BOOK REVIEWS

Heterogeneity in the Crust and Upper Mantle: Nature, Scaling, and Seismic Properties

JOHN A. GOFF AND KLAUS HOLLIGER, EDITORS

Kluwer Academic/Plenum Publishers, New York; ISBN 0-306-47447-6; xix + 358, pp.; 2003; $142.

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Plate tectonic models succeed at predicting observations at scales of 100–1000 km, but tend to fail for observations at outcrop scales. Such predictions become nebulous when considering small-scale heterogeneous structure originally generated in the lower crust or upper mantle, whether the observations are made from outcrop, from boreholes, or remotely by seismic methods. Earth scientists have classically dealt with the problem of small-scale heterogeneity by treating it as "noise" from both an observational and modeling standpoint; however, the increased comprehension of the scale invariance of many geologic processes has spurred investigators to attempt to characterize observations at all available scales. Modelers have responded by adopting more of a statistical characterization approach for spatial variability.

Heterogeneity in the Crust and Upper Mantle offers a state-of-the-art assessment of how the difficulty of understanding small-scale heterogeneity is being addressed by active researchers across a spectrum of disciplines, including structural geology, seismology, and statistical physics.

This volume of 13 chapters presents studies on heterogeneity on scales from centimeters to hundreds of kilometers, dealing more or less evenly with well-documented field geological observations of heterogeneity, how the scale of heterogeneity relates to the underlying processes, and ways in which heterogeneity is manifest and modeled as seismic wave complexity.

Chapter 1 starts the book on a firm field geologic foundation by using observations of exposed lower crustal rocks to introduce the concept that seismic heterogeneity arises from the combined effects of pre-existing lithologic and ductile strain heterogeneity. A review follows detailing how observations of small-scale variability from deep seismic reflection profiles can be reconciled with a petrological model in which felsic and mafic igneous intrusions are discontinuously distributed through the crust, but whose observed seismic velocity may be complicated by the effects of free fluids and anisotropy. Outcrop-scale observation and seismic reflection response are brought together in chapter 3 with a forward seismic reflection model of a classic region of exposed deep crustal rocks (inner arc of the western Alps) for which the authors conclude that the commonly observed seismically "layered lower crust" can be explained by crustal extension fabrics accompanied by magmatic underplating. The field observation portion of the volume concludes with a comparison of the variability observed in oceanic seismic reflection data with the fine-scale variability of fast-spreading ocean crust exposed along the Hess Deep Rift, which indicates that seismically inferred layer thicknesses roughly match the outcrop dimensions.

Beginning with chapter 5, the reader's attention is turned toward a discussion of power law scaling phenomena in borehole sonic log measurements in which upper crustal velocity fluctuation is related to the effects of small-scale fracturing, which in turn may point toward a generalized behavior for heterogeneity in physical properties throughout the Earth. This concept is pursued further in the next chapter, with the conclusion that low-frequency spatial amplitudes of fracture heterogeneity cannot be predicted, and thus, must be measured geophysically.

Chapter 7 summarizes various attempts to construct non-Gaussian statistical models of spatial heterogeneity in sedimentary strata, a common element of which is that a power law applied over a wide range of scales approximates reproducible statistical measures of the data. Finally, in chapter 8, the scale invariance of fine-scale heterogeneity (for example, in tectonic deformation or seismic wave propagation) is modeled as a multi-fractal distribution with statistics that match measured rock property statistics.

The remainder of the book commences with an up-to-date review of the effects of field acquisition and data processing on lower crustal images derived from deep seismic reflection profiles, and how these effects can act as powerful filters of the actual heterogeneity. In chapter 10, synthetic seismograms of wide-angle seismic arrivals from the deep crust (PiP) provide a means of visualizing heterogeneity in terms of various filters of the seismic wave source, for example, as fine-scale complexity imposing a smoothing of velocity structure versus manifested as scatterers. The heterogeneity of the uppermost mantle is next expressed as random velocity fluctuations that cause scattering of the high-frequency, top-of-mantle refracted phase (Pn), a model of which suggests that regional upper mantle velocities may require re-evaluation.

