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Book review

GEOLOGICAL FLUID DYNAMICS SUB-SURFACE FLOW AND REACTIONS

Owen M. Phillips. Cambridge University Press, 2009,
ISBN 978–0–521–86555–5, £40, 298pp.

Fluid flows beneath the planet's surface are very difficult to investigate and so are relatively unknown in comparison with oceanic, terrestrial and atmospheric flows. *Geological Fluid Dynamics* integrates fundamental science with informed pragmatism in examining sub-surface flow through porous or fractured media. The first chapter provides a brief introduction to the rapidly developing subject of geological fluid mechanics. The second chapter lays out the basic physical and chemical principles involved in describing permeable media and flows through them. The third and fourth chapters cover the behaviour of classical porous-media flows and buoyancy-driven flows. The fifth chapter focuses on the chemical interactions that can take place between interstitial fluid and permeable media. There is a further brief final chapter, which lists several examples of geological flows.

Phillips starts the book by defining geological fluid mechanics as being 'concerned with applying the principles of fluid mechanics to the geological sciences' and states that the aim of his book is to focus on 'passive and reacting fluids through porous or fractured geological media'. He outlines certain fascinating outcomes of geological flow (the slow growth of mineral deposits for example) and reminds the reader of the hazards that arise from the pollution of groundwater and aquifers, and from the underground storage of high-grade radioactive material. Noting that geological data are particularly difficult to acquire, Phillips recommends a proper scientific approach to the analysis of geological fluid flows – an approach in which simple models are developed that address major physical constraints, include measured parameters, are correctly balanced chemically and physically, and are straightforward to apply in practice. This approach sets the tone for the remainder of the book.

Chapter 2 examines the basics. First, the structural characteristics of typical permeable media are considered. A huge range of spatial scales is encountered. The intermolecular distances in aqueous solutions are ~0 (10^{-9} m). Typical interstices in rocks are ~0 (>10^{-6} m), whereas fractures can be from about 0 (10^{-2} m) to about 0 (10 m). Phillips carefully guides the reader through definitions of void fraction and porosity before turning attention to thermo-fluid mechanics. Darcy's law is discussed with regard to hydrostatics, interstitial flow through a uniform matrix, permeability, and reduced pressure and buoyancy. Basic mechanical energy, thermal energy and dissolved species balances are presented, and the importance of flow uniqueness and minimum dissipation constraints is emphasised. Equations of state are briefly touched upon. The chapter ends with a section on dispersion, focusing on that of a steady plume in an aquifer.

Chapter 3 is devoted to typical porous-media flows. First, flow in uniform permeable media is examined, whereby the transport velocity is directed down the gradient of reduced pressure. Phillips indicates how incompressible flow in homogeneous media may be described by Laplace's equation in pressure, and presents useful analytical solutions for flow around and through spherical inclusions and flows drawn towards cracks. The concept of groundwater age distribution in an aquifer is introduced and Lagrangian analysis is used to determine a suitable timescale. Physical and mathematical descriptions of the dispersion of dissolved contaminants and injected tracers are given. Anisotropic dispersion in layered media is considered, leading to analysis of the dispersal of contaminants in the confining layers of a surface aquifer. The transport of fluid containing dissolved passive contaminants and reactants through fracture-matrix media is examined. Useful formulae are derived for contaminant and solute front speeds. The chapter ends by considering flow transients, such as arise from seismic events, where there is an initial shock-like pressure pulse that travels at the speed of sound, followed by a diffusion-like process through the rock structure.

Buoyancy-driven flows are the subject of chapter 4. These flows are of great interest because they do not obey the uniqueness constraint and so can be unstable. The chapter considers the rotationality of buoyancy-driven flows, lays out the governing conservation laws and underlines the importance of the Péclet number and the Rayleigh number in characterising buoyancy-driven flows. The chapter gives a detailed account of internal flows within submerged permeable banks, platforms and reefs. Plumes and salinity-driven flows are also described. Thermal instabilities are also considered, in particular the classical Rayleigh–Darcy instability of a horizontal layer of viscous fluid confined between plates, the lower of which is hotter than the upper. Thermo-haline

circulations driven by both temperature and salinity differences are classified as being stabilising or destabilising according to Rayleigh number and Turner's density ratio. It is hypothesised how a coastal lagoon in an arid region can become hypersaline, leading eventually to the formation of bedded dolomites. The chapter concludes with a description of the Saffman–Taylor instability of fronts that occurs when an interstitial fluid is being replaced by another fluid with different viscosity and density.

Chapter 5 turns to chemically reactive flows. Reaction types are first considered, namely dissolution, combination and replacement reactions. The chapter examines scenarios in which the interaction between the interstitial fluid and the rock matrix leads to reaction fronts, gradient reactions and mixing zones. Leaching and deposition of mineral constituents are investigated. An explanation is given of the growth of mineral deposits over geological timescales, given the very slow speed of the reaction front with respect to the interstitial fluid velocity. Finally, isotherm-following reactions, paleo-convection and the geological distribution of mineral deposits are described.

Almost as a postscript, chapter 6 provides some bibliographic pointers and describes several further examples of geological flows, including coastal salt wedges.

This profound, readable, authoritative and insightful book provides a mine of information for modellers of geological processes. It is likely to be of considerable interest to a wide range of earth scientists, geotechnical engineers and hydrologists.

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