BOOKS: GEOPHYSICS

Much About Motion in the Mantle

Yanick Ricard

Twenty years ago, geophysicists Donald Turcotte and Gerald Schubert published *Geodynamics: Applications of Continuum Physics to Geological Problems* (Wiley, New York, 1982), which became one of the most useful books in the sciences of the deep Earth. Now, Schubert and Turcotte have joined Peter Olson to produce a thick volume of much greater ambition, *Mantle Convection in the Earth and Planets*.

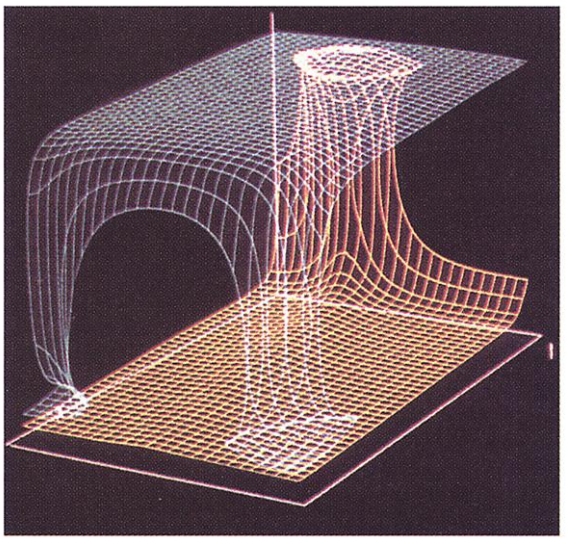
Mantle Convection in the Earth and Planets
by Gerald Schubert, Donald L. Turcotte, and Peter Olson

Cambridge University Press, Cambridge, 2001. 956 pp. $200, £140. ISBN 0-521-35367-X. Paper, $74.95, £49.95. ISBN 0-521-79836-1.

Convection is the basic mechanism by which buoyancy variations in a fluid (due to temperature or composition) generate or influence motions. It is the mechanism that moves the clouds and drives the oceans as well as makes the cream swirl in your cup of coffee. The development of the theory of convection began some 85 years ago with Lord Rayleigh's analysis of instability in fluids heated from below, but it was not easy for geoscientists to accept that a mechanism applicable to a fluid like water could also be relevant to understanding the behavior of the solid mantle composed of silicates. Even as geologists, oceanographers, and geophysicists compiled a vast array of observations in favor of large-scale horizontal displacements at Earth's surface, physicists continued to argue into the 1960s for the implausibility of mantle convection because seismic studies pointed to the extreme rigidity of the mantle.

Today, mantle convection is accepted as the fundamental phenomenon that drives the motion of tectonic plates. Besides shaping Earth and the other solid planets, it also rules the interior dynamics of the gaseous planets. On our planet, mantle convection operates with a time scale of tens of millions of years and with velocities around five centimeters per year. Hot, rising currents erupt at the mid-oceanic ridges, where they cool slowly and add material to the tectonic plates that form Earth's cold boundary layer. The plates ultimately sink as subducting slabs that, in turn, pull the plates away from one another and maintain the ridge activity. Internal convective flow occurs in other terrestrial planets and many moons, although only Earth seems to have a surface divided into quasi-rigid plates separated by weak boundaries.

Most books in the fields of geosciences and fluid dynamics lack a comprehensive presentation of solid state convection. In geological textbooks, authors are usually reluctant to provide a detailed account of the nature of mantle convection. After concluding wide coverage of surface geology and presenting the deep Earth in terms of concentric shells, they often simply introduce convection as the sculptor of grand tectonics and the undertaker for oceanic crust and sediments. Although there is a plethora of textbooks on fluid dynamics, physicists are usually more interested in fluids with large kinetic energies than in slow and viscous flows. When one knows that the icy or siliceous mantles are 15 to 25 orders of magnitude more viscous than water and that the mantle total kinetic energy is as small as that of a car (centimeter per year is indeed a very small velocity), one realizes that these textbooks cannot be useful for a geologist.



