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EDITED BY
Karen Hudson-Edwards,
University of Exeter, United Kingdom

REVIEWED BY
Gabriel Michael Filippelli,
Indiana University, Purdue University Indianapolis, United States

*CORRESPONDENCE
W. Berry Lyons,
lyons.142@osu.edu

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Grand Challenges in environmental geochemistry

W. Berry Lyons*

School of Earth Sciences and Byrd Polar and Climate Research Center, The Ohio State University, Columbus, OH, United States

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In his text book entitled, Principles of Environmental Geochemistry, Nelson Eby, (2004) states that "environmental geochemistry involves an understanding of how natural systems work and the human impact on these systems". He also states that the combination of both natural process and anthropogenic activities need to be investigated if environmental problems are to be understood and solved. Many of the major challenges facing humanity today involve the application of environmental geochemistry. These include water quantity and quality issues, the impact of agricultural management practices, such as fertilizer application and soil erosion, the ramifications of human perturbations on the carbon cycle, including all the impacts of a warming climate, the exchange of chemicals among all the surface reservoirs of the planet (crust, hydrosphere, atmosphere and biosphere), and the relationship of chemical cycling on ecosystem and human health. Increased population growth, urbanization, landscape modification, and the association of chemical changes with these activities have severely affected the geochemistry of Earth's surface reservoirs and have led to the realization that the consequences of these activities degrade sustainability of human survival. Environmental geochemistry is fundamentally interdisciplinary, as a knowledge of both earth and environmental sciences is needed, along with a strong underpinning in basic chemistry. As Eby has correctly stated, the need to study the impact and relationship of human behavior on natural processes, and *vice versa*, encapsulates the discipline of environmental geochemistry and in my view supports the justification of this Section within the overall major discipline of geochemistry.

Thus, the first Grand Challenge of Environmental Geochemistry is to promote and encourage environmental geochemistry as a topic unto its own. As Rob Mason pointed out in his Specialty Grand Challenge for Frontiers in Environmental Chemistry-Inorganic Pollutants, there are many journals that publish a wide range of papers with an environmental chemistry focus (Mason, 2020), but what about environmental science from an earth sciences perspective? I recently scanned through the research articles published in 2020 in two of the most highly valued geochemistry journals, Geochimica et Cosmochimica Acta and Chemical Geology, and I roughly estimated only a very small number (<5%) dealt with anthropogenic topics or environments. In my view, a specialized venue for environmental geochemical science is clearly missing, because it is estimated that by 2050 the human population will grow to 10 billion people (United Nations, 2017), and a US National Research Council report stated that "even identifying 'natural' landscapes on the planet is now difficult" (NRC, 2010). This same report asked questions about the long-term legacy of human impacts on Earth's surface environments and acknowledged the need to address future environment impacts on Earth under the guise of coupled human-landscape dynamics. Although this report was directly aimed a geomorphic and Earth surface process, the same arguments could be made for the geochemical aspects and dynamics of the Earth's critical zone and biogeochemical cycles. Not only have humans surpassed nature as the most quantitative mover of Earth materials (Hooke, 1994), but humans have also been major disrupters of most of the elements in the periodic table (Klee and Graedel, 2004).

What are some areas that this Section of the journal acknowledges as current and future areas of great interest? Until recently the investigation of human-made and human managed landscapes has primarily been the domain of engineers and agricultural scientists. In the past 20 years I have become much more interested in the geochemistry and biogeochemistry of human made and managed landscapes. As the human population continues to increase, the need for more food, and for water to grow that food will become a major environmental challenge. The impact of excess nutrients, N and P, from agricultural lands on water quality has clearly been documented on all continents except Antarctica on local, regional, and in some cases, even continental scales (Fowler et al., 2013; McDowell et al., 2020; Zou et al., 2022). However, elements, other than N and P can be introduced *via* fertilizer and manure (McBride and Spiers, 2001; Gardner et al., 2022; Rogers et al., 2022). These minor and trace elements have, in general, been less studied. In addition, many agricultural lands are losing soil much faster than it is being produced by natural process (Montgomery, 2007). Globally agricultural lands are a major source of sediments to the aquatic environment and the chemicals associated with this material are redistributed by stream and river systems (Wilkinson and McElroy, 2007). Agricultural practices such as tilling and the application of ammonium fertilizer, and its subsequent oxidation, also can lead to elemental loss from soils (Pierson-Wickmann et al., 2009). The planting and harvesting of crops like corn and soy can lead to Si loss from soils (Vandevenne et al., 2012; Carey and Fulweiler, 2016; Sethna et al., 2022).

