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Chapter 34

Current trends and future directions in environmental geochemistry research

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Abstract

Increasing population growth and rapid industrialization with passing time have augmented the rate of deterioration of the environment, which is having a clear negative impact on human and ecological health. Although considerable research is now being undertaken in critical areas such as global change, environmental quality, and ecological protection, more collaborative, inter-disciplinary research is needed in order to ensure long-term environmental sustainability. A thorough understanding of the geochemistry of the earth's intrinsic processes is needed to develop a comprehensive, holistic model for the protection of the environment to ensure long-term sustainability in a global scale. This chapter briefly discusses some of the more salient current trends in environmental geochemistry research and a few of the many potential future directions of research in this area, often in close collaboration with experts in other scientific disciplines and policy makers geared towards maintaining earth system sustainability.

Technological and scientific advances aiming at improving the quality of our lives often come with a substantial pressure on the environment's resources and sustainability. Sustainability is intrinsically related to environmental quality. Maintaining a clean environment is of utmost importance to the public because of its impact on human and ecological health. Understanding the chemistry of the environment is necessary to better understanding environmental quality issues. Hence, environmental geochemistry as a discipline has been steadily gaining prominence for the last few decades due to increasing public awareness of major environmental issues relating to human and ecological health. The emergence of new concepts and innovative practices in environmental geochemistry has inspired us to assemble original scientific works from a group of experts from various areas of geochemistry in this book. This chapter briefly discusses certain current trends a few of the many potential future directions of innovative research in this fast-emerging field.

One of the areas where geochemistry plays a very important role in nuclear waste management. Advances in nuclear waste management are critical in accurately predicting nuclear waste stability in depository areas (e.g., Yucca Mountain) under a variety of harsh soil environments. Accurate modeling of long-term (hundreds of years) kinetics of nuclear waste degradation in soil environments is of utmost importance for the regulatory agencies.

Phytoremediation of toxic metals in contaminated soils with the use of specific plants that actively or passively absorb large quantities of toxic compounds from Rhizosphere has also become an active field of geochemical research due to its environment-friendly character and its relatively low-implementation cost. Mechanistic studies that underline the major factors influencing contaminant absorption capacity of plants are of great importance. Still unresolved are the mechanisms by which low molecular organic plant exudates interact with soil organic carbon during contaminant uptake by the plant.

A comprehensive understanding of aqueous speciation of toxic metalloids in environmental systems is still incomplete. Although lately much research has been focused in this area, this is one emerging research field that will continue to develop as a result of recent advances in the use of hyphenated analytical techniques such as IC-ICPMS or HPLC-ICPMS in environmental research in the future. Speciation of metalloids, such arsenic, chromium, selenium, etc., in soil and water environments are prime examples of innovative concepts and practices that are currently developed for use in environmental geochemical research. Future research on this subject will most likely to focus on better understanding the association of different metalloid species with dissolved organic carbon, and how this complexation influences the overall metalloid availability in soil solution environments.

Characterization and monitoring of surface- and groundwater geochemistry is another area that is continuously evolving due to vast improvements in sensitivity of the new state-of-the-science analytical instrumentation. Research in soil and sediment geochemistry is also an active field, and attempts are being made to better understand and predict fate and transport of contaminants in soils both qualitatively and semiquantitatively. This generation has experienced tremendous advances in analytical methodology that are capable of measuring micro- and nanogram quantities of chemicals and their corresponding toxicities on human and ecological health. A significant number of findings have been reported on new and emerging contaminants in water and soil systems, which were previously unknown to the scientific and regulatory communities. Accordingly, maximum contaminant levels for contaminants in water and soil have been adjusted (mostly lowered) to comply with updated federal regulations.

Such developments in the analytical sciences and better understanding of the toxicology of the emergent contaminants have played a tremendous role in countering the negative effects of anthropogenic input to the environment, which has increased exponentially over the years with increased modernization of the agricultural and industrial practices. Increased toxicant input in the form of excess fertilizers, manures, biosolids, and industrial wastes has resulted in rapid deterioration of soil and water quality. A more comprehensive understanding of all the physical, chemical, and biological factors influencing chemical fate and transport in both unsaturated and saturated media is needed prior to developing the ability to accurately model such processes in a wide range of spatial and temporal scales. Development of such all-encompassing, holistic models will tremendously improve the predictive capabilities that are so needed to maintain a sustainable environment.

High-tech molecular instrumentation techniques, such as XANES (X-ray absorption near edge structure) and EXAFS (extended X-ray absorption fine structure), will continue to serve as robust analytical tools in elucidating sorption/desorption mechanisms of chemicals at the solid/liquid and solid/air interface. In the future, more advanced molecular techniques will allow us to conduct such studies at the micrometer scale (e.g., X-ray spectromicroscopy). The increase in spatial resolution will be accompanied by concomitant advances in understanding complex reactions at the true microscopic level of micron-based and sub-micron particles.