Chapter 12 furnishes a case study based on the exposed rocks of the Precambrian Grenville province (Quebec) that integrates seismic reflectivity modeling of rock properties with maps of spatial attributes of reflectivity—for example, correlation length—in order to characterize heterogeneity throughout the crust. The book concludes with a modeling approach for characterizing stochastic heterogeneity using a coherence analysis of fluctuation in seismic amplitude and phase followed by an inversion.

In summary, this well-written volume provides a glimpse into the highly specialized but critically important field of studying small-scale heterogeneity in structures and processes related to deformation, igneous intrusion, and sedimentation. The presentation of material achieves an excellent balance between a theoretical and an observational approach so that any reader will be able to gain entry into this burgeoning field.

—JOHN H. MCBRIDE, Brigham Young University, Provo, Utah

The Dynamic Structure of the Deep Earth: An Interdisciplinary Approach

SHUN-ICHIRO KARATO

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The interior of the Earth is largely inaccessible to direct observation; the deepest drill holes are only .1% of the Earth's radius. One might call it the undiscovered country. The mysteries of the interior have spanned a great deal of scientific and non-scientific literature. Most of what we know about the interior comes from seismological observations, our most informative probe of the deep Earth. Seismology reveals the variations of seismic velocities both laterally and at depth. Converting that information into knowledge about the structure, composition, and dynamical state of the Earth's interior requires other disciplines, high-pressure mineral physics, and geodynamics in the broadest sense. Without mineral physics, it would be impossible to properly translate the seismic information into knowledge of composition and dynamics.

Shun Karato, a leader in mineral physics who is now at Yale University, provides the proper context to use a great variety of mineral physics data for interpreting both seismological observations and their relation to the dynamics of the interior. As such, *The Dynamic Structure of the Deep Earth: An Interdisciplinary Approach* is a welcome and unique addition to books on the geophysics of the Earth, as I can recall no other that combines a focus on the deep Earth with equal play given to several different disciplines. It is not a textbook, although it could be used as background reading in a graduate-level seminar. The book was originally published in Japanese in 2000 by the University of Tokyo Press; it was translated and updated for the current English edition.

I found the book enjoyable because it does not present science in the abstract, but rather it mentions the researchers by name and institution, giving a sense of the fluid and human nature of the scientific enterprise. Not surprisingly, as a geodynamicist, I would have liked a more complete discussion of mantle dynamics, but also more coverage of the work on rotational dynamics and geomagnetism that has been so important in our renewed interest in the core.

Although some background knowledge of the Earth is needed, the book is easily accessible to senior undergrads and graduate students, and one might even dare say to non-Earth scientists with an appetite for science. In fact, one of the very pleasing aspects of this book is that very simple physical explanations are given for complex concepts such as the behavior of defects; and the basic principles behind very sophisticated investigations are covered in simple terms, such as seismic tomography and the effects of phase transformations on flow and anisotropy. The writing nicely weaves classic discovery, established knowledge, and recent and forefront research, including the author's own. Even though this is a very personal presentation of what we know about the deep Earth, Karato is careful to give credit to others and present their research. The book combines a narrative on the main subject with asides in boxes explaining the concepts introduced in the narrative. These are both explanatory and more advanced than the narrative.

The organizing principle of the book is the connection between observation (for example, seismic tomography, anisotropy, and geoid anomalies) and interpretation (composition, dynamics) through the lens of experimental and theoretical mineral physics, with a special emphasis on rheology and rock mechanics. The book sets out to explain, from the first section out of the total of six, the connection to the equilibrium properties—density and elasticity—of Earth materials and seismic wave velocity, and their transport properties (that is, anelasticity and viscosity). The attenuation and dispersion of seismic waves (the frequency dependence of seismic wave velocity) and viscous flow in the mantle depend on the motion of defects—dislocations and vacancies in the crystal structure—although the two processes occur at vastly different time scales. By focusing on what we know experimentally and theoretically about the anelastic or rheological properties of minerals, one may connect the presumably static or snapshot picture of the planet unveiled seismologically with its dynamics. The author is well qualified to take this approach, given both his research path and his efforts to promote the use of a wider variety of mineral physics data for the interpretation of seismic observations and the construction of dynamical models.

