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Edited by Janice P. L. Kenney , Harish Veeramani , Daniel S. Alessi
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Analytical Geomicrobiology

A Handbook of Instrumental Techniques

Geomicrobiology is the study of microbes and microbial processes and their role in driving environmental and geological processes at scales ranging from the nano, to the micron, to the meter scale. This growing field has seen major advances in recent years, largely due to the development of new analytical tools and improvements to existing techniques, which allow us to better understand the complex interactions between microbes and their surroundings.

In this comprehensive handbook, expert authors outline the state-of-the-art and emerging analytical techniques used in geomicrobiology. Readers are guided through each technique, including background theory, sample preparation, standard methodology, data collection and analysis, best practices and common pitfalls, and examples of how and where the technique has been applied. The book provides a practical go-to reference for advanced students, researchers, and professional scientists looking to employ techniques commonly used in geomicrobiology.

Janice P. L. Kenney is an assistant professor at MacEwan University, and a member of the Geochemical Society. She is interested in how contaminants, such as radionuclides, are transported in the environment, and she employs techniques in geochemistry and geomicrobiology to better understand the fate of these elements.

Harish Veeramani is a research facilitator at Carleton University, and previously worked as a lecturer in water engineering at the University of Glasgow. He specializes in applied environmental microbiology for the remediation of heavy metal contaminants, including radionuclides.

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Foreword

As a discipline, geomicrobiology's origins can be traced to the microbiologist Lourens Baas-Becking's 1934 book *Geobiology*, in which he argued that although microorganisms exist everywhere, the environment selects which species dominate any given habitat. In the decades since, geomicrobiology has transformed into a scientific discipline that covers all aspects of how the biosphere shapes, and is shaped by, our planet's surface environments and deep-Earth processes alike. Ignited by technological advances in stable isotope and organic geochemistry, electron microscopy, synchrotron radiation, and other surface probing techniques, as well as molecular biology, studies in geomicrobiology are providing new insights into how interacting biological and physical processes have influenced environments, both locally and globally, across our planet's entire 4.5-billion-year history.

A key topic within geomicrobiology includes life's control over elemental cycling, from the weathering and dissolution of rock, to the assimilation of diverse bioessential nutrients necessary for all forms of life, to the diagenetic transformations taking place during sediment burial. These processes cover a vast range of spatial scales, from micron-sized niches to reservoirs as immense as the oceans, and temporal scales from seconds to billions of years. The central theme running through all this research is the recognition that life shapes the environment to the same degree that environmental change drives the spatial and temporal distribution of life. This co-evolution of life and its environment, specifically investigations of the cause-and-effect relationships and associated feedbacks, is the defining quality of geomicrobiology. Indeed, the more we learn about how life interacts with the planet, the more we realize that it is the feedbacks and drivers between the two that are the key agents of change. For example, one can ask: How did microbial genetic innovation in the past lead to biological reactions that modified Earth's surface? Environmental change, through processes such as tectonics, in turn influences biology, which can create new opportunities for evolutionary innovation – sometimes in unexpected ways. In this regard, geomicrobiologists are at the forefront of studies that strive for a more complete understanding of the Earth as a dynamic, interrelated system, to know our origins, to predict our future, and to explore for life beyond our planet and solar system.

One of the greatest challenges in any emerging field is the exchange of relevant information – specifically methodologies – among different subdisciplines. In part, this problem reflects historical gaps among the disciplines that contribute to geomicrobiology, and specifically the highly specialized training that each subgroup receives. Although expertise in any given subdiscipline in geomicrobiology requires specialized training, it is the cross-fertilization among these seemingly disparate fields that defines geomicrobiology – and highlights the need for a book that integrates the tools being utilized by our community. *Analytical Geomicrobiology: A Handbook of Instrumental Techniques* does

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just this. It presents a summary of the advanced instrumentation used today to determine how organics, metals, and/or minerals interact with bacterial surfaces and their environment. It is designed to give researchers a broad knowledge of the available analytical techniques and will provide for the first time a way for researchers to standardize their methodologies.

The chapters begin with an introduction of the standard methods used to study bacteria and their secondary mineralization products, including commonly used techniques in general microbiology and geochemistry. Following are two chapters on isothermal titration calorimetry and potentiometric titrations, tools that are key to characterizing the surface chemistry and thermodynamics of metal binding to bacterial cell envelopes, microbial exudates, and biogenic minerals. Chapter 4 covers the use of multi-collector inductively coupled plasma-mass spectrometry (ICP-MS) to measure stable isotopes, a technique of increasing importance in geomicrobiology used to understand the biotic and abiotic cycling of metals in marine and terrestrial environments. Chapters 5–8 focus on imaging techniques, including atomic force microscopy, scanning tunneling microscopy, transmission and scanning electron microscopy, and various fluorescence *in situ* hybridization (FISH) techniques. All of these techniques are commonly used to visualize materials at the micro to nano scale, and the authors of these chapters have put particular effort into providing information specific to sample preparation for geomicrobiological samples. Spectroscopic techniques comprise the next five chapters, including benchtop techniques such as infrared, Mössbauer, and X-ray photoelectron spectroscopies, the use of X-ray diffraction techniques to study biogenic minerals, and a chapter on the use of synchrotron-based X-ray absorption spectroscopy. Finally, Chapters 14 and 15 discuss advanced microbiological tools to study microbial communities and their functions, including signature lipid biomarkers, and provide a survey of phylogenetic techniques available to the geomicrobiology community.

The layout of the chapters makes this book an easy reference tool for both experienced and novice researchers. In each chapter, the authors first provide a succinct and insightful introduction to the instrumental technique at hand, along with key references for further reading. Following this, an applied example of the technique is discussed in detail. This allows the reader to immediately appreciate the sampling methods, tools, materials, and expertise required to use the technique, and to decide whether the instrumental method is appropriate to answer a particular scientific question. While studies in peer-reviewed publications often use the advanced tools discussed in this book to determine how metals, organics, and minerals interact with microbes, those journal publications necessarily provide little information about how to use the technique, or for that matter, why it was even chosen. This book, written by worldwide experts in geomicrobiology, provides an entry point for novice and experienced scientists to select the most appropriate instrumental techniques to study their system. Perhaps most importantly, the text brings together in one place analytical tools used in the many subgroups of geomicrobiology. The aim of the book is simple: to promote more collaboration and integration among scientists in our field by informing them of the analytical possibilities.

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