FRONTIERS IN GEOFLUIDS[1]

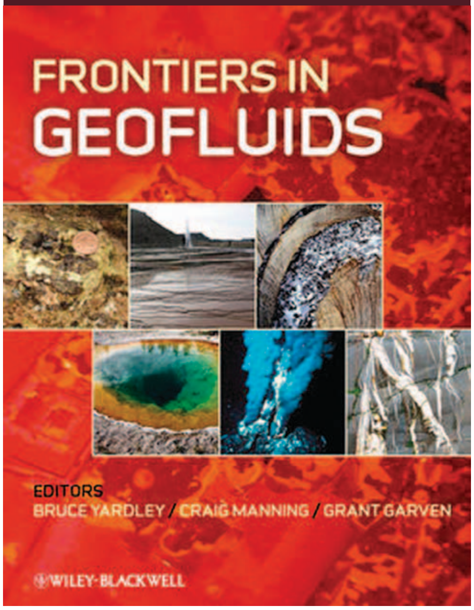
A REVIEW AND MUSINGS ABOUT GEOFLUIDS RESEARCH

Frontiers in Geofluids is actually a collection of invited papers published in 2010 to mark the tenth anniversary of the launch of the journal *Geofluids*. It is composed of 19 research and review articles varying in length from 7 to 32 pages and written by 39 different authors, many of whom are leading authorities in the study of geological fluids. The topics cover a wide range of subjects, including the speciation and equations of state of fluids, mineral–fluid equilibria, mineral–fluid reactions and reaction mechanisms, the structural and stratigraphic control of fluid flow, the creation and destruction of permeability, the relation between heat flow and fluid flow, and the relation between earthquakes and groundwater flow. The study methods reported involve theoretical calculations, laboratory experiment, field studies, and the analysis of rock and fluid samples. The latter two methods are applied specifically to sedimentary rocks and sedimentary basins, groundwater flow, seafloor and continental hydrothermal systems, hydrocarbon and ore deposits, metamorphic rocks, and melt inclusions. Individual articles range from a systematic review of a subject (e.g. A. Liebscher on phase equilibria and physical properties of aqueous fluids) to results of new research (e.g. B. W. D. Yardley, D. E. Harlov, and W. Heinrich on the experimental simulation of retrograde metamorphism), although most articles have more of a mix. The level of *Frontiers in Geofluids* is similar to that of "Frontiers" papers in *Earth and Planetary Science Letters* and *Reviews in Mineralogy and Geochemistry*. The volume has a broader reach than "Frontiers" papers, but is not as comprehensive as *RIMG* volumes.

The 19 articles can be grouped in a number of ways. The editors chose five subject categories: theory and experiment (4 articles), sedimentary basins (3), ocean crust and upper mantle (4), continental crust (6), and other (2, one each on ore deposits and melt inclusions). A more revealing two-part subdivision, however, can be made in terms of the underlying science discipline: (1) physical aspects of fluids and fluid flow, including rock and fluid mechanics and heat flow (7 articles), and (2) chemical aspects of fluids and fluid flow (12 articles). The two kinds of studies seem to peer at each other across an abyss. The physics articles ignore any chemical reaction between fluids and rocks, while the chemistry articles generally ignore the mechanics of fluid flow or even fluid flow entirely. (A notable exception is the paper by D. Dolejs and C. E. Manning, which models the precipitation of minerals in veins.) The reason that fluids are important in Earth science is because they flow. When fluid flows through rock, reaction between the two is not just possible, but inevitable. Flowing fluids transport heat and mass at kilometer to crustal scales, and they have played a vital role in processes such as the distribution of elements in the crust, the cooling of the planet, the driving of mineral reactions in thousands of cubic kilometers of the crust, the formation of most ore and hydrocarbon deposits, and the evolution of life, if not the origin of life itself. A quantitative understanding all these (and other) important processes requires integrated studies of the physics and chemistry of fluids and fluid flow, not just a consideration of one or the other by itself.

The title, *Frontiers of Geofluids*, is appropriate because the volume is an excellent snapshot, of interest to all readers of *Elements*, of how far studies in geological fluids have progressed in scope and sophistication over the last two decades. The volume, however, could also be considered a kind of manifesto for research opportunities because of its compelling documentation of the gap between studies of the physics and chemistry of fluid flow. Bridging that gap is the next frontier. The foundation of such integrated studies—transport theory—has been known for decades in hydrogeology and chemical engineering. This theory includes statements of the conservation of energy (the heat equation), of mass (the advection-diffusion equation), and momentum (usually Darcy's Law). As several authors note (e.g. C.-Y. Wang and M. Manga, p. 213), further advances in fluids research will involve new research in theory, laboratory experimentation, and field studies. Some theoretical problems include the incorporation of complex fluid and solid solutions into transport models and the consideration of rock mechanics in modeling the development of permeability in flow systems, for example. Experimental measurements are needed of mineral–fluid equilibria, mineral–fluid reaction rates, intercrystalline and intracrystalline diffusion rates, and permeability in porous media undergoing mineral–fluid reaction. Future field studies will focus on the spatial distribution of minerals, mineral assemblages, and the elemental and isotopic compositions of rocks and minerals, as well as their structural context, in active and fossil fluid flow systems on a spectrum of scales from microns to kilometers. These spatial distributions both record the various processes of heat and mass transport in fluid flow systems that can be decoded by transport theory and serve as tests for transport models that seek to explain the distributions.

To achieve this vision of a quantitative marriage of the physics and chemistry in studies of fluid flow, however, a new educational paradigm is called for. Just as the study of chemical thermodynamics is now considered a requirement in the training of geochemists, petrologists, and mineralogists, so should transport theory. Even a basic understanding of transport theory is a powerful tool for making back-of-the-envelope calculations that can solve the essence of a problem. Likewise, geophysicists need to have more training in phase equilibria. It may be too much to ask that each individual master all aspects of fluid flow, but even collaborative research will require among the partners a broader familiarity of both chemical and physical aspects of fluids and fluid flow than is currently the case.



On the practical side, *Frontiers in Geofluids* is in an attractive volume printed on heavy glossy paper, perfect for those like myself who enjoy scribbling notes in the margins and marking pages with dog-ears or Post-its for future reference. Typographical errors are remarkably few (e.g. there is an occasional mismatch in numbering between text and figure captions). Oddly, some figures that are in color in the electronic version of *Geofluids* appear in black and white in the printed version (however, with only minor loss of clarity). It is likely that few will choose to purchase the volume for themselves. Students and professionals whose institutions allow them access to *Geofluids* on the Wiley-Blackwell website can download any or all of the 19 articles for free. They would only lack the index. For those who do wish to have their own copy, as of December 12, 2011, print copies can be purchased for as low as $75.82 from Amazon; an electronic version for a Kindle is $80.43.

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1 Garven G, Manning CE, Yardley BWD (eds) (2011) Frontiers in Geofluids. Wiley-Blackwell, viii + 318 pages, $150.00/€60.00/£49.99