Risk assessment and management provides a new frontier in environmental geochemistry research that generates useful information on the health effects of contaminated environment on humans via a wide range of exposure routes, including direct ingestion of soils, especially by children in playgrounds and residential yards. This has become a more serious problem in recent years because of the "urban sprawl" that the world is experiencing with passing time. Yesterday's farmlands that experienced continuous fertilizer and pesticide application for decades are becoming today's backyards as urban development continues to encroach upon rural landscape. Potential bioaccessibility of metals and metalloids in contaminated soils and their health effects due to prolonged exposure in low doses is one area that has not yet been adequately studied. More comprehensive models are needed to predict metal bioaccessibility in a wide range of environmental conditions. New in-vitro bioaccessibility tests with better predictive capabilities are required to simulate the trends offered by more dependable, yet extremely expensive animal trials. Because estimated risk is a direct function of the input parameters, a better understanding of bioaccessibility is needed to more accurately predict the health risk associated with chronic human exposure to contaminated media.

Future research in environmental geochemistry should focus on the complex interactions of the chemicals and the environmental media at the solid/solution interface in both macro- and microscales. Characterization and monitoring, microbe–contaminant interactions, coupled with modeling, high-performance computing, as well as molecular characterization of submicron colloidal particles will quite emerge as major themes driving the research in environmental geochemistry for the upcoming decades. There is a great need for innovative, effective, yet inexpensive contaminant remediation technologies, which demands more focused research in this area. Inter-disciplinary studies coupling the fundamental biological, chemical, and physical processes are inevitable prerequisites in gaining further insight into such complex reactive processes that control contaminant mobility and transport in the environment.

The need to provide mechanistic answers to unsolved environmental problems related to geochemical processes will possibly shift the current trend of emphasis on short-term (1–2 years) studies to longer-term ($>$5–10 years) monitoring and analysis of environmental processes. With the progress of time, economics will play a more crucial role in determining the applicability of the emerging environmental remediation technologies. Decisions on the feasibility of applicable environmental technologies will be made more and more not only on the basis of science, but on the cost-effectiveness of the methods. Striking the perfect balance between science and will be absolutely necessary to make educated decisions on the appropriate environmental technologies. If financial viability takes precedence over scientific soundness without exercising proper judgment and discrimination, it can turn out to be a slippery slope causing irreversible damage to the environment, thereby hurting human and ecological health.

Inter-disciplinary studies addressing complex organo-mineral processes ranging from the pore scale to the field-scale should be given more attention in environmental geochemical research. The obvious knowledge gap that currently exists between the variety of microbial processes in aquatic environments and their ultimate effects on contaminant fate and transport will be the driving force behind developing more fruitful research collaborations between geochemists and microbiologists. There is a great need for unraveling the heterogeneous and complex interactions of the microbes with the chemicals and the porous media responsible for contaminant immobilization in soils, and/or plume cleanup in contaminated groundwater. Microbial genetics and proteomics should become more commonly used tools in recognizing the specific strains responsible for such biodegradation processes; applying these techniques to genetically modify strains to further accelerate and/or enhance contaminant cleanup need to be a research priority.

Global climate change currently is a major focus area of the scientific community at large. Collaborative efforts in an international scale are already in progress in order to understand the rates and processes that are responsible for causing climate change. For example, a lot of research is currently being done and some significant policy implementation has been made in recent years to reduce greenhouse gas emissions. Geochemists and atmospheric scientists will continue to combine their skills and knowledge to investigate the mechanisms behind greenhouse gas emissions in a wide range of spatial scales, from microbial activities in the minute soil pores to the role of rapid industrialization in continuous generation of Sox, Nox, and acid rain.

New inter-disciplinary collaboration pathways will open up between the environmental geochemists and biomedical scientists as more linkages continue to be established between pathogenic compounds and infectious agents in the environment and their potential human exposure. One such infectious agent that has received serious attention in recent years is the prions, which have proved to be rather persistent in soils. Prions cause transmissible spongiform encephalopathies (TSE) in cattle (the "mad cow" disease). One of the major sources of cattle exposure to prions is the contaminated soil, and the leading cause of human exposure to prions is via consumption of the contaminated meat. The soil can be contaminated by causative agent as a result of (i) accidental dispersion from storage plants of meat and bone meal, (ii) incorporation of bone meal into fertilizers, (iii) spreading of effluents of slaughterhouses, and (iv) burial of carcasses of contaminated animals. A thorough understanding of the geochemical behavior of prions in various environmental systems and their subsequent toxicological effects on bovine or humans is urgently needed.

There are many other areas of environmental and biomedical research where the input of geochemists are not only advantageous but absolutely required. A lot of research is currently being done, but a lot more needs to be done with passing time. Overall, the future seems promising for environmental geochemists as there are major unresolved issues and challenges that need to be met in order to ensure environmental sustainability, protection of natural ecosystems, and for the protection of human health caused by exposure to toxic compounds in soil, plants, water, and air.