

Elements

An International Magazine of Mineralogy, Geochemistry, and Petrology

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A woman wearing a high-visibility yellow and blue safety vest is using a soil sampling tool on a green lawn. In the background, the Big Ben clock tower and other London buildings are visible under a blue sky with some clouds. A red double-decker bus is also present in the background.

Social and Economic Impact of Geochemistry

JOHN LUDDEN, FRANCIS ALBARÈDE, and MAX COLEMAN, Guest Editors

Mineral Exploration, Mining, Remediation

Environmental Mineralogy

Geochemistry of London

Stable Isotopes: Food to Forensics

Medical Isotope Metallomics



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An International Magazine of Mineralogy, Geochemistry, and Petrology



Volume 11, Number 4 • August 2015

ABOUT THE COVER: British Geological Survey (BGS) staff geologist taking a sample in front of the United Kingdom's Houses of Parliament (London) as part of the BGS London Earth project (see pages 253-258 in this issue).

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Elements is published six times a year. Individuals are encouraged to join any one of the participating societies to receive *Elements*. Institutional subscribers to any of the following journals—*American Mineralogist*, *Clay Minerals*, *Clays and Clay Minerals*, *Mineralogical Magazine*, and *The Canadian Mineralogist*—also receive one copy of *Elements* as part of their 2015 subscription. Institutional subscriptions are available for US\$165 (US\$180 non-US addresses) a year in 2015. Contact the executive editor (jross.elements@gmail.com) for information.

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The Mineralogical Society of America is for individuals interested in mineralogy, crystallography, petrology, and geochemistry. Founded in 1919, the Society promotes, through research, education, and publications, the understanding and application of mineralogy by industry, universities, government, and the public. Membership benefits include *Elements* magazine, access to the electronic version of the *American Mineralogist*, as well as discounts on journals, Reviews in Mineralogy & Geochemistry series, textbooks, monographs, reduced registration fees for meetings and short courses, and participation in a society that supports the many facets of mineralogy.

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The Mineralogical Society of Great Britain and Ireland is an international society for all those working in the mineral sciences. The Society aims to advance the knowledge of the science of mineralogy and its application to other subjects, including crystallography, geochemistry, petrology, environmental science and economic geology. The Society furthers its aims through scientific meetings and the publication of scientific journals, books and monographs. The Society publishes *Mineralogical Magazine* and *Clay Minerals*. Students receive the first year of membership free of charge. All members receive *Elements*.

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The Mineralogical Association of Canada was incorporated in 1955 to promote and advance the knowledge of mineralogy and the related disciplines of crystallography, petrology, geochemistry, and economic geology. Any person engaged or interested in these fields may become a member of the Association. Membership benefits include a subscription to *Elements*, reduced cost for subscribing to *The Canadian Mineralogist*, a 20% discount on short course volumes and special publications, and a discount on the registration fee for annual meetings.

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The Clay Minerals Society (CMS) began as the Clay Minerals Committee of the US National Academy of Sciences - National Research Council in 1952. In 1962, the CMS was incorporated with the primary purpose of stimulating research and disseminating information relating to all aspects of clay science and technology. The CMS holds annual meetings, workshops, and field trips, and publishes *Clays and Clay Minerals* and the CMS Workshop Lectures series. Membership benefits include reduced registration fees to the annual meeting, discounts on the CMS Workshop Lectures, and *Elements*.

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The Geochemical Society (GS) is an international organization founded in 1955 for students and scientists involved in the practice, study, and teaching of geochemistry. Our programs include cohosting the annual Goldschmidt Conference™, editorial oversight of *Geochimica et Cosmochimica Acta (GCA)*, supporting geochemical symposia through our Meeting Assistance Program, and supporting student development through our Student Travel Grant Program. GS annually recognizes excellence in geochemistry through its medals, lectures, and awards. Members receive a subscription to *Elements*, special member rates for *GCA* and *G-cubed*, and publication and conference discounts.

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Founded in 1985, the **European Association of Geochemistry** is a non-profit organization dedicated to promoting geochemistry internationally. The society is an active and dynamic organization of over 2800 members that leads the European Goldschmidt conference organization, publishes *Geochemical Perspectives* and *Geochemical Perspectives Letters*, recognizes scientific excellence through awards, organizes a Distinguished Lecture Program, sponsors workshops and conferences in Europe, supports students and Early Career Scientists, publishes job opportunities, newsletters, blogs, press releases and partners with other learned societies to strengthen geochemistry internationally.

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The International Association of Geochemistry (IAGC) has been a pre-eminent international geochemical organization for over 40 years. Its principal objectives are to foster cooperation in the advancement of applied geochemistry by sponsoring specialist scientific symposia and the activities organized by its working groups and by supporting its journal, *Applied Geochemistry*. The administration and activities of IAGC are conducted by its Council, comprising an Executive and ten ordinary members. Day-to-day administration is performed through the IAGC business office.

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The Société Française de Minéralogie et de Cristallographie, the French Mineralogy and Crystallography Society, was founded on March 21, 1878. The purpose of the Society is to promote mineralogy and crystallography. Membership benefits include the *European Journal of Mineralogy, Elements*, and reduced registration fees for SFMC meetings.

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The Association of Applied Geochemists is an international organization founded in 1970 that specializes in the field of applied geochemistry. It aims to advance the science of geochemistry as it relates to exploration and the environment, further the common

interests of exploration geochemists, facilitate the acquisition and distribution of scientific knowledge, promote the exchange of information, and encourage research and development. AAG membership includes the AAG journal, *Geochemistry: Exploration, Environment, Analysis*; the AAG newsletter, *EXPLORE*; and *Elements*.

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The Deutsche Mineralogische Gesellschaft (German Mineralogical Society) was founded in 1908 to "promote mineralogy and all its subdisciplines in

teaching and research as well as the personal relationships among all members." Its great tradition is reflected in the list of honorary fellows, who include M. v. Laue, G. v. Ischermak, P. Eskola, C. W. Correns, P. Ramdohr, and H. Strunz. Today, the Society especially tries to support young researchers, e.g. to attend conferences and short courses. Membership benefits include the *European Journal of Mineralogy, GMit*, and *Elements*.

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The Società Italiana di Mineralogia e Petrologia (Italian Society of Mineralogy and Petrology), established in 1940, is the national body representing all researchers dealing with mineralogy, petrology, and related disciplines. Membership benefits include receiving the *European Journal of Mineralogy, Plinius*, and *Elements*, and a reduced registration fee for the annual meeting.

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The International Association of Geoanalysts is a worldwide organization supporting the professional interests of those involved in the analysis of geological and environmental materials. Activities include the management of proficiency-testing programmes for bulk-rock and micro-analytical methods, the production and certification of reference materials and the publication of the Association's journal, *Geostandards and Geoanalytical Research*.

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The Polskie Towarzystwo Mineralogiczne (Mineralogical Society of Poland), founded in 1969, draws together professionals and amateurs interested in mineralogy,

crystallography, petrology, geochemistry, and economic geology. The Society promotes links between mineralogical science and education and technology through annual conferences, field trips, invited lectures, and publishing. Membership benefits include subscriptions to *Mineralogia* and *Elements*.



Affiliated Societies

The International Mineralogical Association, the European Mineralogical Union, and the International Association for the Study of Clays are affiliated societies of *Elements*. The affiliated status is reserved for those organizations that serve as an "umbrella" for other groups in the fields of mineralogy, geochemistry, and petrology, but that do not themselves have a membership base.

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The Sociedad Española de Mineralogía (Spanish Mineralogical Society) was founded in 1975 to promote research in mineralogy, petrology, and geochemistry. The Society organizes annual conferences and furthers the training of young researchers via seminars and special publications. The *SEM Bulletin* published scientific papers from 1978 to 2003, the year the Society joined the *European Journal of Mineralogy* and launched *Macla*, a new journal containing scientific news, abstracts, and reviews. Membership benefits include receiving the *European Journal of Mineralogy, Macla*, and *Elements*.

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The Swiss Society of Mineralogy and Petrology was founded in 1924 by professionals from academia and industry and amateurs to promote knowledge in the fields of

mineralogy, petrology, and geochemistry and to disseminate it to the scientific and public communities. The Society coorganizes the annual Swiss Geoscience Meeting and publishes the *Swiss Journal of Geosciences* jointly with the national geological and paleontological societies.

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The Meteoritical Society is an international organization founded in 1933 for scientists, collectors, and educators to advance the study of meteorites and other extraterrestrial materials and their parent asteroids, comets, and planets. Members receive our journal, *Meteoritics & Planetary Science*, reduced rates for *Geochimica et Cosmochimica Acta*, which we cosponsor, the *Meteoritical Bulletin*, and *Elements*. We organize annual meetings, workshops, and field trips, and support young planetary scientists worldwide. Through our medals and awards, we recognize excellence in meteoritics and allied fields.