Flow in a box. Steady-state bimodal patterns have been found in numerical models of convection in rectangular boxes heated from below when the sides of the box are less than twice the depth. These isothermal surfaces developed in a 1.7 by 1 by 1 box at a Rayleigh number of 10^5.

CREDIT: AFTER B. TRAVIS, P. OLSON, G. SCHUBERT, *J. FLUID MECH.* **216**, 71 (1990).

The coverage by Schubert, Turcotte, and Olson is, therefore, very helpful and important. The authors discuss most of the critical work that has been done on this broad subject. Numerous illustrations depict geophysical and planetary data, conclusions from numerical modeling, and results from laboratory experiments; many of these are taken from the primary literature. Some chapters are rather descriptive and others quite technical. I really appreciated the analyses of the approximations that lead to the equations for mantle convection. I have not previously encountered such careful treatment in a book, and the approximations are often loosely discussed or even inaccurately carried out in scientific papers. The authors also offer the most complete analysis of convection I have seen, from marginal stability to second order analysis up to Lorenz approximations and numerical simulations. Although studies of planetary interiors are rapidly evolving, I am certain that these technical chapters will remain unchanged and fundamental for many decades. I also very much enjoyed the authors' review of our understanding of the interiors of various planets and satellites.

I have two small criticisms. First, the chapter on geochemistry does not do justice to the progress, difficulties, and hopes of the variety of research conducted over the last ten years that has attempted to link chemistry and convection. There is now seismological evidence for large exchanges of material throughout the mantle, and observations of crustal recycling in volcanoes have become ubiquitous. These findings show that the concepts of isolated reservoirs and primitive homogenous layer are oversimplified. Second, the book's exhaustive coverage—although a major strength, along with the book's mathematical rigor—detracts from its readability. The authors have not tried to ignore the unavoidable complexities of research in order to defend a clear point of view. Their position is scientifically honorable but pedagogically more risky. Nonspecialist readers may find it difficult to measure the progress that has been made, to understand what the current "hot topics" are, and to see the likely directions of future research. The absence of clear overviews along such lines probably reflects the long time needed to compile such a formidable collection of results and the possibility that each writer had his own views of the planetary engines.

But these are minor shortcomings. Like Geoffrey Davies's more focussed book *Dynamic Earth* (Cambridge University Press, Cambridge, 1999), *Mantle Convection in the Earth and Planets* fills an im-

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portant gap in the literature. The book will be indispensable to most Earth and planetary scientists and graduate students. It will also demonstrate the exciting contributions their discipline offers their colleagues in modern physics.

BOOKS: ENVIRONMENT

Pregnancy in a Polluted World

George M. Woodwell

A diabolical scheme for injecting terror into American culture and causing 3000 deaths on American soil is enough to set off war in Afghanistan, threats of expanded wars, and bellicosity around the globe. Yet few Americans blanch at their nation's annual toll of 40,000 highway deaths or the thousands mentally crippled by exposure to lead or mercury distributed knowingly by industries. Although the emergence of terrorism as a major political force dominates attention in the United States at the moment, and incipient wars have the potential for deflecting public attention indefinitely, there remains a series of demanding environmental problems that are incrementally and inexorably degrading the human circumstance. They are serious enough to rival war in their potential for generating uncertainty as to the human future. The toxic effects of industrial effluents, one of these issues, are discussed with rare expertise by ecologist and poet Sandra Steingraber in her new book, *Having Faith*.

Having Faith
An Ecologist's Journey to Motherhood
by Sandra Steingraber

Perseus, Cambridge, MA, 2001. 351 pp. $26, C$39.50. ISBN 0-7382-0467-6.

The topic is arcane and has been obscured, often deliberately, by defenders of our current approach to handling such effluents. The concepts, for instance, that dose makes the toxin and that thresholds for effects are universal, are convenient but clearly misleading and often quite wrong. Similarly mistaken is the popular and attractive assumption that dilution into a large environment is possible and is effective in protecting the public from the effects of noxious products. That approach to waste disposal is advanced in ignorance (or defiance) of the many routes that toxins may follow through the environment and of natural mechanisms that concentrate a wide variety of toxins in ways and places that affect life, often with devastating consequences.

