Eruptions That Shook the World

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Citation: Physics Today **65**(5), 55 (2012); doi: 10.1063/PT.3.1563
View online: http://dx.doi.org/10.1063/PT.3.1563
View Table of Contents: http://scitation.aip.org/content/aip/magazine/physicstoday/65/5?ver=pdfcov
Published by the AIP Publishing

microscopy (STEM), is now in widespread use in the physical and biological sciences. And its importance will only grow as nanotechnology and nanobiology continue to flourish. Many applications of electron microscopy are testing the limits of current imaging capabilities and highlight the need for further technological improvements. For example, high throughput in the combinatorial chemical synthesis of catalysts demands automated imaging. The handling of noisy data also calls for new approaches, particularly because low electron doses are used for sensitive samples such as biological and organic specimens.

Modeling Nanoscale Imaging in Electron Microscopy addresses all those issues and more. Edited by Thomas Vogt and Peter Binev at the University of South Carolina (USC) and Wolfgang Dahmen at RWTH Aachen University in Germany, the book came out of a series of workshops organized by the Interdisciplinary Mathematics Institute and the NanoCenter at USC. Those sessions took the unusual but innovative approach of bringing together electron microscopists, engineers, physicists, mathematicians, and even a philosopher to discuss new strategies for image analysis in electron microscopy.

In six chapters, the editors tackle the ambitious challenge of bridging the gap between high-level applied mathematics and experimental electron microscopy. They have met the challenge admirably. I believe that high-resolution electron microscopy is at a point where it will benefit considerably from an influx of new mathematical approaches, daunting as they may seem; in that regard *Modeling Nanoscale Imaging in Electron Microscopy* is a major step forward. Some sections present a level of mathematical sophistication seldom encountered in the experimentally focused electron-microscopy literature.

The first chapter, by philosopher of science Michael Dickson, looks at the big picture by raising the question of how we perceive nanostructures and suggesting that a Kantian approach would be fruitful. The book then moves into a review of the application of STEM to nanoscale systems, by Nigel Browning, a leading experimentalist in the field, and other well-known experts. Using case studies, the authors show how beam-sensitive samples can be studied with high spatial resolution, provided one controls the beam dose and establishes the experimental parameters that allow for the optimum dose.

The third chapter, written by image-processing experts Sarah Haigh and Angus Kirkland, addresses the reconstruction, from atomic-resolution images, of the wave at the exit surface of a specimen. The exit surface wave is a fundamental quantity containing not only amplitude (image) information but also phase information that is often intimately related to the atomic-level structure of the specimen. The next two chapters, by Binev and other experts, are based on work carried out using the experimental and computational resources available at USC. Examples in chapter four address the mathematical foundations of compressed sensing as applied to electron microscopy, and in particular high-angle annular dark-field STEM. That emerging approach uses randomness to extract the essential content from low-information signals. Chapter five eloquently discusses the efficacy of analyzing several low-dose images with specially adapted digital-image-processing techniques that allow one to keep the cumulative electron dose low and still achieve acceptable resolution.

The book concludes with a wide-ranging discussion by mathematicians Amit Singer and Yoel Shkolnisky on the reconstruction of a three-dimensional object via projected data taken at random and initially unknown object orientations. The discussion is an extension of the authors' globally consistent angular reconstitution approach for recovering the structure of a macromolecule using cryo-electron microscopy. That work is also applicable to the new generation of x-ray free-electron lasers, which have similar prospective applications, and illustrates nicely the importance of applied mathematics in the physical sciences.

Modeling Nanoscale Imaging in Electron Microscopy will be an important resource for graduate students and researchers in the area of high-resolution electron microscopy.

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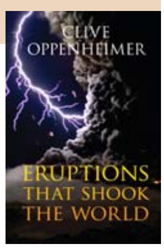
Eruptions That Shook the World

Clive Oppenheimer
Cambridge U. Press, New York, 2011.
$30.00 (408 pp.).
ISBN 978-0-521-64112-8



Geological and biological evolution and epic myth are punctuated by such catastrophic events as massive volcanic eruptions that shake Earth, change the climate, cover a continent with ash, and reset evolution. The term super volcano, popularized by the Discovery Channel, does not begin to describe the phenomenon, which leaves some evidence in geological, archaeological, and DNA records, but blows most of it away. Civilization, certainly, and humankind, probably, will not survive the next one. Clive Oppenheimer's *Eruptions That Shook the World* makes the case that we should understand these events. It also inadvertently makes the case that contemporary theories about the ultimate causes of world-class eruptions are as myth-driven as those involving Hades and Poseidon.

Oppenheimer, a reader at the University of Cambridge, argues that volcanoes and life have been intertwined throughout time. Did volcanic eruptions extinguish dinosaurs, change evolution, help humans evolve, decimate human populations 73 000 years ago, and contribute to the French Revolution? Oppenheimer uses all sorts of evidence to unravel the stories behind some of the greatest and most significant volcanic cataclysms. The book is well illustrated, including many examples of magnificent mushroom clouds—volcanic plumes—that bear startling resemblances to the cartoon in chapter 1 showing "killer plumes" in Earth's interior. Each chapter starts with a well-selected quote and ends with a useful summary.