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The Japan Association of Mineralogical Sciences (JAMS) was established in 2007 by merging the Mineralogical Society of Japan, founded in 1955, and the Japanese Association of Mineralogists, Petrologists, and Economic Geologists, established in 1928. JAMS covers the wide field of mineral sciences, geochemistry, and petrology. Membership benefits include receiving the *Journal of Mineralogical and Petrological Sciences (JMPS)*, the *Ganseki-Koubutsu-Kagaku (GKK)*, and *Elements*.

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BOUNTIES FROM THE EARTH



Gordon Brown

Most of us, including me, use the products of modern technology without fully appreciating what raw Earth materials are required to make a cell phone, a modern internal combustion engine, an aluminum beer can, or the concrete used in buildings. Moreover, many of us don't know much about the processes by which these common products and materials are made, such as the electrolytic production of aluminum from bauxite (discovered by Hall and Héroult in 1886), or the production of electronic-grade, single-crystal silicon needed to make silicon semiconductors. In a more general sense, many of us don't fully appreciate the role played by geochemical and mineralogical processes in concentrating Nature's bounty of raw materials into the form of metal, mineral, and hydrocarbon deposits that are increasingly needed by the 7.4 billion humans currently inhabiting Earth.

My interest in the raw materials needed to build the structures and products of ancient and modern civilization began when I taught my first mineralogy course at Princeton University in 1971. I realized I could make the study of minerals more interesting by discussing some of their ancient uses. For example, did you know that Roman soldiers were paid salt rations and that this led to the saying "a person is not worth his salt," as well as to the word "salary" (Hurlbut 1970)? Did you know that lead (symbol Pb, from the word "plumbum") smelted from galena was used by Romans to make water pipes—hence the origin of the word "plumbing"—as well as to make lead containers for storing their wine and for preparing sapa, which was a sweet syrup made by boiling acidic wine in lead containers? The sapa, consisting mainly of lead acetate, was added to wine to sweeten it (Lessler 1988). Did you know that the Romans made primitive cement by burning limestone to produce quicklime and that a controversy still exists about whether the Great Pyramids of Giza were made either by molding limestone blocks in place from a geopolymeric concrete or by quarrying limestone blocks and moving them into place (Folk and Campbell 1992; Barsoum et al. 2006)?

My interest in the modern uses of minerals was further piqued in 1984 when I visited the British Museum of Science in London (UK) and saw a fascinating exhibit showing the minerals that are needed to fabricate the components of an internal combustion engine. That well-designed exhibit underscored the fact that modern society is profoundly impacted by the minerals and rocks that we extract and then process into the various raw materials needed to make cement, window and flat-panel glass, glass ceramics, aluminum and steel, and modern electronic devices such as cell phones and the MacBook Pro I used to write this editorial.

Internal combustion engines are complicated, but not nearly as complicated as the iPhone in my pocket. When one "googles" the raw materials needed to build an iPhone, a list of components is usually found, but little information is given about the minerals or elements that go into building the circuit board, SIM card, batteries, and other iPhone components. So, we tend not to think about the raw materials necessary to manufacture such devices. After some digging, however, I found the figure below (FIG. 1) showing the rare earth elements (REEs) needed to make key components of an iPhone. These and other REEs are concentrated by geochemical processes in economic deposits of REE-containing minerals, notably bastnaesite, monazite, xenotime, and lateritic ores in which REEs are adsorbed onto clay minerals. This is but one example of how geochemistry and mineralogy have had a profound impact on modern civilization. Can you imagine living in the modern world without a cell phone?

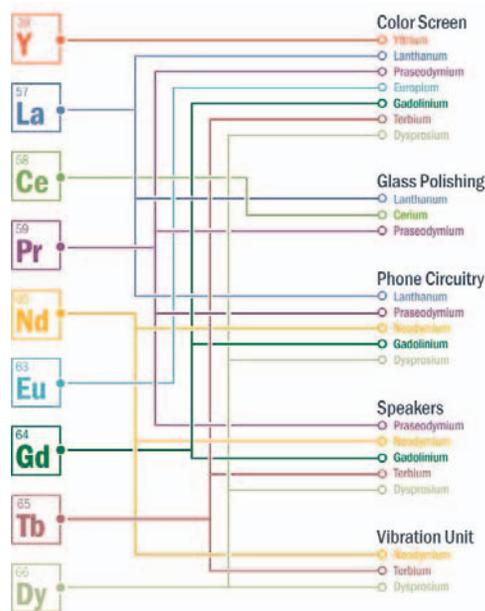


FIGURE 1 The nine rare earth elements used in the components of an iPhone. IMAGE REPRODUCED WITH PERMISSION FROM GREENE (2012).

This issue of *Elements* provides examples of the impacts of geochemistry and mineralogy on modern civilization, including the discovery and environmentally sustainable development of metal and mineral deposits, the importance of minerals and mineral-microbe interactions to environmental problems, the symbiotic relationship between mineralogy and materials science, in addition to the importance of geochemistry in understanding anthropogenic impacts on chemical contamination of groundwater, surface waters, soils, and air at major urban centers. Also included are thought-provoking articles describing the use of stable isotopes to detect adulterated foods, to conduct forensic investigations of criminal activities, and to detect and

Cont'd on page 228

THIS ISSUE

Geoscientists impact society. They find new mineral resources, mitigate environmental problems, create designer materials for industrial applications, advance medical testing methods, track food industry products, aid in law enforcement activities, and so much more. One can't say that "the sky is the limit" for geoscientists, for they are also studying the worlds beyond our planet and applying that knowledge to benefit society. The authors in this issue present several exciting facets of the seemingly limitless potential of our science. Ludden et al. (pp 253–258) also remind us that a geoscientist's job involves more than expanding the scientific knowledge base. It is our responsibility to effectively communicate our knowledge and, ultimately, to translate it into answers and solutions that can be used by industry, society, and policymakers. It is a difficult job but, if done well, the outcome will surely be beneficial to the future of our science and society.

THE IMPACT OF ELEMENTS

This issue is focused on the impacts of geochemistry, so it is a good occasion to update our readers on the "impact" of *Elements*. *Elements* was designed to impact our community by delivering a high-quality scientific magazine that delivers thematic review articles, opinion pieces, society news articles, advertisements for products and services related to our community, job postings, book reviews, and topical features (see below).

The standard yardstick by which to measure "impact" is Thomas Reuters' Impact Factor and article citation rates. The 2015 Journal Citation Reports®, released in June, indicated that *Elements'* 2014 impact factor is 4.463, which makes it rank 3rd among mineralogy journals and 7th among geochemistry and geophysics journals. In 2014, our 379 citable articles had 1866 citations, giving an average of 4.9 per article. *Elements* has had over 8600 citations since its inaugural issue in 2005.

As of August 2015, the most highly cited issues since the time of publication are:

- v3n1 – "Zircon, Tiny but Timely" (754)
- v2n2 – "Arsenic" (451)
- v4n5 – "CO₂ Sequestration" (403)
- v1n5 – "Large Igneous Provinces" (356)
- v3n4 – "Frontiers in Textural and Microgeochemical Analysis" (340)



These numbers, along with the continued commitment of the 17 participating societies to produce this magazine, the high-quality products and services advertised in our issues, and the over 15,000 members who continue to receive each issue are just a few indicators that *Elements* magazine is making a positive impact on our scientific community.

ELEMENTS FEATURES

Elements is your magazine, and you can contribute to the many features—some published regularly, others from time to time. Unless otherwise indicated, send your ideas and contributions to Jodi Rosso (jrosso.elements@gmail.com).

People in the News highlights the accomplishments of members of our community: awards they have received, especially outside our community, or exciting new projects in which they are engaged.

Triple Point raises issues of broad interest to the readers of *Elements* and explores different aspects of our science (teaching, publishing, historical aspects, etc.), our societies, funding, policy, and political issues.

The ***Elements'* Toolbox** presents new technological developments of interest to our readers. You can send your ideas and suggestions for coverage to Michael Wiedenbeck (michawi@gfz-postdam.de).

CosmoElements keeps us in touch with exciting discoveries in cosmochemistry, provides short articles that can be used in the classroom, and offers reports on space missions that carry geochemical and mineralogical instruments. Contact Cari Corrigan (corrigan@si.edu).

A Life in Science is dedicated to supporting the career aspirations and progress of geoscientists, from students to retired professionals. It focuses on ways to make your life easier and to help you establish a satisfying career in the geosciences. Contact Penny King (penny.king@anu.edu.au).

Travelogue: Have you done fieldwork in, or traveled to, an exotic location? Consider writing an account of your experiences.

Parting Shots fills one of the back pages, and its job is to entertain, to provide something lighter than all the serious stuff in the earlier pages. Intriguing, beautiful, or baffling photographs take the reader on a relaxing voyage into the web of connections that makes the realm of *Elements* so enthralling. Contact Ian Parsons (ian.parsons@ed.ac.uk).

