature*, **382**, p. 221–224, 1996.

13. Deuss et al, Seismic observations of mantle discontinuities and their mineralogical and dynamical interpretation, *Phys. Chem. of the deep Earth*, p. 297–323, 2013.

14. Deuss, Heterogeneity and anisotropy of Earth's inner core, *Annu. Rev.*, **42**, p. 103–126, 2014.