Reviews

Coordinated by Sven Treitel

Crustal permeability, edited by Tom Gleeson and Steve Ingebritsen, ISBN 978-1-11916-656-6, 2016, Wiley, 472 p., US$160 (paper), US$128.99 (eBook).

Understanding fluid flow is critical to many aspects of the earth sciences. The fundamental relation for fluid flow is, of course, Darcy's law relating pressure gradients to fluid flux. Two parameters are required: viscosity for fluid properties and permeability for rock. Viscosity of various fluids (water, oil, and even magma) is relatively well known compared to the permeability of various earth materials and regions, which varies over many orders of magnitude. *Crustal Permeability*, edited by Gleeson and Ingebritsen, is a valuable resource for the study and understanding of this widely varying parameter.

The book consists of 30 individual papers (which together cite about 1500 articles) grouped into three parts and seven subcategories (see Figure 1 in which the pie slices are scaled to the number of pages devoted to each category). The individual papers that make up the book originated from presentations given at two USGS Powell Center workshops and are revised and updated from papers originally published in early-to-mid 2015 as part of a Geofluids thematic issue.

In total, 123 authors contributed to the papers in this book. A glance at their affiliations shows excellent representation of scientists mostly from North America, Europe, and Japan (with one or two authors each from Australia, New Zealand, India, and China). The book editors, Tom Gleeson, University of Victoria, Canada, and Steve Ingebritsen, USGS, are among the top thought leaders in the study and understanding of crustal permeability.

The goal of the book is to present the first book-length treatment of permeability in the earth's crust, but it is not a textbook. At its core, the book is an anthology of individual papers, so there is significant variation in writing and figure style throughout the volume, but the editors have added meaningful structure and perspective to the volume through their introductory and concluding papers. The figures throughout the volume are of systematically high quality, and they are made available as PowerPoint slides at a companion website. Another companion website is a persistent data portal designed for sharing of crustal permeability data.

Taken together, the papers in this volume are a meaningful and relatively comprehensive reference for anyone concerned with the flow of fluids within the earth's crust at a wide range of scales varying from the lab to the full crust. The book deals in an integrated fashion with the oft-disparate studies of permeability as either a static or a dynamic (time-varying) variable in earth processes.

The individual chapters range from broad theory to specific case studies. Issues relevant to a number of current societal concerns are covered in chapters on development of enhanced permeability by hydraulic fracturing and continental-scale hydraulic responses to large earthquakes. Other chapters address fundamental questions such as "How well can we predict permeability in sedimentary basins?" and "Is the permeability of crystalline rock in the shallow crust related to depth, lithology, or tectonic setting?" The editors end the volume with a forward-looking conclusion paper in which they propose a framework for a unifying and systematic characterization of permeability through its full crustal variations. They cite the holy grail as an "ability to quantify or predict permeability and its variability with space, direction, and time" within the earth's crust. A laudable goal and this volume is a positive step in that direction.

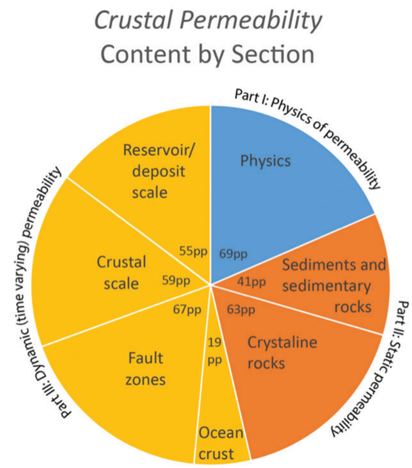

Figure 1. Part and subcategory content of *Crustal Permeability* (edited by Gleeson and Ingebritsen) by relative number of pages.

This book represents an excellent resource and reference for any professional earth scientist concerned with earth systems and processes influenced by the flow of fluids. This would include a wide-ranging list of topics as varied as petrogenesis, orogenesis, seismic hazard (including — importantly — induced earthquakes), and tectonic modeling. This volume would also be a useful reference for graduate-level course work.

— Rick Saltus
University of Colorado

Wavefronts and rays as characteristics and asymptotics: 2nd edition, Andrej Bóna and Michael A. Slawinski, ISBN 978-9-81464-478-5, 2015, World Scientific Publishing Co., 344 p., US$98.

This book is an interesting and readable exposition of the theory of characteristics of partial differential equations. While there are many other books on this topic, this book pays special attention to those equations the solutions of which represent waves, and describes how the characteristics of such equations are related to rays and wavefronts. As such, it should prove useful to geophysicists studying wave phenomena from a theoretical standpoint.