Mineralogy Matters is dedicated to promoting the importance of the subject of mineralogy. Contact David Vaughan (david.vaughan@manchester.ac.uk).

Jodi Rosso, Executive Editor

EDITORIAL *Cont'd from page 227*

follow the progress of human diseases such as cancer. An overriding message in these articles is the importance of analytical methods that can detect low concentrations of elements and isotopes and map their distribution in solids, soils, water, air, food, and human tissue. These articles illustrate very well the impact that geochemistry is having on modern society through well-chosen examples and case studies.

In closing, let's consider cement, one of the most important commodities derived from natural raw materials. Portland cement, the most common variety, is made by heating impure limestone (i.e. containing aluminosilicates) with additives such as shale, sand, slag, fly ash, bauxite, and iron ore, all of which then produces a material called klinker. A small amount of gypsum or anhydrite (typically 5% of the total) is added to the klinker, and the mixture is finely ground and mixed with water. Complex chemical reactions occurring in the klinker–water mixture result in new phases, including needle-shaped crystals of ettringite, a sulfate that adds great strength to Portland cement (Cotterill 2008). It's somewhat mind-boggling to find out that 4,180,000,000 metric tonnes of cement (mostly Portland cement) was used by humans in 2014 (USGS 2015), with the three largest producers—China, India, USA—responsible for consuming 59.8%, 6.7%, and 2.0%, respectively.

Earth's bounty of natural resources will continue to be utilized by humans to build our infrastructure and transportation systems, to power our society, and to develop even more useful personal devices than the cell phone. However, we must continue developing and practicing environmentally sound methods of extracting this bounty.

Gordon Brown, Stanford University

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2014 ROBERT WILHELM BUNSEN MEDAL TO CHRIS HAWKESWORTH



The 2014 Robert Wilhelm Bunsen Medal of the European Geosciences Union (EGU) was awarded to **Chris J. Hawkesworth** of Bristol University (UK) for his outstanding contributions to a vast spectrum of geochemical subjects, most notably his work on the history and evolution of the continental crust.

Chris has addressed and answered an enormous range of geological questions using the powerful geochemical tools of trace elements and isotopes. His diverse interests have ranged from dating major archeological episodes, tracing brain disease using zinc isotopes, and monitoring the consequences of a "Snowball Earth" using isotopes of calcium. His chief focus, however, has been on global petrological problems, where his most prominent contributions have furthered our understanding of the history and evolution of the continents. He has elucidated the genesis of key crustal components, ranging from arc lavas to continental flood basalts and granites, both ancient and modern. He has documented the development and modification of the mantle lithosphere on which the continents rest, and he has unraveled the long-standing tangle of accretion and cannibalism in models of crustal growth.

Chris has often been at the forefront of the development of new techniques to solve old problems. He was one of the first to recognize and exploit the potential of neodymium isotopes to trace the rate and mechanism of crust formation. He used mass-spectrometric analysis of uranium-series disequilibrium to investigate the rates and styles of processes in subduction zones, and he has used osmium isotopes to explore the continental lithospheric mantle. Most recently, he has harnessed the power of laser-ablation hafnium analyses in zircon to reconstruct the evolution of the continental crust.

Chris has been involved in the creation and development of three influential isotope laboratories: at the Open University (UK); the University of St Andrews (UK); and his current place of work, Bristol University. These labs have trained and welcomed a huge number of researchers who are now active throughout the world. He has served the Earth science community through notable editorships, participation in many international review panels and the Council of the European Union of Geosciences (now EGU) from 1997 to 2003.

2014 EMU MEDAL FOR RESEARCH EXCELLENCE AWARDED TO ENCARNACIÓN RUIZ-AGUDO



The European Mineralogical Union (EMU) Medal for Research Excellence has been awarded to **Encarnación Ruiz-Agudo**, Department of Mineralogy and Petrology, University of Granada (Spain). She is awarded this medal in recognition of her important contributions to the field of mineral-water interactions and related phenomena. Her research topics range from weathering processes and geochemical proxies to crystal-growth processes and environmental remediation. The

awarding of this medal also recognizes Dr. Ruiz-Agudo's active involvement in mineralogical research and collaborations with scientists at the European level. Her stature in the international mineralogical community is underlined by her being a guest editor of the June 2013 issue of *Elements* ("The Mineral-Water Interface").

IAN SWAINSON, SERIES EDITOR FOR RIMG



Ian Swainson has been named Series Editor for the Reviews in Mineralogy & Geochemistry (RiMG). The series is jointly published by the Mineralogical Society of America and the Geochemical Society, and, on occasion, with other groups.

Currently, Ian is the Letters Editor for *American Mineralogist* and will remain so. He has a broad interest in Raman, infrared, and neutron inelastic spectroscopy, as well as X-ray and neutron powder-diffraction applications to solid-state chemistry and physics, materials science, and Earth sciences. Born in Vancouver (British Columbia, Canada), Dr. Swainson grew up in the United Kingdom, mostly in North Wales. He has degrees from the University of Cambridge (UK), where he specialized in mineralogy, crystallography, and related fields, with a PhD on phonon-induced orientational disorder and the phase transition in cristobalite. Upon graduating, he moved to the Canadian neutron source at the National Research Universal Reactor, Chalk River, Ontario where he worked on the then-new C2 neutron powder diffractometer. He chaired the beam time review committee for powder diffraction at Chalk River, and has served on similar review committees for the Oak Ridge National Laboratory (Tennessee, USA), and the National Institute of Standards and Technology (NIST). He has coorganized several powder-diffraction workshops, primarily aimed at graduate and post-doctoral students. He helped develop the proposals for what became the Sylvia Fedoruk Canadian Centre for Nuclear Innovation, Saskatoon, Saskatchewan, and for the associated cyclotron and nuclear substance laboratory. Dr. Swainson replaces Dr. Jodi Rosso, who had been the RiMG Series Editor since 2000 and has moved into the position of executive editor of *Elements* magazine.

GEOLOGICAL ASSOCIATION OF CANADA AWARDS



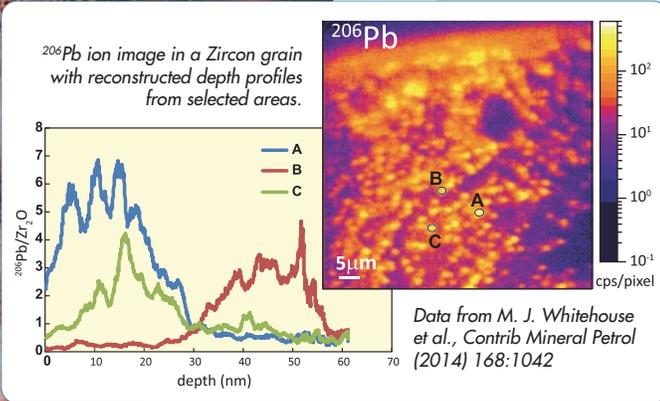
Richard A. F. Grieve, Natural Resources (Ottawa, Ontario), has been selected as the 2015 winner of the Logan Medal, the highest recognition of the Geological Association of Canada, awarded for sustained and distinguished achievement in Canadian Earth science. By bringing his meticulous studies of Canadian impact craters to the rest of the world, Richard Grieve has won international acclaim for his insights into impact processes to the benefit of terrestrial geology and

planetary sciences. As chief geoscientist and then chief scientist, he has worked tirelessly for the geoscience programs of the Earth Sciences Sector of Natural Resources Canada and for the general good of geoscience in Canada.



Sandra M. Barr, Acadia University (Nova Scotia), is the recipient of the Ambrose Medal for sustained and dedicated service to the Canadian Earth science community. For almost 40 years, Sandra Barr has devoted her time and energy to a variety of geoscience associations and institutions at local, national, and international levels, including the Atlantic Geoscience Society (AGS), the Association of Geoscientists for International Development, and the Geological Association of

Canada. She has received both of the AGS's major awards, as Distinguished Scientist and for Distinguished Service. She was also a coauthor of *The Last Billion Years: A Geological History of the Maritime Provinces of Canada*.



