BOOK REVIEW

EARTH'S CORE AND LOWER MANTLE, edited by C.A. Jones, A.M. Soward and K. Zhang, The Fluid Dynamics of Astrophysics and Geophysics, Vol. 11, Series Editors A.M. Soward and M. Ghil, Taylor and Francis, London, New York, 2003, VIII+218 pp., £78.99, hardback (ISBN 0-415-30936-0).

This volume, published in 2003, is a compilation of eight articles that, together, provide a comprehensive, up-to-date survey of the dynamics of the Earth's deep interior. The authors, all established authorities in their fields, were invited keynote lecturers at the 7th symposium of SEDI (Studies of the Earth's Deep Interior) held in the summer of 2000. An earlier volume in this book series (Crossley, 1997) arose in a similar way from the 4th SEDI symposium held in 1994. It had a rather different emphasis, with much more on the mantle. Though arising from the 2000 SEDI meeting, the articles in the present volume are more recent, all containing references to papers published in 2001 or even 2002.

The topics covered are: Convection and the lower mantle (Gerald Schubert), Thermal interaction of the core and mantle (Peter Olson), Electromagnetic and topographic coupling, and length of day variations (Dominique Jault), Convection in rotating spherical shells and its dynamo action (Friedrich Busse, Eike Grote and Radostin Simitev), Energy fluxes and Ohmic dissipation in the earth's core (Paul Roberts, Christopher Jones and Arthur Calderwood), Dynamo and convection experiments (Henri-Claude Nataf), Dynamics of the core at short periods: theory, experiments and observations (Keith Aldridge), Geomagnetic reversals: rates, timescales, preferred paths, statistical models, and simulations (Catherine Constable).

A major area of development during the past six years has been that of fully three-dimensional hydrodynamic dynamo simulations. Indeed, a report on the pioneering work by Glatzmaier and Roberts was presented at SEDI in 1994 (Glatzmaier & Roberts, 1995). The importance of this activity is emphasised by its pervasiveness; as well as the chapter devoted to this topic, it also plays a role in the chapters by Olson, Constable, and Roberts *et al.* The review by Busse *et al.* addresses this area, starting with a discussion of non-magnetic convection in a rapidly rotating system. The discussion of hydrodynamic dynamos focusses predominantly on work by Busse and his co-workers (using a model that has stress-free boundaries, an insulating inner core and no hyper-diffusivity). Two key features they identify (common with other studies) are the increasing difficulty of achieving a self-sustaining dynamo as the magnetic Prandtl number is reduced, and that there is no observed diminution of the critical Rayleigh number at the onset of dynamo action.

Nataf gives a comprehensive review of a range of experimental work motivated by the dynamo problem. While including discussion of mantle convection, core–mantle coupling and crystallization of the inner core, his main focus is on convection in the core and, in particular, on experimental dynamos. The year 2000 saw successful results for both the Riga and Karlsruhe dynamos. These "kinematic" dynamos (ones in which the flow is strongly directed by the container geometry and in which the magnetic field generated has little influence on the flow) are described in detail. Nataf then proceeds to discuss work in progress by several groups and the prospects for dynamos in simpler geometries, for example spheres, where the flow is not closely directed by the geometry and there is the opportunity for the magnetic field to strongly influence the flow.

The chapter by Aldridge surveys work on inertial instability in a rapidly rotating homogeneous fluid. A key message is that while the period of inertial modes may be short, they can lead to a significant long term response. Moreover, while most dissipation of boundary-driven modes takes place in boundary layers, large amplitudes can be excited in the fluid interior. For these reasons inertial instabilities driven by precession or semi-diurnal tides may be relevant to the geodynamo problem. Additionally, there is the prospect of high quality data from superconducting gravimeters and very long baseline interferometry being capable of observing inertial modes and so providing a additional window on the dynamics and material properties of the core. Aldridge gives a comprehensive survey of work in this area over the past four decades, with a particular emphasis on experimental work.

The role of the core–mantle boundary in controlling the flow of heat from the core into the mantle is fundamental to the evolution of the whole Earth. Olson gives a good introduction to the issues, especially the lateral variation in heat flow which primarily influences convection in the core. He proceeds to discuss models and experiments that explore this effect, and relates their results to observational evidence.

Schubert follows this with a review of mantle convection and its consequences for the structure of the lower mantle. In particular he assesses the idea, motivated by geochemical arguments and observations, that there exists in the bottom half of the lower mantle a compositionally dense layer containing a high primordial concentration of radiogenic heat sources. Schubert refutes this idea. He uses a number of arguments, the most telling of which is the analysis that the inevitable thermal boundary layer between this dense layer and the rest of the mantle would have a clear seismic signature. The seismic evidence to date is that no such boundary exists.

The exchange of angular momentum between the mantle and the core is believed to be an important cause of the observed decadal changes in the length of the day. Jault reviews the role of torsional Alfvén waves and electromagnetic and topographic core–mantle coupling in this process. There have been many studies of aspects of this problem, taking a number of different approaches. Each has made its own approximations and assumptions about the conductivity of the lower mantle and/or the topography of the core–mantle boundary. Further studies have taken a kinematic approach, estimating the torques resulting from flows in the core deduced from the geomagnetic secular variation. This is a very welcome review putting the various studies into context.

Starting with a very helpful definition of the terminology, Constable discusses the paleomagnetic record of reversals of the Earth's magnetic field and its interpretation. A commentary on the dating of these records leads into a statistical analysis of the variation in the reversal rate over time, including a review of evidence for a correlation with field intensity and directional stability. This chapter concludes with a discussion of the structure and duration of reversals. It is clear that there is currently considerable activity in this field, in acquiring and analysing the data (which inevitably is patchy in space and time), with growing interplay with numerical modelling. Constable has produced a comprehensive, up-to-date and honest evaluation of what can be deduced and prospects for the future.

Roberts *et al.* explore the issue of the thermal evolution of the core, linking this to the Ohmic dissipation predicted from geodynamo models, the growth of the inner core and the paleomagnetic evidence on the longevity of the geomagnetic field. Their estimate is that the Ohmic dissipation lies between 1 TW and 2 TW, and is based on the assumption that convection in the core is vigorous enough to produce a dynamo that undergoes reversals. The analysis presented here is based on an update of the work of Braginsky & Roberts (1995) in the light of recent experimental and theoretical advances in our knowledge of parameter values at high pressure and temperature. A key conclusion is that in the absence of any radiogenic heat source in the core, the inner core is relatively young; their preferred value is 1.2 GYr though they explore the sensitivity of this value to the uncertainties in four of the least well-determined parameters. All values of the inner-core age fall short of the 3.5 GYr we know the Earth's magnetic field has existed. The poor thermodynamic efficiency from a cooling fully molten core presents a difficulty in generating a field prior to inner-core nucleation unless there is radiogenic heating. While the conventional view is that there is no significant potassium in the core, recent work has shown that potassium will form a high-pressure alloy with nickel. Motivated by this, Roberts *et al.* explore the consequences for their model that all the potassium apparently "missing" from the Earth is in the core.

To summarise, this is a collection of eight individual articles, most of which give a wide review of activity in their area. Though not formally coordinated, they complement each other very well to provide an excellent comprehensive reference work that should have lasting value. This book is definitely one for the library, though it is unfortunate that the price will inhibit individual purchase.

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References

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