The book is intended for graduate students, researchers, and teachers. The authors state that readers should be familiar with linear algebra, differential and integral calculus, vector calculus, and tensor analysis. However, in my opinion, readers who also have taken an introductory course in partial differential equations would benefit more from the book and would find it easier to absorb than those who have not. And while a knowledge of tensor analysis would be useful for better understanding the material on elastodynamics, I don't believe it is necessary. A reader who has not studied tensors would still fare well enough because tensors are only used to present fundamental equations, such as the stress-strain relation (Hooke's law). More advanced topics from tensor analysis, such as covariant and contravariant tensors and the covariant derivative, are not used.

The first three chapters deal with first- and second-order linear and first-order nonlinear partial differential equations (including some discussion of first- and second-order semilinear and quasilinear equations). These are followed by a chapter on the propagation of discontinuities, which should be of interest to geophysicists studying wave propagation theory, as it is motivated by the concept of a wavefront. The last chapter is devoted to caustics, a topic which is also of interest in geophysical studies of waves, as it deals with the focusing of waves, a phenomenon which occurs when seismic waves propagate through complex subsurface structures.

Each chapter contains useful examples on the application of the theory. Furthermore, each chapter begins with preliminary remarks as well as insightful motivational examples, which prime the reader for the material to follow. Each chapter ends with closing remarks that nicely summarize the material in the chapter.

In addition, each chapter ends with a set of exercises and their fully derived solutions. The inclusion of the derived solutions to all the exercises, which immediately follow the exercise questions, makes it a bit difficult to use the book as a text for a course, in the sense that instructors would have to create their own homework and examination problems. On the other hand, it makes the book very useful for self-study, and provides an additional set of examples that would aid the reader in the comprehension of the material.

The "Appendices" are a useful and substantial portion (almost one-third) of the book, and thoroughly cover the mathematics and physics needed to fully understand the material in the main text. Like the main chapters, the "Appendices" include insightful examples (but no exercises with solutions at the end). Many readers of this book would already be familiar with many of the topics covered in the appendices. Nevertheless, the "Appendices" are a nice convenience, and as the authors themselves point out, the "Appendices" could even be used as material for a course on mathematical methods.

The changes from the first edition essentially comprise changes in the exercises in Chapter 1 and changes in the "Appendices" section. Overall, this book is well worth studying for geophysicists interested in how characteristics can provide a deeper understanding of ray and wave phenomena and, in general, the theoretical aspects of ray and wave theory.

— Edward S. Krebes
University of Calgary

Predicting the unpredictable: The tumultuous science of earthquake prediction, by Susan Elizabeth Hough, ISBN 978-0-69117-330-6, 2016, Princeton University Press, 280 p., US$19.95.

Predicting earthquake has a very long history. The seismology community is divided into those who believe that some level of research should be conducted and others who flat out say that earthquakes cannot be predicted. However, this search has occupied scientists for many years. Some of these studies are discussed in this volume; they range from the late 19th century to the present, and all are seeking to detect preseismic signals. Some of these predictions are made by seismologists, while others come from physicists and radio scientists. Several of the preseismic parameters discussed are hydrologic, electromagnetic (VAN method), crustal properties (V_P/V_S), patterns of small earthquakes, anomalous crustal warping (Palmdale Bulge), gas (radon), heat emanations, and animal behavior. The one precursor appearing throughout this book seeks to establish the time interval between major earthquakes in a search for a pattern leading to a prediction or a forecast and, in some cases, using probability methods — i.e., we are overdue.

The 4 February 1975 Haicheng, China, 7.3 magnitude event, however, was "predicted" by noting the occurrence of an increasing number of stronger and tightly spaced (in time) foreshocks. On this basis, an accurate prediction was made, and as a result a large number of casualties were avoided. Events leading up to this major earthquake prediction and the aftermath are described at length. It was initially believed, therefore, that the Chinese had found a prediction method. But subsequent studies by Kelin Wang and others showed that many other factors were involved.

In July 1976, an unpredicted magnitude 7.6 earthquake occurred in Tangshan, China, thus damping enthusiasm that a prediction method had been found. In the early 1970s, other methods initially giving hope that a prediction method was discovered were an increase in the ratio of the seismic velocities, V_P/V_S, proposed by the Soviets, and another an increase in the amount of radon in water wells. The latter was an offshoot of the dilatancy theory proposing that rocks, when stressed, increase their volume of pore space. Further research showed that these methods did not survive rigorous analysis. However, the radon enhancement theory keeps reappearing, especially in Italy.

In more recent times, several predictions were proposed that achieved a great deal of public notoriety: for example, the Brady-Spence prediction (scaling mine rock bursts to earthquake energies), the Palmdale Bulge (an up-warp of the crust), and the Browning event. Iben Browning had a PhD in biology, but studied climatology. He predicted that a major earthquake would occur in December 1990 in the region of New Madrid, Missouri, which he based on tidal stresses resulting from an alignment of the planets. His "theory" was picked up by several papers and received some attention in the media. Of course, there was no earthquake. The first two predictions were made by earth scientists, but the last one was not.