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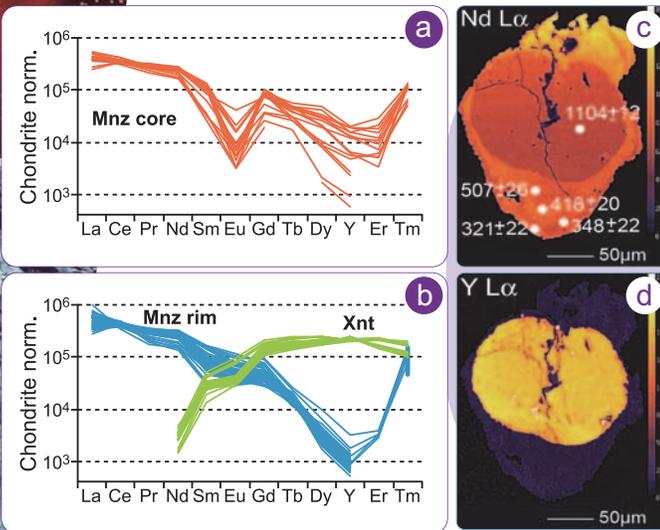
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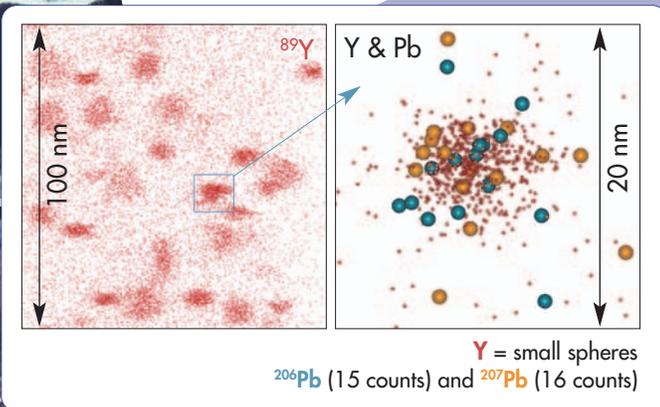
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a&b: Chondrite-normalized REE profiles as determined by EPMA. Monazite cores contrast with monazite rims and associated xenotime.
c&d: WDS maps of Nd and Y distributions.
Points marked on the Nd map show EPMA age determinations in Ma, 2 σ .
Data acquired on the SX Ultrachron model, courtesy of Dr. Julien Allaz, Univ. of Colorado and Dr. Michael Jercinovic, Univ. of Massachusetts.

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Courtesy of Valley, J. et al. Hadean age for a post-magma-ocean zircon confirmed by atom probe tomography. *Nature Geoscience* (2014).

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TRANSLATIONAL GEOSCIENCE: CONVERTING GEOSCIENCE DISCOVERY INTO SOCIETAL, ECONOMIC, AND ENVIRONMENTAL IMPACTS

Craig M. Schiffries¹

1811-5209/2015/011-232\$0.00 DOI: 10.2113/gselements.11.4.232

Translational geoscience—which involves the conversion of geoscience discovery into societal, economic, and environmental impacts—has significant potential to generate large benefits. But, it has received little systematic attention or resources. In contrast, translational medicine—which focuses on the conversion of scientific discovery into health improvement—has grown enormously over the past decade and provides useful models for advancing translational science into the geosciences and other fields.

The geosciences address many of society's greatest challenges, including (but not limited to) energy, water, and mineral resources; climate change; natural hazards mitigation; sustainable development; environmental protection; infrastructure and materials; and waste disposal. Past issues of *Elements* have addressed many of these topics, and this issue addresses the broader impacts of such topics as stable isotope biogeochemistry (Ehleringer et al. 2015), the application of stable metal isotopes to medicine (Albarède 2015), environmental mineralogy (Calas et al. 2015), and urban geochemistry (Ludden et al. 2015). Translational geoscience can accelerate the conversion of geoscience discoveries in these and other areas into greater societal, economic, and environmental impacts.

Before discussing translational science as potentially applicable to the geosciences, let's first look at how it has been developed and applied in the biosciences.

NEW VISION FOR TRANSLATIONAL SCIENCE

In his capacity as director of the US National Institutes of Health (NIH), Elias Zerhouni (2005) provided a new vision for translational science and took bold actions to “ensure that extraordinary scientific advances of the past decade will be rapidly captured, translated, and disseminated for the benefit of all Americans.” Zerhouni (2005) launched a major program to support a nationwide consortium of hubs at 62 medical research institutions that could work together to improve the translational research process. Likewise, the European Commission established the European Advanced Translational Research Infrastructure in Medicine (EATRIS) program, which comprises over 70 leading academic institutions across Europe.

In 2011, Francis Collins, who succeeded Zerhouni as director of NIH, said the time was right to for “reengineering translational science.” According to Collins (2011), “the triple frustrations of long timelines, steep costs, and high failure rates bedevil the translational pathway.” He noted, “little focused effort has been devoted to the translational process itself as a scientific problem amenable to innovation.” He further said, “translational science needs to shift from a series of one-off solutions toward a more comprehensive strategy.” He launched NIH's National Center for Advancing Translational Sciences (NCATS), which addresses translation on a system-wide level as a scientific and operational problem.

The US White House has broadened the imperative for translation to include research supported by all federal agencies. A memorandum of 9 July 2015 from the Executive Office of the President of the United States (Donovan and Holdren 2015) says:

The Nation depends on science, technology, and innovation to promote economic growth and job creation, maintain a safe and sufficient food supply, improve the health of Americans, move toward a clean energy future, address global climate change, manage competing demands on environmental resources, and ensure the Nation's security.

Simply supporting research is not sufficient, however, Federal agencies should ensure that the results of that research are made available to other scientists, to the public, and to innovators who can translate them into the businesses and products that will improve all of our lives.

The imperative for translation also extends to the type of research and development (R&D) that strengthens the scientific basis for decision-making. According to Donovan and Holdren (2015), “Both mission-centered agencies and R&D agencies should focus on creating user driven information and tools that enable the translation of scientific observations to decision-making frameworks.”

Despite its importance, investments in translational research should not come at the expense of basic research. Focusing on biomedical research in the United States, Zerhouni (2009) said, “Our country needs more and better translational research, both for the sake of our patients and because much of the research funding in the United States comes from the primary expectation of the American public that such scientific investigations will reduce the burden of disease. This is not to say, as many fear, that we should reduce our focus on basic research. On the contrary, I believe the opposite to be true...” Success in translational research may stimulate support for additional investments in basic research.

TRANSLATIONAL GEOSCIENCE

Geoscience is vastly different from biomedical science. Nevertheless, both can benefit from the principles of translational science. Adopting the approach of Collins (2011), translational geoscience would benefit from a focused effort devoted to the translational process itself as a scientific problem amenable to innovation. The geosciences would benefit from setting up institutions comparable to the NIH's National Center for Advancing Translational Sciences, which addresses translation on a system-wide level as a scientific and operational problem and convenes expert teams from diverse scientific disciplines and institutions to reduce, remove or bypass significant bottlenecks across the entire continuum of translation, as well as training future translational-science workers.

Natural hazards mitigation is one of many geoscience issues that would benefit from advances in translational science. This topic may also be amendable to collaboration between translational medicine and translational geoscience, at least to the extent that natural hazards mitigation is a field that addresses public health and safety.

A tsunami monitoring and warning system was installed in the Indian Ocean after the great Sumatra–Andaman earthquake and tsunami of 26 December 2004, which caused approximately 228,000 fatalities, 1.8 million people to become homeless, 5 million people to need immediate aid, and resulted in \$14 billion in damages. Although UNESCO announced that the Indian Ocean Tsunami Warning System was “up and running” in June 2006, an editorial in the journal *Nature* (2006) stated that a tsunami in Indonesia had killed more than 500 people on 17 July 2006. In a tragic failure of translational science, a tsunami warning was received but the government did nothing with the information. The Indonesian science minister feared that raising a false alarm would cause unnecessary panic (*Nature* 2006).

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Regarding the Indian Ocean Tsunami Warning System, the same *Nature* (2006) editorial argued, “Too much emphasis has been put on the expansion of the high-tech early warning system, and not enough on improving local preparedness.” Eight years later, and an opinion piece in *Nature* by Witze (2014) noted that this pattern still persisted despite concerted efforts to complete the communications chain: he states, “Ten years after the devastating Sumatra earthquake, warnings for the Indian Ocean go out, but often fail to reach the people most at risk ... The geophysical components of the Indian Ocean tsunami-alert system generally work well ... but warnings often fail to travel the last mile.”

The effectiveness of the Indian Ocean Tsunami Warning System, which cost more than \$450 million to set up, will be compromised greatly if further improvements in local preparedness are not achieved. Efforts in translational geoscience could benefit from advances in translational medicine, a field that has developed strategies for minimizing the multiple translational roadblocks that so often impede public health interventions, some of which involve communications, human behavior, organizational inertia, and allied topics (Woolf 2008).

Just as the Indian Ocean Tsunami Warning System was implemented after a devastating tsunami, most countries with earthquake early warning systems built them after a devastating earthquake (USGS 2014). Shortly after the 1995 Kobe (Japan) earthquake that resulted in 6,400 fatalities, Japan invested \$600 million in an earthquake early warning system. The system operated successfully during the magnitude 9.0 Tohoku earthquake of 2011, and no trains were derailed as a result of this historic earthquake. Other countries that built earthquake early warning systems of varying quality and coverage after devastating earthquakes include China, after the 2008 Wenchuan earthquake that killed 87,587 people, and Mexico, after the 1985 Mexico City earthquake that killed 10,153 people (USGS 2014). The United States, and many other countries with major earthquake hazards, have not yet implemented early warning systems.

