

Mineral-fluid interfaces and interactions: From molecular to local, regional, and global-scale processes

MICHAEL F. HOHELLA, JR.,
CHRISTOPHER J. TADANIER, STEVEN K. LOWER, BRIAN
H. LOWER, TREVOR A. KENDALL, TRACY A. CAIL,
AND ANDREW S. MADDEN

Nanogeoscience and Technology Laboratory, Department of
Geological Sciences, Virginia Tech, Blacksburg, VA
24061-0420 USA (hochella@vt.edu)

Mineral-fluid interfaces are ubiquitous in the Earth's atmosphere, hydrosphere, and biosphere, as well as within the solid Earth itself. The consequences of this vast interfacial area (on the order of trillions of square kilometers on this planet) and enormous reaction domain are inescapable, literally establishing the ways that the solid Earth communicates with the fluid Earth. The transfer of matter and energy across this interface is the key to understanding processes such as the development of soils and the distribution and movement of plant nutrients, microorganisms, and contaminants within them, the quality of the world's fresh water, the chemistry of the atmosphere, and ultimately, the geochemical cycling of all elements. Despite this overarching scope, and the chemical complexity that follows in all of these fields and subfields of study, it is instructive to consider the fact that any mineral-fluid interaction consists of only one or both of two fundamental steps. These are the attachment or detachment of chemical species to or from mineral surfaces. Although many other processes stem from these (e.g., surface diffusion, redox reactions, molecular modification, growth, dissolution, etc.), attachment and detachment steps remain the fundamental cornerstones of interface chemistry. Recognizing, characterizing, and ultimately predicting these fundamental steps lies at the heart of environmental interface science. It is possible to study their fundamental nature at the nanoscale, both experimentally and theoretically, with many recent advances which are rapidly expanding this area of research. These include *ab initio* and semi-empirical interfacial molecular modeling, as well as the application of various experimental nanotechnology approaches.

Scales of mantle heterogeneity and melting

A.W. HOFMANN^{1,2}, A. V. SOBOLEV¹, W. ABOUCHAMI¹,
S.J.G. GALER, AND K.P. JOCHUM¹

Max-Planck-Institut für Chemie, Postfach 3060, 55020 Mainz,
Germany (hofmann@mpch-mainz.mpg.de)
Lamont-Doherty Earth Observatory, 61 Rt. 9W, Palisades, NY
10964, USA

Systematic sampling of ocean ridges and individual oceanic hot spots such as Hawaii and detailed analyses of many melt inclusions in individual basalt samples demonstrate that the mantle is chemically and isotopically heterogeneous on scales covering many orders of magnitude. At the ocean-size scale, we now know that the source region of mid-ocean ridge basalts is not a homogenized or well-mixed reservoir that can be characterized by a single, "typical" set of geochemical parameters. For example, lead isotopes from Indian Ocean MORB show little overlap with those from Pacific MORB.

On single hot spot scale, the two parallel chains of volcanoes from the Hawaiian Islands ("Loa" and "Kea trend") show consistent trace element and isotopic differences. These differences reflect lateral-scale heterogeneities in the source region, which are drawn into the plume, stretched vertically during ascent, and preserved by laminar flow within the plume. On a still smaller scale, the 3 km drill core on Mauna Kea shows rapid chemical and isotopic fluctuations. Their interpretation is controversial: they reflect either horizontal layering [1] or vertical striations [2] within the plume.

The smallest scale of heterogeneity is revealed by melt inclusions in phenocrysts. Extreme chemical and isotopic heterogeneities are found in melt inclusions from single basalt specimens and even from single olivine crystals [3,4]. These reflect source heterogeneities within the melting region, the true dimensions of which are not yet known, but may be in the meter to kilometer range.

All of these heterogeneities are not random, but can usually be mapped by intensive sampling combined with large numbers of high-quality analyses by modern micro- and macro-analytical methods. Together with new, high-resolution images obtained by seismic tomography and high-resolution dynamic modeling of convection processes, these results are likely to produce a new understanding of how mantle processes work.

References

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