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Wavefronts and Rays as Characteristics and Asymptotics, 2nd edition, by Andrej Bóna and Michael A. Slawinski, ISBN 978-9-81464-478-5, 2015, World Scientific Publishing Co., 344 p., US$98.

This textbook provides a coherent treatment of the physics of wave propagation and the mathematical methods to describe such phenomena. This second edition of the book has some refinements over the first edition and some additional appendix material. The authors focus on the method of characteristics to examine the partial differential equations (PDE) of motion that mathematically describe wave phenomena. This is because the characteristics of these equations have physical meanings and relate to what a physical scientist calls rays and wavefronts in wave propagation. The use of the mathematical methods is exemplified with their application to the elastodynamic and Maxwell equations.

In Chapter 1, the authors introduce the method of characteristics and demonstrate its use in solving first-order linear partial differential equations, including systems of such equations. They start with simple examples and finally discuss the solution to the Maxwell equations. Chapter 2 is dedicated to the solutions of second-order partial differential equations and systems of such equations using the method of characteristics. The authors show why only hyperbolic PDEs — wave equation being one example — among the second-order PDEs may be solved using characteristics. Chapter 3 studies the characteristics of nonlinear first-order PDEs. One such example familiar to geophysicists is the eikonal equation. The eikonal equation is itself the characteristic equation of second-order PDEs like the wave equation. In Chapter 4, solutions to differential equations are described using asymptotic series. This allows the possibility of having discontinuities in the solutions. The application of this method is demonstrated by formulating solutions of the elastodynamic and Maxwell equations. These discontinuities in the solution propagate along characteristics only and are essentially what a physical scientist understands as wavefronts. The authors show how the discontinuities in the solution are related to characteristics discussed in the previous three chapters. The last chapter discusses caustics, which commonly arise when describing wave phenomena using ray theory. In addition to the five chapters, the book contains six informative appendices that supplement the material in the book — one more than was contained in the book's first edition.

The book is written keeping in mind mathematically oriented applied scientists and engineers. Hence the rigor of the formulations is kept at a level that is accessible for such an audience. Many solved examples and exercises with solutions make it a useful text for self-learning. The authors clearly explain the physical meaning of various mathematical terms, and that adds to the book's utility for physical scientists, including geophysicists. Practitioners interested in computer realizations of some of the calculations, however, may find it useful to supplement this book with algorithmic details found in references such as Červený's *Seismic Ray Theory* and Chapman's *Fundamentals of Seismic Wave Propagation*.

This second edition of the book is available in Kindle, hardcover, and paperback formats and is affordable for a large section of students. It is a well-organized and logically consistent volume in which the authors, according to Norman Bleistein, "provide the community interested in wave propagation with a new set of insights and tools to carry on with their research." The "reciprocal relationship between physics and mathematics" in the specific context of wave propagation will be illuminated for readers of the book. I strongly recommend it as a valuable resource for any physical scientist, including graduate students and advanced researchers, working on wave-propagation-related problems.

— Amit Padhi
Houston, TX

The Eagle Ford Shale: A Renaissance in U.S. Oil Production, edited by J. Breyer, ISBN 978-0-89181-390-3, 2016, AAPG, AAPG Memoir No. 110, 64 p. (plus DVD), US$178.

This book is a collection of papers on the Eagle Ford Shale, which is a prolific producer of oil and gas from shale in southeast Texas. It is different from a more standard book in that the book part contains only short versions (or expanded abstracts) of the papers comprising this memoir. The full papers are contained on the accompanying DVD. This format does allow for longer papers and more figures and photographs than might otherwise be available in a standard, book-only publication.

The Eagle Ford Shale was known to have hydrocarbon potential as far back as 1933, but efficient production needed to wait until technology improved. Since 2008, production in the Eagle Ford has helped fuel the increase in U.S. oil production. The Eagle Ford and Bakken are the preeminent shale oil plays in the United States. The book itself has 12 papers (the first paper is divided into two parts) covering various geologic, geochemical, geophysical, and petrophysical aspects of the Eagle Ford Shale. Each of the papers in the book is only three to seven pages long with a couple of figures. Therefore, they each provide a short read to introduce the particular subject. The DVD contains the full papers with much more detail. The DVD is searchable across all the papers or within one paper for any search term desired. The geologic emphasis of the publication is notable in that four papers contain more than half of the 397 pages in the DVD PDF file. In particular, the first part of the first paper on the biostratigraphic and geochemical constraints on the stratigraphy and depositional environment in the Eagle Ford is 87 pages (about 20% of the total DVD content); it contains lots of detail and figures that can be very useful in understanding the overall Eagle Ford shale unit. One paper concentrates on the geophysical aspects of exploration and production in the Eagle Ford. Chapter 6 illustrates how seismic attributes have been used to determine mechanical facies (i.e., frackability), fracture intensity, and porosity estimates in the interval.