# FUTURE DIRECTIONS IN GEOCHEMISTRY AND MINERALOGY: A VIEW FROM THE NATIONAL SCIENCE FOUNDATION

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*Dr. Margaret S. Leinen heads the Directorate for Geosciences at the National Science Foundation in the United States. She is a past president of the Oceanography Society, and prior to her appointment at NSF, she served as Dean of the Graduate School of Oceanography and Vice Provost for Marine and Environmental Programs at the University of Rhode Island. Her research focuses on the history of biogenic sedimentation in the oceans and its relationship to global biogeochemical cycles. As Dr. Leinen is the top administrator of the NSF Directorate that funds many of our readers, we asked her to offer some insights into the state of geochemical research. She kindly consented.*

I've never had the nerve to refer to myself as a geochemist or mineralogist in spite of using geochemistry and mineralogy extensively in my own research. Rather, I am an admirer of the three fields that come together in *Elements*. I have been especially delighted by the new journal because it so successfully reaches beyond the individual and group scholarship represented in *Geochimica et Cosmochimica Acta* to the excitement that happens when geoscientists bring multiple fields of expertise to bear on important problems and scientific questions. Looking at the past year it is clear that others are important partners in your excitement—biology, nanotechnology, geophysics, to name but a few.

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Reading the pages of the first four issues of *Elements* is an exhilarating tour of new directions in mineralogy, geochemistry, and petrology. The articles make clear that the pace of innovation and evolution in the fields has accelerated in the last decade: new paradigms are elbowing out many old rules. For example, research demonstrates that the physical properties of minerals and their reactivity change with size because surface energy is no longer small relative to the total phase energy in nanoparticles. Over the past decade the interactions between geological and biological processes have emerged clearly. We have moved from a point of view that emphasized physical and chemical Earth processes to one that recognizes that nearly all processes we study are touched by the biology that is such a unique characteristic of our planet in the solar system. These changes in mineralogy, geochemistry, and petrology mirror rapid changes in geoscience as a whole.

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First, geoscientists have proposed and have received the first funding for observations that allow us to look at processes operating at very large spatial scales and decadal time scales. The EarthScope project is the largest and most complex geological experiment that has ever been undertaken by the US. This continent-scale experiment looks at the structure and dynamics of North America using seismology and geodetic technology (to study stress and deformation); it also examines fault mechanisms by direct measurement from a drill hole across the San Andreas Fault (www.earthscope.org). This rich landscape of continent-scale dynamics will lay the groundwork for new understanding of large-scale geochemical cycling and the interactions among mineralogy, geochemistry, petrology, deep structure, and dynamics.

Building on this foundation of capability for large-scale Earth observations, the ocean science community has proposed an ocean observatory initiative (OOI) that would use electro-fiber optic cables to connect ocean instruments to each other and to shore. OOI will provide the first sustained capability to observe the interior of the ocean and its seafloor (www.orionprogram.org). The hydrologic science community has joined with the engineering community to propose a series of hydrological observatories that will allow scientists to observe entire watersheds and incorporate study of engineered components of those systems. These new large-scale observing systems will provide extraordinary context for individual investigator research. In fact, such observing systems hold the promise of providing the observational and process-oriented framework that will allow studies of much smaller-scale phenomena and processes to be extrapolated to larger scales. Such scaling has been a formidable challenge in the past.

Reconciling laboratory experiments with the more complex real environment has also been a major challenge. A second major trend, related to the observatories, is the development of in situ sensors that can be remotely controlled from the laboratory over wired and wireless networks (e.g. www.cens.ucla.edu). The potential of such instruments to provide high-quality environmental characterization provides the opportunity to study small-scale materials and processes in the field as a bridge to lab experiments, further enhancing the scalability of studies done at the microscale or even the nanoscale.

Geoscientists are some of the most demanding consumers of high-performance computing. About 40% of the NSF-funded computing in excess of 1 Teraflop processing speed is done by geoscientists. Your future demands have been reflected in a call for geoscience computing at the petascale (http://www.geo-prose.com/projects/pdfs/petascale_broch.pdf). This capability will be critical for representing and translating the complexity of geosystems to models that simulate environments we cannot recreate (Earth's interior, past environments), for achieving a simulation of processes based on first principles (e.g. complex multi-element chemical reactions on surfaces), and for integrating dense in situ observation into holistic representations of the environment to unveil large-scale phenomena.

Finally, encouraging efforts to develop greater inter-operability between large data sets is a major priority for the NSF and the community. The opportunity to link one's own observations with a rich mix of other relevant observations promises to allow geoscientists to draw more extensive and/or more interdisciplinary conclusions about their own work and its relation to other fields.

These important developments represent new tools, which are as important as new instruments. I believe that these tools, combined with the creative genius of this community, will ensure that the next decade will be as exciting as the past one has been.