METASOMATISM AND THE CHEMICAL TRANSFORMATION OF ROCK*

The concept of metasomatism, or the chemical alteration of solid rocks, stems from the classical observations and interpretations of pioneering geochemists and petrologists, starting with V. M. Goldschmidt and including Hans Ramberg, Peter Misch, and D. S. Korzhinsky. Much of the early discussion centered around the origin of granite. In the middle decades of the last century, experimental studies on the melting of quartzofeldspathic rocks at elevated H_2O pressures began to subvert earlier interpretations of metasomatism. The experiments showed that rock melting temperatures dropped drastically from above 1000 °C into the 600–800 °C range thought to prevail during high-grade crustal metamorphism, fostering the implication that many of the intuitive interpretations based on the textures of granites could be better explained in the larger context of magmatism. Andrew Putnis and Haakon Austrheim state the situation succinctly in chapter 5 of *Metasomatism and the Chemical Transformation of Rock*" (p. 143). Referring to "the ultimate demise of metasomatism as a large-scale process," they go on to say: "The magmatists won the argument with the experimental work of Tuttle and Bowen (1958) and for many years metasomatism was neglected…"

Recent developments in chemical, isotopic, and petrographic analysis have brought metasomatism roaring back into the vocabulary of petrology, as the 15 articles in this book edited by Daniel E. Harlov and H. Austrheim make abundantly clear. One problem has been that the chemical effects of metasomatic processes are often much more subtle than those of igneous processes. An example is the "cryptic" alteration of mantle peridotites, which alteration can now be apprehended by sophisticated modern trace element and isotopic analysis. Most importantly, the complex physical chemistry of multicomponent fluids and their interactions with rocks in reactive flow is orders of magnitude more difficult conceptually than a ternary melting diagram; hence the former lack of interest in an arduous, low-reward effort to understand it in detail.

The metasomatic nature of every petrologic regime, from the oceanic crust (chapter 8, by W. Bach, N. Jons, and F. Klein) to skarns and ore deposits (we already know those are metasomatic, but F. Pirajno's descriptions in chapter 7 give a nice overview), to metasomatic processes in the mantle lithosphere (chapter 12, O'Reilly and Griffin) and in the deeper parts of the crust (chapter 11 by J. L. Touret and T. G. Nijland) mandate a concerted effort toward a quantitative understanding of fluid–rock interaction. Touret's pioneering research on fluid inclusions demonstrates that virtually every kind of rock has the remnants of mineralizing (indeed, metasomatizing) fluids trapped in the minerals, including rocks of the "dry" granulite facies lower crust. Recognition of metasomatism in virtually all rocks is trundling forward with steamroller momentum.

The treatments in this book of the various topics on metasomatism reflect the predilections of the authors. B. W. D. Yardley's title (chapter 2), "The Chemical Composition of Metasomatic Fluids in the Crust," should have the modifier "Upper," since the author's emphasis is on brines of sedimentary origin. Mineralizing fluids of higher grade but relatively shallow-seated metamorphic rocks like skarns and greisens are briefly addressed by Yardley. The other treatments range from elementary, as in Pirajno's textbook description of ore deposits, to the dauntingly analytical chapter 14, by J. A. D. Connelly and Y. Y. Podladchikov, "A Hydromechanical Model for Lower Crustal Fluid Flow," in which they set forth their mathematical theory of fluid-filled porosity waves travelling through otherwise impermeable rocks.

Several very useful and well-written articles of the book may be singled out. R. Klemd's chapter 10, "Metasomatism during High-Pressure Metamorphism: Eclogites and Blueschist Facies Rocks," is a clear, informative, and, to this reviewer, very entertaining description of patently metasomatic features of rocks from exposed high-pressure and ultrahigh-pressure terrains. Klemd and his coworkers have concentrated on the chemical relations of blueschist-to-eclogite transitions in places like the Tianshan of western China.

My favorite article is chapter 12 by S. Y. O'Reilly and W. L. Griffin, "Mantle Metasomatism." This summary of their and many others' research on mantle peridotites in the form of volcanic xenoliths and in exposed ultramafic masses (ophiolites) reveals the profound metasomatism shown by every mantle rock, including the so-called "fertile" lherzolites, which, for so many years, have been thought to be pristine, undepleted potential source rocks for basalt magmas. The "pyrolites" of yesteryear are now thought to be refertilized, previously depleted dunites and harzburgites.

Even extraterrestrial rocks (meteorites) show the effects of metasomatism. Chapter 15 on this subject, by A. J. Brearley and A. N. Krot, is the longest paper in the book. Some of the least thermally altered meteorites, the carbonaceous chondrites, show veins containing such volatile-bearing minerals as sodalite and scapolite, and, occasionally, OH-bearing phyllosilicates. Even the unequilibrated ordinary chondrites show evidence of fluid-assisted metamorphism, presumably recording processes in the regoliths of asteroidal parent bodies. This well-illustrated summary should be of considerable value to meteorite geochemists.

Chapter 3 on thermodynamic modeling and thermobarometry, by P. Goncalves, D. Marquer, E. Oliot, and C. Durand, is a good summary of the use of pseudosections as applied to metasomatic rocks. M. Rubenach's chapter 4, on structural controls on metasomatism, gives a fascinating account of deformation-related mineralization in one of the world's most spectacular metasomatic terrains, the Mt. Isa Inlier of Queensland, Australia. Chapter 6 on the geochronology of metasomatic events, by I. M. Villa and M. L. Williams, makes the point that all isotopically datable metamorphic events are by definition metasomatic. This chapter is a useful discussion of the procedures and problems of dating metasomatic rocks. Chapter 1, by the book's editors, gives thumbnail sketches of all the articles.

A well-cited article in this book might prove to be chapter 15, by M. Unsworth and S. Rondenay, on the mapping of fluids in the crust and lithosphere by geophysical methods, including seismic profiling and electrical resistivity studies. These authors make a good case for the large-scale existence of interconnected, saline pore fluids in areas of the lower crust undergoing thermal activation, as in the Great Basin of the western United States. Where there are low-resistance channels there must be some kind of conducting fluids, and hence, probable metasomatic action. This and other papers of this book (e.g. Klemd and O'Reilly and Griffin) seem to lean to the view that deep-seated fluids (C–O–H fluids and brines) result from subduction of surficial volatiles.

The original metasomatism controversy was centered around the origin of granite, whether or not there is an important process that could be called "granitization." There is no discussion of this kind of metasomatism in Harlov and Austrheim's book. The commonly noted metasomatic phenomena of "ghost" gneissic foliation that passes seemingly uninterrupted through granites and K-feldspar megacrysts that grow across boundaries of mafic inclusions in granite seem still to be off-limits for respectable scientists. Some day the tainted subject of granitization will also return to the realm of legitimate discussion.

A shortcoming of my copy of this book is the low quality of many illustrations in black-and-white reproduction. A full-color version is now available with much improved illustrations.

All in all though, this heavyweight book goes a long way toward making up for a half century of neglect of one of the principal petrogenetic processes of the rocky universe.

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