The Impact of Geochemistry

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As geochemists and mineralogists, we are well aware of the impact of our science. We can often reel off examples of how our discoveries have influenced industry and improved humankind's knowledge about how the Earth works, as well as how natural and anthropogenic processes have led to its present state. Moreover, because of a century of analytical developments and conceptual breakthroughs, geochemists are now versatile and can now work across the entire spectrum of the Earth sciences. However, we are not so good at promoting the social and economic impacts of geochemistry.

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EXAMPLES OF GEOCHEMICAL IMPACT

This issue of *Elements* demonstrates the application of geochemistry to a variety of societally and economically important areas, including, (1) exploration for and sustainable exploitation of mineral deposits; (2) environmental mineralogy, the interaction of microbial organisms with minerals and the close links between minerals and materials science, particularly in the areas of energy-related materials and nuclear waste disposal; (3) the use of geochemistry as a guide to solving environmental problems in cities, using London (England) as a case study; (4) the use of stable isotopes to detect adulterated foods and beverages and; (5) to detect and monitor the progress of diseases in humans. A significant driver for the research described in all of these articles is analytical achievement and translating this to a societal application. There is no doubt that academic and government geochemists working together with the analytical industry have pushed the limits of discovery-mode science, which has led to applications that are routinely used to benefit society and the economy.

The papers in this issue focus on the prosperity of our society and our standard of living. Our quality of life is directly related to our ability to find, exploit, and manage our metal and mineral resources. The first in this series of papers (Kyser et al. 2015) points out that metal and mineral deposits are, in fact, geochemical anomalies and, as such, applied geochemistry plays a critical role throughout the mineral resources value chain from early-stage exploration to mine closure. Minerals also help us design new materials for advanced technologies, ranging from energy production to management of contaminated areas and the ultimate disposition of wastes. The second paper (Calas et al. 2015) discusses evidence of the environmental importance of nanomaterials, non- and poorly crystalline phases and interactions between minerals and ubiquitous microbial activity. It is probable that in both of these cases geochemistry will lead to further economic advantages to ensure a more sustainable planet with cleaner exploration strategies and mineral extraction and to better environmental cleanup activities.

The challenges and importance of communication between scientists and policy makers are featured in the third paper (Ludden et al. 2015). This paper also examines how the application of geochemical tools and approaches can provide evidence to underpin decision-making, as well as defining solutions to environmental problems in cities; in this case London and its surroundings. The paper questions our ability to move from the provision of geochemical evidence to describing a solution and then convincing politicians to put this into practice.

Ehrlinger et al. (2015), in the fourth paper, demonstrate how the classic geochemical technique of isotopic tracing and technology can be applied to two sectors of relevance to society: food authenticity and public safety. One involves the use of stable isotopes as biogeochemical markers, which can allow us to tell if food and beverages have been adulterated and so protect consumers from fraud. A second theme involves stable isotopes in areas of interest to law enforcement to determine origins and travel histories of unidentified murder victims and tracing the origins of illicit drugs. Such advances in forensics could only have been achieved by expansion from the traditional applications of mass spectrometry.

The final paper in the series (Albarède 2015) discusses a highly innovative and promising area for geochemistry: diagnosing and monitoring the progression of disease in humans. The conventional stable isotope systems of C, H, O, N, and S are rarely used for medical purposes because they lack specificity. However, new medical applications of less conventional stable isotopes are arising, such as Fe in heme cores, Cu in erythropoiesis (red blood cell production), and Ca in bones. These "unconventional" isotopes are increasingly being used because they have a much smaller number of specific functional roles in biology and because they have a shorter turnover rate in the body. The whole periodic table is now opening up to medical and environmental applications thanks to isotope geochemistry.

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The hydrocarbon sector is not directly featured in this issue as it was the focus of other recent *Elements* issues on unconventional hydrocarbons (*Elements*, v10, n4, 2014) and carbon capture and sequestration (*Elements*, v4, n5, 2008). The geochemical results presented by the authors in those issues further demonstrate the key role that our science has had on advancing the industrial sector, including the definition of geochemical baseline conditions, monitoring environmental effects, and enabling sustainable ways of material extraction.

RESEARCH WITH A PURPOSE: THE FUTURE

All of these examples illustrate how geochemists are involved in the Earth's future state, summarized in the concept of *natural capital* (Schumacker et al. 1973; Helm 2015). Natural capital is defined as the world's stock of natural resources (land, air, water, living organisms) that provides us with goods and services for survival and well-being. Geochemists are investing in the world's natural capital by providing solutions to problems that economically, socially, and physically threaten our well-being.

Society now has expectations from scientists that it did not have a few decades ago when the focus was primarily on basic research. Although a significant amount of innovation is based on long lead-time basic-research discoveries (e.g. lasers, DNA, polymers etc.), society demands more immediate social and economic benefits from current scientific research endeavors. The explicit need to demonstrate the impact of our science is now being used in many nations as a means by which funding is allocated. The UK Research Evaluation Framework (REF), which was completed in 2014, required university departments to submit impact cases that were evaluated and then integrated into the final research score of a department (or groups of departments). These scores were then used to define funding levels for a five-year period. In all, nearly 7000 impact cases were delivered, and in the Earth Systems and Environment Sciences sector, 171 cases from ~40 universities were evaluated.

While not representing the evaluated output, we have produced a word frequency diagram from the titles of the impact case studies (Fig. 1; Van Noorden 2015). Although this is a UK-centric view, it does provide a general indication of impact priorities in geoscience departments. Words most frequently used include *climate*, *change*, *environmental*, *management*, and *sustainable*. Interestingly, the words used significantly less are oil, gas, nuclear, waste, and water. The focus from common and material nouns to abstract nouns denoting processes may reflect a change towards the concept of natural capital. One hope is that associated industries are able to accommodate the number of students produced in geoscience departments in these endeavors.

Figure 1 A word frequency diagram for the titles of the impact case studies from geoscience departments that were submitted to the 2014 UK Research Evaluation Framework. Words used more frequently are represented by larger font size and darker color. Grey text indicates the number of times that word was used.

COMMUNICATION & TRANSLATION

Overall, one of the biggest challenges we face as geoscientists is communication. Our scientific results cannot only provide the evidence to underpin decision-making, they are also essential for building solutions to environmental problems. Yet, our ability to move from the provision of evidence to describing a solution, and then convincing politicians and implementing agencies to put this solution into practice, is in question. This is a problem that crosses all of the activities of geochemistry when we, as scientists, identify a problem, be it environmental or health related. This translation of our science needs to become second nature. Just as medical scientists search for both the highest-impact publication for results and the means of translating this into a pharmacological solution, we as geochemists should not simply move onto the next interesting problem until we have found a way to move the results into innovation.

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