In 2018 the global human population had 4.2 billion living in urban areas with another 2.5 billion expected by 2050. It has been estimated that urban land area is growing at a rate as high as ~9,700 km^2 per year, a rate faster than population growth itself (Liu et al., 2020). High population densities in cities with their subsequent increases in consumption and waste dominate geochemical cycles in relatively small areas (Lyons and Harmon, 2012). The increased flux of chemicals coupled with impervious surfaces and engineered water systems in urban landscapes have drastically changed the natural geochemical and hydrological cycles in these areas. The input of both legacy and present-day chemicals from vehicular operation such as engine and tire wear, and fossil-fuel burning residues impact degrade soil and water quality in urban regions (Gardner and Carey, 2004; Filippelli et al., 2015; Long et al., 2015; Kaushal et al., 2020). As the demand for more safe potable water increases, because of urban growth and climate change, a need to understand the processes and dynamics of urban geochemistry will increase. The geochemistry of human engineered and managed systems will become even more societally pertinent in the future, and this Section of Frontiers in Geochemistry is an ideal venue for important papers on these topics.

Another focus of environmental geochemistry growing in importance is the impact of environmental conditions on human health. It has recently been estimated that in 2019, ~9 million people died from environmental pollution (Fuller et al., 2023). This topic was championed by the great Clair Patterson and his steadfast, unyielding pursuit of documenting global Pb pollution in the 1960s and 70s, and Pb's potential impact on human health (Settle and Patterson, 1980). With the development of more sophisticated analytical tools along with the application of Earth sciences approaches to health problems, there has been more and more work done on this topic. A few very recent examples demonstrating the breadth of this work include: Dietrich et al., 2021; Coyte et al., 2022; Rossi et al., 2022; Neumann et al., 2020. These diverse studies range from the investigation of environmental conditions on human bone health, to using geochemical tools to track pollution sources, to the impacts of both natural phenomena such as volcanic eruptions, to the potential influence of deicing salts on hypertension.

As society moves to non-carbon based transportation and energy systems, we will need to establish the environmental impact of mining all the Cu, Co, Ni, Li, and REEs that will be required for the development of this alternative energy system. For example, it has been estimated that globally total Cu demand will double from ~21 million tons in 2021 to ~49 million tones in 2035, with ~21 million tons needed for the energy transition markets (Global, 2022). Research quantifying the transport and fate of mining and manufacturing waste is not new to environmental geochemistry, but the amount of these elements that will be needed and the short time frame that is currently required to extract them will certainly add new problems for the minimization of pollution from these operations.

These topics that I have briefly discussed above are meant to be examples of the types of research areas that will play a significant role in environmental geochemistry in the coming years. There are other, less applied, areas of research importance that represent areas of need for our development of a better understanding of environmental geochemical processes and the fate and transport of chemicals.

All of the topics above are focused on the impact of humans and human activities on low-temperature geochemical and biogeochemical processes. There are many environmental geochemical problems which are more related to natural processes that affect the surficial geochemistry of the planet and still remain of much interest to our community. Our new journal will welcome papers on these topics as well as the more applied ones. Over the past 2 decades Earth scientists have succeeded in forging a home for the investigation of soils, which was once the primary domain of agronomists and others usually housed in schools or departments of agriculture. In the US, the National Science Foundation has supported a series of Critical Zone Observatories focused on soil-water-atmosphere and biological interactions (Lin et al., 2011; Brantley et al., 2017). This type of research is now international in scope (e.g., Floury et al., 2019), and reflects the community's recognition that the understanding of soil processes is an important task for Earth and geoscientists. The documentation and elucidation of surficial processes continues to be an important focus of the low-temperature geochemical community. For example, the relationship between physical weathering and erosion, rates of chemical weathering, and the quantification of acid sources for weathering are still topics of much interest at many temporal and spatial scales (e.g., Ferrier and West, 2017; Schachtman et al., 2019; Bufe et al., 2021; Tipper et al., 2021). The geochemical fate of landscape surfaces and shallow depths resulting from the rapidly retreating cryosphere and the transport and fate of the products will also drive much research interest in the next few decades (Deuerling et al., 2018; Cuozzo et al., 2020; Hatton et al., 2021). The increase in dust emissions and deposition will also be an important topic that this journal hopes to better document in the future (Hooper and Marx, 2018). Another potential topic that has fascinated me over the past couple of decades is better relating hydrological connectivity and high frequency changes in aquatic geochemistry (McGuire and McDonnell, 2010; Neal et al., 2012). This list is not meant to be all inclusive, but just provide some research topics of interest to me that could find a home in the journal.

Finally, the on-going scientific need to better manage and provide access of scientific data, for both scientific community and lay usage is a very important challenge for all of us. Just this past September the US White House Office of Science and Technology Policy provided guidance directed toward research funded by federal grants, to make data publicly available by the latter portion of 2025. The importance of open-access journals such as this one will provide another venue for Earth and environmental scientists working in the field of environmental geochemistry, in particular, to publish open access results.

The launch of a journal section within Frontiers in Geochemistry is meant to provide a journal focused on chemical problems and research tied to the Earth's surface and its various surficial reservoirs of chemical elements. Many of the research areas encompassed by the scope of this Section have great societal significance, and hopefully the answers to these problems will lead to a more environmentally sustainable planet. The merging of geochemistry and environmental science to better assess the interaction between anthropogenic and natural process, as Nelson Eby envisioned in the writing of his textbook, provides the grandest challenge for us, as we launch this Environmental Geochemistry Section of Frontiers in Geochemistry.

Author contributions

WBL is the exclusive author of this Specialty Grand Challenge article.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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