The first four sections of the book advance from the one-dimensional to the three-dimensional structure of the Earth, particularly the mantle-core structure and dynamics, and hence, the origin of the magnetic field is addressed. Progress in depth, starting with the lithosphere and shallowest mantle to the deepest mantle, is also covered, as is an aside on deep earthquakes. The book provides a fairly complete look at the structure and dynamics of the deep Earth, but it is very much organized along the themes and topics of research of the authors' career. This is not a criticism of the book, as I feel that this approach infuses it with an enthusiasm and excitement that might be lacking otherwise. From the very first section, the basic rheological concepts that tie the narrative and interpretation of observations are introduced within the context of well-established observations of the Earth's radial velocity, mineralogical structure, and temperature profile. Considerably more detail on the relationship between seismic wave attenuation and rheology can be found in section 2, where the author discusses the origin of the asthenosphere, as well as in section 4.

In section 2, the other dominant theme of the book and of the author's career emerges: the role of water in Earth's dynamics. For example, the origin of the asthenosphere—the seismic low velocity zone—has been debated in the literature. The preferred mechanism for explaining both the very low seismic velocities and the largest values attenuation invoke small amounts of partial melt. The author has been very much an advocate of a different explanation based on the dramatic effect of water on material properties, and particularly on rheology, both the viscosity of materials and the attenuation of seismic waves. In this section, he lays out the experimental foundation of his results, explaining how experiments show that partial melt would actually lead to larger viscosities and lower attenuation.

In section 3, along with a discussion of seismic tomography and its interpretation, in terms of the thermal and chemical heterogeneity of the mantle, there is a long discussion of global near-surface and deep-mantle (D") anisotropy. The chapter does not do justice to the history or the recent work on both the mineral physics end (prediction and measurement of the elastic constants of relevant minerals at high-pressures and temperatures) and to the dynamical interpretations of the observations. The biggest shortcoming is in section 4, a very basic look at mantle circulation (convection), which ignores a great deal of important work on both the general structure of the flow, as well as the connection between mantle dynamics and surface geological and geophysical observables such as plate motions and topography. Perhaps that is a necessary omission in a book that does not intend to be a comprehensive textbook, but rather a personal view of deep Earth studies.

May this book inspire a new generation of young and, hopefully, many female deep Earth geophysicists to pursue the kind of interdisciplinary knowledge required to understand the mysteries of the interior, always keeping in mind that without that understanding, our knowledge of the Earth remains incomplete.

—CAROLINA LITHGOW-BERTELLONI, University of Michigan, Ann Arbor

NEW BOOKS

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This new column lists recently published books that have been received by Eos *staff.*

Arctic Environment Variability in the Context of Global Change, Bobylev, Kondratyev, and Johannessen (Eds.), Springer-Praxis, ISBN: 3-540-43458-5, $169.

Biological Oceanography, Charles B. Miller, Blackwell Publishing, ISBN: 0-632-05536-7, Paperback: $64.95.

Cratering In Marine Environments and on Ice, H. Dypvik, M. Burchell, P. Claeys (Eds.), Springer-Verlag, N.Y., ISBN: 3-540-40668-0, $109.

Intra-Oceanic Subduction Systems: Tectonic and Magmatic Processes, Larter and Leat (Eds.), The Geological Society of London, ISBN: 1-86239-147-5, £85 ($156).

Metamorphosis of a Geophysicist, John R. Herman, PublishAmerica, ISBN:104137-1327-0, Paperback: $19.95.

Our Affair With El Niño, S. George Philander, Princeton University Press, ISBN: 0-691-11335-1, $26.95.

Reactive Flow Modeling of Hydrothermal Systems, Michael Kuhn, Springer-Verlag, N.Y., ISBN:3-540-20338-9, $109.

Subsurface Sediment Mobilization, Van Resnberger, Hillis, Maltman, and Morley (Eds.), Geological Society of London, ISBN: 1-86239-141-6, £95 ($175).

The Oceans and Climate, 2nd Edition, Grant Bigg, Cambridge University Press, N.Y., Hardback, ISBN: 0-521-81570-3, $100; Paperback, ISBN: 0-521-01634-7, $50.