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The issues have become only more arcane and obscure, at least to the person in the street, with the recognition of pheromones that control aspects of plant and animal behavior at extremely low concentrations (perhaps on the order of one part in a trillion) and of the no less subtle effects of a wide variety of substances on the endocrine system. These latter effects extend to influences on human embryology and development, the realm that Steingraber probes in detail. The book is a highly personal examination of the author's pregnancy and the birth and nurturing of her daughter Faith. In addressing the effects of toxic substances, she continues to explore the topic at the center of her earlier book *Living Downstream: An Ecologist Looks at Cancer* (Perseus, Cambridge, MA, 1998).

Steingraber, a brilliantly skilled artisan of image and language, has a lucid command of much larger realms of science, scholarship, and human nature than most of us manage. She moves with apparent ease from details of personal experience and attitude through an equally detailed review of pituitary function and embryology. Her observations of the world about her amplify and leaven the intimacy of the connections between that crudely managed world and the meticulously controlled warmth and comfort of the human womb.

The beauty and grace of Steingraber's presentation almost overwhelm the seriousness of her message. Greed—supported by persistent mendacity on the part of industrial interests that are frequently, if not usually, defended by governments—has produced a chemical corruption of the globe that affects human conception, embryogenesis, fetal development, birth, and life thereafter. For DDT, radioactivity, mercury, lead, the polychlorinated biphenyls, and various by-products of the plastics industry, research has amply elaborated sources, movement through the environment, and physiological mechanisms of damage in humans. Steingraber observes that while sensitivity to the extent of the general contamination of Earth with noxious wastes leads many of us to scorn tap water in favor of bottled water, we expose ourselves in our showers to large quantities of tap water and thus potentially absorb more of its noxious burden than we would drink. The safety offered by bottled water is an illusion, and she argues correctly that there is no alternative to keeping water supplies and the world clean.

Steingraber's insights into the assumptions and attitudes that delay or prevent governmental actions and the ultimate effectiveness of belated regulations are refreshingly clear. The assumption that thresholds (levels, along gradients of exposure, below which effects are nonexistent or at least negligible) exist is misleading. Also deceptive is its corollary, the belief that "assimilative capacities" allow organisms to accommodate to some level of exposure of any toxin. Both concepts are permissive human inventions that are convenient but contribute to the contamination of the environment. Inevitably, biophysical cycles both rarefy and concentrate whatever exogenous toxins we introduce. Humans do not and cannot live isolated from the world around us. The mammalian placenta is not a barrier to toxins, and human milk is universally contaminated—although Steingraber judges that its clear advantages to the newborn outweigh the hazards its use entails.

She also points out that political action has been, and remains, effective. Restrictions on the use of DDT led, over time, to important reductions in DDT residues in the environment and reduced concentrations in human milk. Similarly, the removal of tetraethyl lead from gasoline reduced the levels of lead in the blood of urban children. Such successful outcomes support calls for action against other pollutants. Although the neurological effects of mercury have been long known, power plants still spew mercury over the American landscape, and around the world gold mining using mercury is still pursued. There is no escape. Any substance that exists as vapor can be dispersed about the globe and precipitated differentially depending on environmental conditions. The sparsely populated, cold, higher latitudes accumulate a disproportionate burden of such pollutants simply because vapors are condensed in cooler regions. So the Inuit, far removed from the benefits of industry, suffer some of its most egregious consequences.

The events of the past few months mask, at least temporarily, such fundamental concerns about the human future, and they are being used by some to deflect necessary regulatory reforms. *Having Faith*, however, strikes a brilliantly aimed blow in the name of common sense and hope for a future based on political implementation of well-defined biophysical realities of human ecology. Steingraber challenges our democratic capitalistic system to rise to new heights of effectiveness in regulatory control of environmental chemistry as an essential act of self-preservation in a seriously afflicted world.

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