The US Geological Survey (USGS) and its partners are, however, implementing an earthquake early warning system for the west coast of the United States (Given et al. 2014). Earthquakes in this region cause an average annual loss of \$4.1 billion. Research and development efforts for this system began in 2004 and a preprototype earthquake early warning system has been operating in California since January 2012. The USGS plans to implement a limited public warning system by 2018.

The technical implementation plan for an earthquake warning system for the west coast of the United States (Given et al. 2014) contains a short section on user education, which says, “Extensive outreach and education of both public and institutional users will be needed to ensure that earthquake early warning achieves the maximum beneficial effect. Users must be taught to take appropriate actions upon receiving a warning, and understand the limitations and reliability of warning information.” Given et al. (2014) emphasize the importance of developing partnerships with appropriate agencies—including emergency management departments, communications specialists, and special user groups such as hospitals, transportation monitors, and utility providers—to ensure this education occurs. Although a full education plan has not yet been developed, local west-coast groups have been working for many years to improve preparedness, mitigation, and resilience through such organizations as the Earthquake Country Alliance, the Southern California Earthquake Center, and a wide range of partners. More than ten million Californians have participated in Great Shake Out earthquake drills. The combination of robust education and preparedness activities with a technologically advanced earthquake early warning system has the potential to become a model for translational geoscience.

The cost, complexity, and timeframe for developing and implementing earthquake and tsunami early warning systems are comparable to many examples in translational medicine. Translational geoscience can benefit from the advances made in translational medicine, which addressed such topics as improving emergency preparedness, communicating life-saving information to government officials and citizens, explaining false positives and false negatives, working with multiple stakeholders and organizations across all sectors of the economy and all levels of government, and collaborating with scientists and engineers across a broad range of disciplines.

Although he was speaking generally from a position within translational medicine, Collins (2011) makes a point that could equally well apply to translational geoscience, “Opportunities to advance the discipline of translational science have never been better. We must move forward now. Science and society cannot afford to do otherwise.” Prompt actions will enable the geoscience research enterprise to be in the vanguard of the translational science revolution.

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Craig M. Schiffries is director of the Deep Carbon Observatory at the Geophysical Laboratory of the Carnegie Institution for Science (Washington, DC). He served as the first director for geoscience policy at the Geological Society of America, the first director of government affairs at the American Geosciences Institute, and director of the board on the Earth Sciences and Resources at the US National Academy of Sciences. He received a PhD in geology from Harvard University (USA), an honors BA in philosophy, politics, and economics from the University of Oxford (UK), and a BS in geology and geophysics from Yale University (USA).

THE INDUSTRY, ACADEMIA AND GOVERNMENT NEXUS IN GEOCHEMISTRY

Graham Brown¹ and Michael Daly²

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Geochemistry is a key specialist sub-discipline in the global exploration and production of resources. It complements conceptual geological thinking, analytical modelling and traditional fieldwork as part of a multi-disciplinary effort. When properly integrated into the discovery process, geochemistry is a key component of exploration success: conventional geochemical techniques have, for example, played an important role in the discovery of many deposits of base metals, precious metals and oil and gas. Going further along the value chain, geochemistry also plays a key role in the management of oil and gas reservoirs as they are produced. Geochemistry, therefore, is an integral part of both petroleum and mineral industries and it continues to develop and improve its contribution.

However, the awareness, quality and usage of geochemistry can be highly variable in the petroleum and the mineral worlds. To tackle this, one of the major areas for improvement is in in-house and undergraduate teaching of organic and applied exploration geochemistry and industry-relevant research and development (R&D).

Industry wants to constantly improve its efficiency in finding, developing and producing resources. This objective is supported by the technologies available and our capability to deploy and develop them. Effective geochemical tools and techniques (e.g. direct petroleum and ore detection, vectors to ore bodies and petroleum pools, fertility indicators) that reduce risk and improve discovery success are needed in all geological settings and all geographic/geomorphological environments, both onshore and offshore.

As exploration moves into new terrains (e.g. transported cover or prospects existing below salt layers), new techniques need to be developed and new approaches and work flows created (e.g. 'mineral systems' mapping versus traditional 'anomaly hunting'). This should also include an improved understanding of the underlying geochemical processes that operated during ore- and petroleum formation and migration. Furthermore, as our understanding of the geological processes of basin formation, subsidence and sedimentary fill improves, additional demands are made of geochemical modelling. The geothermal evolution of an area of interest and source rock maturation, petroleum expulsion and subsequent migration requires constant upgrading as the input data improves.

However, no matter how good our tools, without capable people they are nothing. Both the mineral and petroleum world require good people – well-rounded practitioners with the capacity to make full (and correct) use of the available geochemical toolbox: this includes everything from the choice of the most appropriate sample medium/method, to planning/implementation of a survey, through to proficient modelling/evaluation/interpretation of the results.

For this type of capability development, the university relationship is crucial and needs to be considered in the two dimensions of education and research. In education, we feel there is a gap in the undergraduate teaching of applied exploration (and mining) geochemistry at some universities. This is to a large degree solved in the petroleum industry by the widespread availability of MSc courses, which at least include some organic geochemistry. However, if applied geochemistry can be

taught to a high standard – something that, for the most part, still remains to be done – then that would have a very beneficial impact on the whole exploration sector.

Industry needs universities to generate well-rounded exploration geoscientists with a comprehensive understanding of the geochemical techniques needed to explore for deposits. While the oil and gas industry has accepted the need to do a large amount of in-house and third-party training of young explorers, the mining/exploration industry has (increasingly) limited capacity to provide an analogous level of required training on an in-house basis. The pool of experienced professionals within the exploration industry who can provide in-house training in applied exploration geochemistry is relatively small. Universities, possibly with financial and/or in-kind industry support, have an opportunity to close this gap. The recent establishment of the Acme Industrial Research Chair in Exploration Geochemistry at the Mineral Deposit Research Unit (University of British Columbia, Canada) is an encouraging development in this regard.

The strategic alignment of research objectives with the long-term needs of industry is a key challenge. However, industry alone should not dictate research directions. The ability to undertake process-oriented research, without consideration of immediate industrial impacts, must be retained. Equally, solving the issues of industry should be recognised as a valid and highly impactful goal of applied research, one that will have academic benefits as well.

Danger to these ideal goals comes when funds are directed to government-initiated R&D projects, politically driven by R&D management, with only limited industry input and even less academic appreciation. As a result, industry-relevant objectives and deliverables may be only vaguely defined; outcomes are often of no, or at best limited, relevance to industry or academia. Recognising this issue does, however, lead to a number of solutions:

1. Collaborative initiation of R&D projects by industry, academia and government.
2. The delivery minded definition of project objectives, products and purpose.
3. Commitment by industry to participate on a long-term basis.
4. Effective monitoring and management of project progress.

Many researchers/lecturers in the academic geochemistry community are unfamiliar with what is done by geochemists in the petroleum/mining/exploration industry. Therefore, they are unaware of some of the social, scientific and technological challenges that face the industry and that could benefit from research. A more open dialog between industry and academia might help, one in which industry can clearly articulate their research needs and strategic priorities. The Centre for Doctoral Training initiative of the Natural Environment Research Council (UK) has been a good step in this direction. Unfortunately, to date, much of it appears to be academia talking to academia about industry. Industry needs to not only be a provider of funds but be committed to an outcome, which requires industry to have a meaningful relationship with academia.

A successful industry–university partnership has several dimensions. Perhaps the most profound development would be if a industry–university partnership is developed beyond a single project or phase of funding. The Industrial Associate programme run by the Department of Earth Sciences, University of Cambridge (UK), has achieved this over several years, and it has proved to be an effective model where industry collaboration has benefitted both parties. This Cambridge programme

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has also produced a significant number of high-quality doctoral students who have either gone on to work in industry or remained in academia but worked on industry problems.

In contrast, one off studentships and projects, initiated by an interested individual and not followed through as that person moves on, have the hallmarks of the worst of university/industry collaboration. They achieve nothing beyond completion of an immediate goal and create very little long-term value for the financial and time investment involved. The issue here requires discipline on both sides. Universities will rarely resist money for a studentship; but, in some cases, they should. Equally, industry needs to have the discipline to see beyond the next cycle and to develop long-term and sustainable relationships that will have significant long-term benefit. This only comes with commitment and a clear view of direction and a belief in process-based research.

