Presidential Address
The Microbial Factor in the Geochemical Equation

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Located at the interface between geology and biology, the field of geomicrobiology has become a rapidly growing frontier in Earth Science. Geochemists, who have traditionally approached geological problems from an inorganic prospective, are directly affected by this development. Using a combination of geochemical and molecular biology techniques, geochemists can now introduce a microbial factor into the geochemical equation, which expands our understanding of biogeochemical mechanisms occurring at or near Earth surface conditions. This approach is really not new. At the turn of the 20^{th} century, G. A. Nadson, a Russian microbiologist, had already proposed that microbes could serve as geologic agents, which control geochemical reactions. He astutely observed the role of microbes in the recycling, fixation and dispersion of elements in nature. The renewed interest to evaluate the impact of the microbial factor in natural systems has been strongly influenced by the application of technical advances, which enable geochemists to image and measure microbial interactions and processes at various scales.

Microbial activity has undoubtedly been modifying the Earth's uppermost lithosphere, hydrosphere and atmosphere since the appearance of life more than 3.5 billion years. The ability of microorganisms to mediate the transformation of dissolved and gaseous substances and concentrate them in inorganic minerals, such as carbonates, pyrite or phosphates, provides evidence of microbial activity throughout geologic time. Additionally, this activity leads to the isotopic fractionation of elements, such as carbon, sulfur and nitrogen, providing tracers to interpret biogeochemical processes related to the evolution of life in Earth history. Thus, we have geochemical and mineralogical tools to interpret the geologic record, but, in order to construct convincing models, we need to validate the actual microbial processes through the study of modern environments and laboratory experiments. Indeed, the present holds the key to the past!

Knowledge about early microbial processes can, in fact, be obtained from the study of their modern counterparts. For example, studies of modern microbial mats and stromatolites provide crucial information to develop models for their formation in the geologic record. From the study of modern analogue environments, it is possible to combine geochemical and biological analyses to estimate the impact microbial activity may have had on paleo-environments. Molecular biology techniques indicate the presence of microbial consortium and distinguish among groups of microbes. Interactions within these microbial communities result in biogeochemical reactions, which generate specific bio-products, including gases, dissolved species, organic matter and biominerals. These products represent microbial "fossils", which are indicative of specific environmental conditions.

Modern environmental settings with peculiar physico-chemical, biological and mineralogical characteristics can be considered as analogues for "fossil" environments, which are defined as those that were common in the geologic past but are rare today. Assuming that the microbial processes have remained relatively constant under specific conditions throughout geologic time, a combination of geochemical and microbiologic studies in such "fossil" environments can provide a better understanding of the boundary conditions associated with the large-scale microbial biomineralization observed in the geologic record. Further, the boundary conditions determined through the study of "fossil" environments can be used to design laboratory experiments to simulate the production of microbial "fossils" under controlled conditions. Thus, by combining studies of modern analogues with well-defined experiments and observations from the rock record, realistic models to evaluate ancient geomicrobiological processes can be developed.

For example, the origin of dolomite, a long-standing enigma in geology, is a geological problem with a probable geomicrobiological solution. In 1928, Nadson proposed that bacterial reduction of sulfate contributes to the precipitation of dolomite. He wrote, "Understanding the essential role played by this bacterial phenomenon may be the solution to the Dolomite Problem and the problems of the Mg cycle in the Ocean." Recently, studies have been conducted in two hypersaline coastal lagoons located east of Rio de Janeiro, Brazil, which represent "fossil" environments in which modern dolomite precipitates. Based on field observations and measurements, culture experiments have been designed to simulate the natural environment, and microbial dolomite has been precipitated *in vitro* (Warthmann et al., 2000; van Lith et al., 2003). Reproducing in the laboratory the processes and products observed in the studied "fossil" environments offers one of the best methods to validate the occurrence of microbial "fossils", such as the biomineral dolomite.

In summary, the study of microbial "fossils" produced in "fossil" environments combined with simulation experiments under controlled conditions provides geochemists a powerful tool to calibrate processes related to microbial activity in ancient systems. This geomicrobiological approach offers the possibility to glimpse into the environmental conditions of the early Earth and better interpret its evolving life forms.

References

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