Eruptions That Shook the World opens with the profound statement, "The Earth is cooling down!" The implications of that cooling are far-reaching and are even now not fully appreciated, 150 years after Lord Kelvin's spat with geologists. The mantle still retains enormous quantities of original heat. Volcanoes do not require heating or the importation of heat and matter from Earth's remote, deep interior. They occur because the mantle melts as it rises, in response to tectonic forces, or because it already contains magma that waits to be tapped. The relatively trivial effects of glaciers are enough to trigger eruptions by changing the load on or the orientation of the least compressive axis in the crust. Cooling, stretching, and breaking of large insulating plates allow the underlying magma to erupt: Hawaii and Yellowstone are prominent examples. Gas pressure and changing stress—not deep hot jets—trigger the release of magma.

Oppenheimer argues that recycled crust covers the core and converts core heat into killer plumes. However, that mechanism for raising or maintaining temperatures is 10 times more efficient at the top of the mantle. Moreover, the largest of the million-year-long eruption episodes signaling the breakup of plates empties out only a fraction of the magma that is stored in the shallow mantle beneath the plates. The large volume of available shallow magma was recently confirmed by Scott Bryan, Edgardo Cañón Tapia, and the late Paul Silver.

What Oppenheimer does not mention is that the understanding of the origin of large volcanic provinces is undergoing a classic paradigm shift—a shift back to the theories that favor top-down, stress-guide, low-pressure, and athermal shear-driven plate tectonic–related processes. This book presents the bottom-up, pot-on-the-stove analogy as noncontroversial conventional wisdom for the formation of killer plumes. That analogy is motivated by the shapes of thunderheads and volcanic plumes in the atmosphere, with no regard for scale or physics.

Mantle cooling drives convection and affects the geotherm in nonintuitive ways. Heat generated by radioactive decay modulates that cooling (see the Letters discussion, PHYSICS TODAY, November 2010, page 8). The competing processes of conductive cooling, radioactive heating, and thermal convection and advection, acting in the upper mantle, create a thermal bump—the cause of the asthenosphere and the source of most magma. J. Tuzo Wilson, one of the fathers of the plate-tectonic and hot-spot hypotheses, proposed that volcanic chains such as the Hawaiian Islands arose from the depths just below the rapidly moving plates.

I recommend *Eruptions That Shook the World* as motivational reading for physics students looking for a thesis topic in Earth or environmental sciences. The book may encourage physicists to take up the fascinating but challenging mission of understanding the workings of deep Earth and the claims that are made for it. The deep-Earth sections need to be read in parallel with Gillian Folger's *Plates vs Plumes: A Geological Controversy* (Wiley-Blackwell, 2010) to get a balanced view of the issues (see also http://www.mantleplumes.org).

Ironically, the early views of Walter Elsasser and others on plate tectonics and mantle convection as top-down processes with volcanoes as byproducts can be understood without invoking deep-Earth physics. However, appreciation of the effects of secular cooling, self-compression and scale, and the classical physics of Elsasser, Francis Birch, Peter Debye, and Eduard Grüneisen is required if scientists want to avoid the fundamental errors that occur in existing canonical models of mantle dynamics and geochemistry. Birch noted that words such as "dubious" and "vague suggestion" become "undoubtedly" and "positive proof" when applied to deep-Earth theories. By extension, "killer plumes" is merely a "high-pressure" name for volcanoes or a thick series of lava flows.

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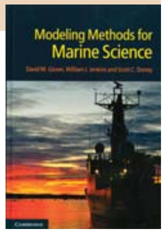
Modeling Methods for Marine Science

David M. Glover, William J. Jenkins, and Scott C. Doney
Cambridge U. Press, New York, 2011. $85.00 (571 pp.).
ISBN 978-0-521-86783-2



The use of mathematical and computational models is now commonplace in interdisciplinary scientific fields. Yet students entering graduate school in those fields come from diverse undergraduate backgrounds, and many are unfamiliar with the mathematical and numerical techniques they will meet in their careers. For graduate students and researchers in marine science who wish to learn how to develop and use computer models, the deficiency has been addressed by *Modeling Methods for Marine Science*, written by biogeochemists David Glover, William Jenkins, and Scott Doney.

The research fields of those highly accomplished and respected authors, who all work at Woods Hole Oceanographic Institution, are reflected in the book's concentration on the tools needed for biogeochemical and ecosystem modeling. The largely self-contained text includes coverage of a broad range of topics and emphasizes a practical, hands-on approach to modeling. Most chapters have a good selection of exercises, and many of the examples in the text include Matlab numerical code.

Modeling Methods for Marine Science is divided into three parts. The first seven chapters provide a brief introduction to Matlab and broad coverage of data-analysis techniques. Those techniques include basic probability and