Graham Brown and **Mike Daly**

ABOUT THE AUTHORS



Graham Brown (MSc, CGeol, EuroGeol) has over 35 years' experience in the mining and exploration business. He is co-founder and director of the private Finnish exploration and development company Sakumpu

Exploration Oy and a former Group Head of Geosciences and Exploration at Anglo American plc. His team has has received industry awards and been credited with discovering the world-class Los Sulfatos copper deposit in Chile (Proectors and Developers Association of Canada) and the northern Finland Sakatti deposit (Fennoscandian Mining and Exploration). Brown served on the council of the Society of Economic Geologists from 2012 to 2014 and is currently the industry representative on the science advisory boards of both the British Geological Survey and the Natural History Museum (UK).



Mike Daly is a British geologist, explorer, and petroleum executive based at the University of Oxford Department of Earth Sciences (UK). He is widely known for his role as global exploration chief for British Petroleum

(BP) and for his academic contributions to geology and tectonics, focusing on Africa. Daly joined Zambia's Geological Survey Department in 1976. After a decade of geological mapping and academia, he moved into the petroleum industry and joined BP, where he developed a technical and business career in exploration. Daly became BP's exploration chief in 2006. He retired from BP in 2014 and is now a non-executive director of Tullow Oil and a partner at Macro Advisory Partners.

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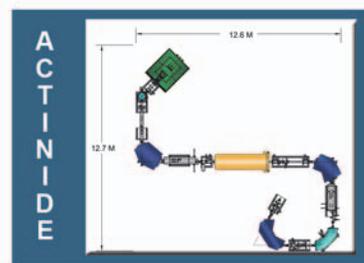
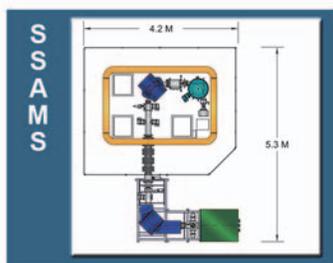
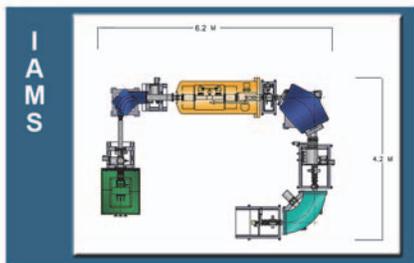
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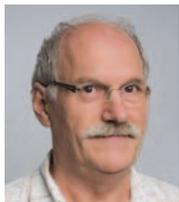
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John Barr was born in Scotland, gained a BSc (hons) in geology at the University of Glasgow (Scotland) in 1986 and an MSc in geochemistry from the University of the Witwatersrand (Johannesburg, South Africa) in 1988. He is married and has three adult children. Barr's career is in the mining and exploration business. Initially he worked both as a mine and an exploration geologist, but his career evolved to focus on geochemistry. Currently, he is the leader of the geochemistry group within Anglo American plc, supporting the operating mines and brownfield exploration. He has also worked in generative targeting and greenfield exploration for a wide range of ore types all over the globe.



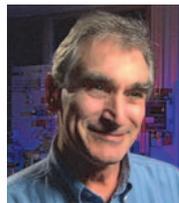
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Max L. Coleman is predominately a geochemist/isotopist with microbiology interests. Educated in the UK (BSc geology and chemistry double honors, University of London; MSc geochemistry and PhD isotope geochemistry, University of Leeds) he has worked in government science (British Geological Survey), industry (British Petroleum exploration) and academia (Professor of Sedimentology at the University of Reading, UK). He applies multidisciplinary, fundamental research to elicit solutions to practical problems in petroleum exploration and production, environmental pollution, radioactive waste storage, forensic science, and carbon capture and storage (cosmic ray muon imaging of subsurface supercritical CO₂). He also searches for life on other planets, working with NASA's Jet Propulsion Laboratory, California Institute of Technology (USA).



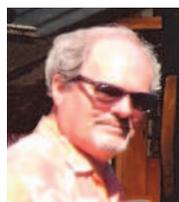
James R. Ehleringer is Distinguished Professor of Biology and director of the Stable Isotope Ratio Facility for Environmental Research at the University of Utah (USA). He recently stepped down as the founding director of the Utah's Global Change and Sustainability Center whose interdisciplinary focus was, and is, on the environment and sustainability. James develops multidisciplinary research projects that range from the impact of global change on natural and urban ecosystems through to forensic science.



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Kurt Kyser received his BS in chemistry from University of California-San Diego (USA) and his MA and PhD from University of California-Berkeley (USA). He is currently the director of the Queen's Facility for Isotope Research (QFIR) at Queen's University (Canada). The interests of his research group include applied isotope geochemistry, fluid-rock interactions, and environmental and exploration geochemistry, with emphasis on both pure and applied science. The current focus of his research is on developing new technologies to help formulate effective exploration for ore deposits, understand how elements migrate in the near-surface environment, and developing management strategies for natural resources.



John Ludden is an executive director at the British Geological Survey since 2006. Prior to this he was Director of the Earth Sciences Division at the French National Centre for Scientific Research (CNRS). He worked as a professor and research scientist at the University of Montreal (Canada), at the Lamont-Doherty Earth Observatory, Earth Institute of Columbia University (USA) and at the Woods Hole Oceanographic Institution (USA). John

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Paul F. McMillan is Sir William Ramsay Professor in the chemistry department at University College London (UK). He completed a PhD degree at Arizona State University (USA) in 1981 and remained there until 2000 as professor and director of the center for solid-state science. His wide research interests include solid-state chemistry, synthesizing new materials, high-pressure-high-temperature science and investigating layered

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Denis Peach is a chief scientist at the British Geological Survey (BGS) and was the manager of the BGS Groundwater Programme (Wallingford, UK). He is a hydrogeologist with broad interests in environmental geosciences, including shallow geophysics, hydrogeochemistry, engineering geology, and numerical modelling. He has 35 years' experience, which includes work for a UK water authority, overseas work in tropical hydrogeological environ-

ments, and work for international consultants in arid-zone hydrogeology. His scientific interests include the development of groundwater modelling in BGS. Denis collaborates with several universities and the Centre for Ecology and Hydrology (part of the UK's Natural Environment Research Council) for an interdisciplinary approach to understanding catchment areas. He is an honorary professor at the University of Birmingham (UK) and former vice president of the Geological Society of London.



Brett J. Tipple is a research assistant professor at the University of Utah (USA) and a research scientist at IsoForensics Inc. His research interests include the fields of isotope forensics, isotope geochemistry, paleoclimatology, and modern and ancient plant ecology. Some of his current areas of research are modern plant ecophysiology and applications of heavy isotopes from human tissues for provenancing. Brett obtained his PhD from Yale

University (USA) in 2009.



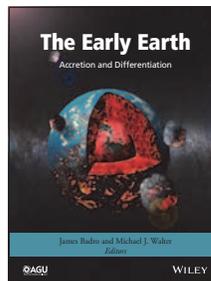
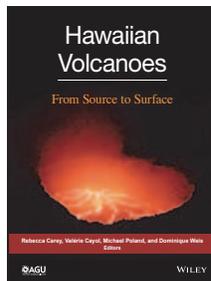
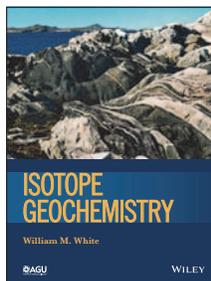
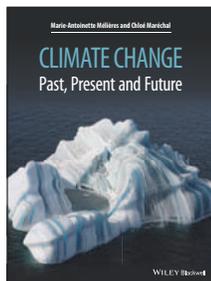
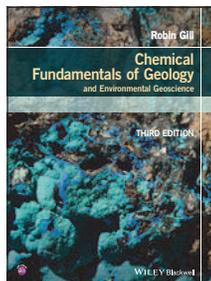
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health. He is also interested in applying stable isotopes to forensic investigations and food traceability.

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The Impact of Geochemistry

John Ludden¹, Francis Albarède², and Max Coleman³

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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.

KEYWORDS: economic, social, impact, communication, geochemistry

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.

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



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.

geochemists should not simply move onto the next interesting problem until we have found a way to move the results into innovation.

ACKNOWLEDGMENTS

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Applied Geochemistry in Mineral Exploration and Mining



Kurt Kyser¹, John Barr², and Christian Ihlenfeld³

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The prosperity of our societies and our standards of living are directly related to our ability to find, exploit, and manage our metal and mineral resources. 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. The fundamentals of element mobility (i.e. transport and fixation) in the near-surface environment are used by geochemists to detect mineral deposits at depth, reveal element distributions in and around deposits, assess the total geochemical environment, and refine effective and benign extraction and waste disposal techniques. Both pure- and applied-research ventures play fundamental roles in providing the techniques to manage metal resources and thereby benefit society.

KEYWORDS: exploration, element dispersion, analytical geochemistry, mineral resources

INTRODUCTION

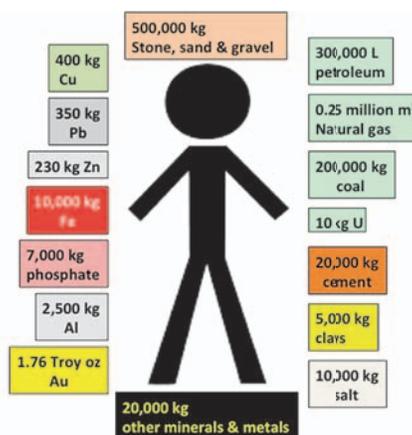
The evolution of our societies and the development of the anthroposphere—that part of the environment modified by humans for use in human activities—have been intimately linked with our ability to extract and exploit metals from the geosphere. As human civilization evolved from the Stone Age on through the Bronze and Iron Ages, our society became dependent on metals for its very existence. Metallurgical knowledge evolved from an art to a science, beginning with the metals used by prehistoric man, such as gold, silver, copper, tin, lead, and iron. Gold and silver were soft, durable, easily worked and visually attractive and so were used for decoration; copper could be hardened by forging and was, therefore, useful as a tool; bronze, an alloy of copper with tin, could be hardened and cast, and so could make more advanced weapons and other tools, which significantly advanced human society. Lead was soft, easily worked, and could be made into vessels and pipes to transport water. Iron, whose name means “stone from heaven” in several languages, so influenced civilization that its discovery led to the transition from the Bronze Age to the Iron Age. The first sources of iron for metallurgy probably came from meteorite finds. Iron oxide ores, like many metals, were discovered when ores were close to camp fires. So began the massive extraction of metals from minerals. Eventually, the development of steel into a material of common use influenced the evolution of our

society. A nation with steel could conquer a nation without steel (Reardon 2011).

In days gone by, even in the Bronze and Iron Ages, people did not use a significant amount of metal resources per person. However, today, each individual uses or requires an average of 1.4 million kg of resources over their lifetime (Fig. 1). The required resources will increase as populations grow and as the standard of living increases in currently less advanced societies.

When populations grow and advance, more resources are always needed, including mineral deposits. Mineral deposits can be

viewed as geochemical anomalies, and, as such, their detection, as well as assessing their impact on the environment, must use geochemical techniques. Areas where geological research, applied geochemistry, and policy intersect in the exploration for and extraction of metals include the following: (1) using element mobility in the near-surface environment to detect deposits at depth (Kelley et al. 2006); (2) revealing element distributions in and around deposits to adequately assess the total chemical environment associated with the deposit and to refine effective and more environmentally benign extraction and waste disposal techniques (Bowell et al. 2011); (3) understanding the effects of both macro- and microenvironments on



1.4 million kg of metals, minerals and fuels in a single lifetime

FIGURE 1 Average lifetime consumption of metal and mineral resources for individuals in first-world countries.

DATA FROM WWW.MINERALS EDUCATION COALITION.ORG.

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element mobility across the geosphere–biosphere interface to define appropriate remediation techniques associated with the extraction of diverse commodities. Geological research, both pure and applied, plays a fundamental role in providing such techniques. Research in applied geochemistry can add value to exploration, extraction, and remediation strategies provided that the results are adequately conveyed to the appropriate individuals in both industry and government and that there is a perceived need to develop new and novel techniques by all concerned. For example, applying isotope tracers to help understand the processes by which various elements move through the geosphere and into the biosphere is a novel area of research with boundless benefits to exploration, extraction, and remediation and will lead to a better understanding of the impact of mining processes on the total environment.

THE BASIS OF GEOCHEMISTRY IN DISCOVERING AND EXPLOITING ORE DEPOSITS

A basic tenet in exploration and environmental geochemistry is that elevated concentrations of metals and compounds in ore deposits or from anthropogenic sources will disperse with time and be recorded as aberrations against “normal” background levels. Environmental and exploration geochemistry have repeatedly proven that this basic tenet is valid because there are numerous cases where the subtle geochemical footprint of an ore deposit goes well beyond the bounds of the ore itself and its associated alteration: it is, in fact, possible to detect “leakage” of elements from deposits at depth (Cameron et al. 2005; Kelley et al. 2006; Coker 2010). The new challenges for geochemists include understanding the processes by which elements migrate (Anand et al. 2014), the rate at which concentrations in the environment change as a result of anthropogenic activity, and identifying those elements or compounds that truly reflect dispersion from ore deposits up to several hundreds of meters below the surface (Coker 2010). There have been very few recent discoveries of ore deposits at the surface (Marlatt and Kyser 2011), which means that most new discoveries will be at depth, which in turn means that we must be able to “see” them from the surface with geophysics and geochemistry. In addition, surface exploration geochemistry for deposits at depth must be able to distinguish elements in metal deposits from elements due to the background geology and from elements in the area that might be from human pollution.

Exploration geochemistry directly benefits society by enhancing the inventory of subsurface metal deposits through new technologies and by tracing element migration in the near surface environment, including across the geosphere–biosphere interface. Amplifying an orebody’s footprint so it can be detected at depth or traced near the surface involves two distinct processes (Fig. 2): (1) primary dispersion, which provides information on alteration and primary element dispersion associated with ore emplacement; (2) secondary dispersion, which provides clues about element migration from alteration and ore zones after emplacement. Overall, the most commonly and successfully applied surface media in exploration surveys are stream sediments, soils, tills, ferruginous materials from lateritic profiles, and plants. The emerging field of biogeochemistry, which focuses in part on the interaction of microbes, plants, and other organisms with Earth materials, offers a new dimension by which elements can be traced from the geosphere to the biosphere (Dunn 2007; Kyser 2012).

Primary Dispersion

During primary dispersion (Fig. 2), components in the mineralizing fluids permeate into the country rock, which alter primary minerals and elevate the concentrations of “pathfinder” elements. Several types of deposits have been discovered using primary dispersion haloes, including deposits of “iron oxide–copper–gold”, other types of Au deposits, and Pb–Zn and Cu deposits (Kelley et al. 2006). These enrichments relative to background concentrations are sometimes evident in the lithochemistry up to several kilometers away from the mineralization (Halley et al. 2015). Hydrothermal alteration minerals associated with mineralizing fluids are normally detected in drill core, outcrop, and from airborne surveys using spectroscopic techniques (Table 1). Lithochemistry is widely used in exploration, and recent advances in field-based, real-time analysis (TABLE 1) have been made using hand-held portable X-ray fluorescence (pXRF) detectors and laser-induced breakdown spectroscopy (LIBS) devices, the results of which, however, should be subsequently verified using certified laboratory analyses. Enrichments and zoning in pathfinder elements specific to an ore-forming fluid may be detected through element isotopic compositions, which reflect the presence of ores and alteration haloes such as H, Li, B, C, O, S, Cu, Zn, Tl, Mo, Pb, and U (Mathur et al. 2009; Barker et al. 2013) or reflect the trace-element composition of specific minerals such as epidote and chlorite (Cooke et al. 2014).

Lithochemical methods on an outcrop or on a drill core have been used in regional reconnaissance, and more locally for detecting the far-field effects of mineralization, particularly around blind targets (Lawie 2009). Lithochemistry combined with mineralogy is useful in geometallurgical work to more effectively extract the elements of interest from the ore and alteration minerals (Lawie 2009).

Secondary Dispersion

Tracing element migration in the near-surface environment and into the biosphere involves understanding the secondary dispersion of elements, including those associated with anthropogenic activity (Fig. 2). Surface media that can be used to reflect secondary dispersion of ores or alteration minerals include stream sediments, tills (McClenaghan and Cabri 2011), vegetation (van Geffen et al. 2012), and ground waters (Leybourne and Cameron

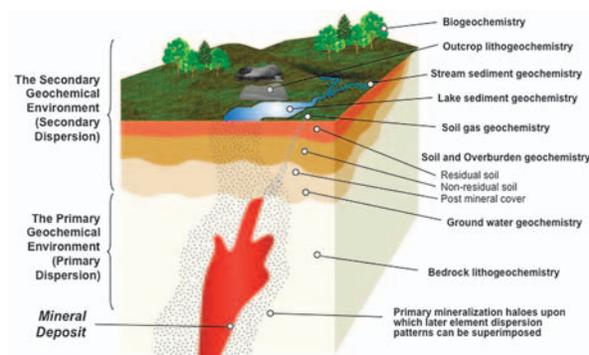


FIGURE 2 Different types of media sampled during exploration and baseline geochemical surveys in the area of a mineral deposit. Proximity of an undercover deposit can be reflected in zoned geochemical enrichments formed during the mineralizing event itself (primary dispersion) or as a result of postmineralization dispersion (secondary dispersion). Primary dispersion haloes can be detected through lithochemistry; secondary dispersion haloes can be detected using ground water, soil (till), soil gas, lake and stream sediments, and biogeochemistry.

2010). Studies of such media have led to numerous discoveries of ore deposits over the years (Eppinger et al. 2013), including the Boyongan porphyry Cu–Au deposit (Philippines), which contained over one million tons of copper and was discovered by Anglo American in 2000 (Braxton et al. 2009).

Because most ore deposits are electron-rich and contain elements in reduced forms, they are potential havens for microbes that can mobilize elements during secondary dispersion. Microbe-mobilized elements can involve aqueous or gaseous complexes in the microbe's waste products or from the decay products of dead microbes. Such complexes migrate to the surface, particularly along fractures and faults, become sorbed on clay and Fe–Mn oxide surfaces, and make their way into the biosphere. These complexes have specific element and isotope signatures that reflect the deposit at depth (Cameron et al. 2005). Tracking these elements and determining their migration processes is something of a current research obsession because in areas of thicker or transported overburden, surface geochemistry is notoriously unreliable. With the current poor understanding of the controlling geochemical processes by which elements migrate, applying these techniques in a robust predictive fashion is fraught with uncertainty and requires additional rigorous scientific research. While the direct approach of drilling through cover and sampling the top of the bedrock is more effective, drilling to any level is an expensive venture, so anything reliable and cheaper is much sought after.

CRITICAL ASPECTS IN APPLIED GEOCHEMISTRY

Many in the academic geochemistry community are unfamiliar with what is done by geochemists in the mining industry and unaware of the numerous questions that

could benefit from research. Applied geochemists would dearly like to know more about the mechanisms by which elements migrate from deposits, what elements provide reliable vectors back to the primary deposit, and what techniques are most effective at detecting these mechanisms. Geochemistry is a strategic technique throughout the chain of exploration and mining, from initial targeting through to resource definition and on into effective mining and, ultimately, mine closure. There are three main areas of applied geochemistry in the mining industry: (1) exploration geochemistry; (2) mining geochemistry (geometalurgy); and (3) environmental geochemistry. Although the goals of these areas are different, the approaches, applications, and techniques of each are similar.

Environmental geochemistry on mine sites and projects involves determining the geochemical baseline, monitoring surface and borehole water-quality, and characterizing ore and waste rocks for potential acid mine drainage and metal leaching. Fast and relatively cheap multielement analysis by inductively coupled plasma atomic emission spectrometry (ICR-AES) and inductively coupled plasma mass spectrometry (ICP-MS) (TABLE 1) have been some of the major technological developments in the last couple of decades. These techniques allow the generation of large multielement data sets of use in both exploration and mining.

The critical importance of geochemical sampling in applied geochemistry cannot be overstated. Sampling strategies must be devised and implemented based on a holistic understanding of the character of the media being sampled, the style of mineralization, and the overall project requirements. It is not uncommon for billion-dollar decisions on a mining project to be made on the basis of assaying just a few hundred kilograms of rock. It is, therefore, essential to get the geochemistry and the sampling right.

TABLE 1 ANALYTICAL TECHNIQUES IN APPLIED GEOCHEMISTRY

Acronym	Technique	Description
CF-IRMS	Continuous Flow Isotope Ratio Mass Spectrometry	Elements of interest (H, C, N, O, S) are prepared as gases and separated in-line with a stable isotope ratio mass spectrometer
DET CRC Lab-at-Rig	Deep Exploration Technologies Cooperative Research Centre Coiled Tubing Drill Rig with sensors in-line	Trailer-mounted assay system that provides near real-time XRF geochemistry and XRD mineralogy on drill cuttings.
ETV-ICP-OES	Electro Thermal Vaporization Inductively Coupled Plasma Optical Emission Spectrometry	Solids or solutions are evaporated into a plasma and excited atoms and ions emit electromagnetic radiation at wavelengths characteristic of a particular element
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry	Plasma used to excite ions in solutions or solids and excited atoms and ions emit electromagnetic radiation at wavelengths characteristic of a particular element
ICP-MS	Inductive Coupled Plasma Mass Spectrometry	Excited ions in plasma torch are introduced to a mass spectrometer detector for both elemental and isotopic analysis
LA-ICP-MS	Laser Ablation Inductive Coupled Plasma Mass Spectrometry	Laser is used to ablate material that is carried into a plasma torch and the excited ions are introduced to a mass spectrometer detector for both elemental and isotopic analysis
LIBS	Laser Induced Breakdown Spectroscopy	Laser is used to sample material and the chemical composition determined using emission spectra
OA-ICOS	Off-Axis Integrated Cavity Output Spectroscopy	The concentration or amount of an isotopic species in a gas phase is determined by absorption spectrometry with a laser
pXRF	portable X-Ray Florescence	Handheld XRF for in situ chemical compositions
QA/QC	Quality Assurance & Quality Control	Correct and transparent protocols are used in analyses to ensure they are of the appropriate quality
Raman	Raman spectroscopy	Raman spectroscopy uses the vibrational modes of molecules; sometimes coupled with SWIR
SWIR	Short Wave Infrared spectroscopy	Infrared reflectance spectroscopy for mineral identification
Synchrotron-based methods	XRD, micro-XRD, XRF, micro-XRF elemental mapping, computed tomography (CT) and fluorescence CT, extended X-ray absorption fine structure (EXAFS) and micro-EXAFS spectroscopy, scanning transmission X-ray microscopy	Synchrotron light used as a source of intense and energy-tunable X-rays for a variety of techniques
XRD	X-Ray Diffraction (portable)	Closed-beam field portable XRD to provide full phase identification of mineral components; sometimes coupled with a qualitative XRF spectrometer.

The theoretical basis for effective sampling in applied geochemistry was formulated in the 1950s by Pierre Gy (Pitard 1993). Gy's formulation is frequently applied in the mining industry and, in most instances, up to 70% of the total variance in chemical composition comes from field sampling and sampling design, 20% from sample preparation, and 10% or less from the actual chemical analysis. To limit these errors, the mining and exploration industry has adopted sophisticated quality assurance (QA) and quality control (QC) protocols that are reflected in international codes, such as the Australasian Joint Ore Reserves Code (JORC www.jorc.org) and the Canadian National Instrument 43-101 *Standards of Disclosure for Mineral Projects* (NI 43-101 web.cim.org/standards). Having well-written and transparent protocols for sampling and analysis and ensuring that these are followed using the appropriate equipment are part of QA. Quality control protocols include analysis of "blind" blanks, matrix-matched certified reference materials (CRMs), and duplicates (normally performed on 5–10% of the samples). Interlab check analyses are also done. Precision error estimates from duplicate and multiple analyses of the CRMs are normally assessed using an average coefficient of variation approach, which uses the ratio of the standard deviations of the values to their means (Stanley and Lawie 2007).

Grunsky (2010) has given a good overview of the essential methodology commonly followed for data interrogation and visualization. Grunsky advises a two-pronged approach to geochemical data interpretation: a geochemical process-based analysis that tries to understand the controls on element associations and data distribution patterns, plus a statistical-based analysis of empirical inter-element relationships. Although one approach can feed into the other, the real power lies in spatially integrating the geochemical data with the available geological and geophysical data.

GEOCHEMISTRY APPLIED TO EXPLORATION

Mineral exploration is a multidisciplinary team effort in which conceptual geological thinking and traditional geological fieldwork are complemented by the key specialist subdisciplines of geochemistry and geophysics. Examples where geochemical techniques have contributed to the discoveries of deposits, to critical baseline studies, and to environmental impacts abound.

One such successful integrated program is exemplified by the discovery of the Sakatti Cu–Ni–platinum-group element (PGE) magmatic sulfide deposit in northern Finland (Fig. 3). The Sakatti Cu–Ni–PGE sulfide deposit was discovered by Anglo American in 2009 (Brownscombe et al. 2015). Initial area selection was primarily based on a conceptual geological exploration model that recognized the geological similarities between the portion of the Central Lapland Greenstone Belt in which Sakatti is located and the world-class Pechenga Ni–sulfide deposit on the Kola Peninsula (Russia). Public-domain geophysical (e.g. airborne magnetics) and geochemical datasets (surface and basal till) obtained from the Geological Survey of Finland were evaluated to identify and to rank targets within the area. The Sakatti target itself was identified as a magnetic body with ultramafic affinity. Much of the area is covered by glacial deposits with only 2% outcrop, so further exploration relied on geochemistry and geophysics of the overlying deposits to delineate the subsurface geology. Targeting areas to drill was accomplished by sampling the basal till layer immediately overlying the bedrock contact. Initial base-of-till sampling at Sakatti was carried out along lines perpendicular to the strike of the magnetic body, with 300 m line spacing and 25 m sample intervals (Fig. 3). A weak Cu–(Ni)–PGE anomaly in the basal till was followed up with additional base-of-till sampling, first to a line spacing of 150 m and finally to 50 m. As a result of this, a 150 m × 150 m subcrop of the mineralized body was delineated below the till cover. Subsequent

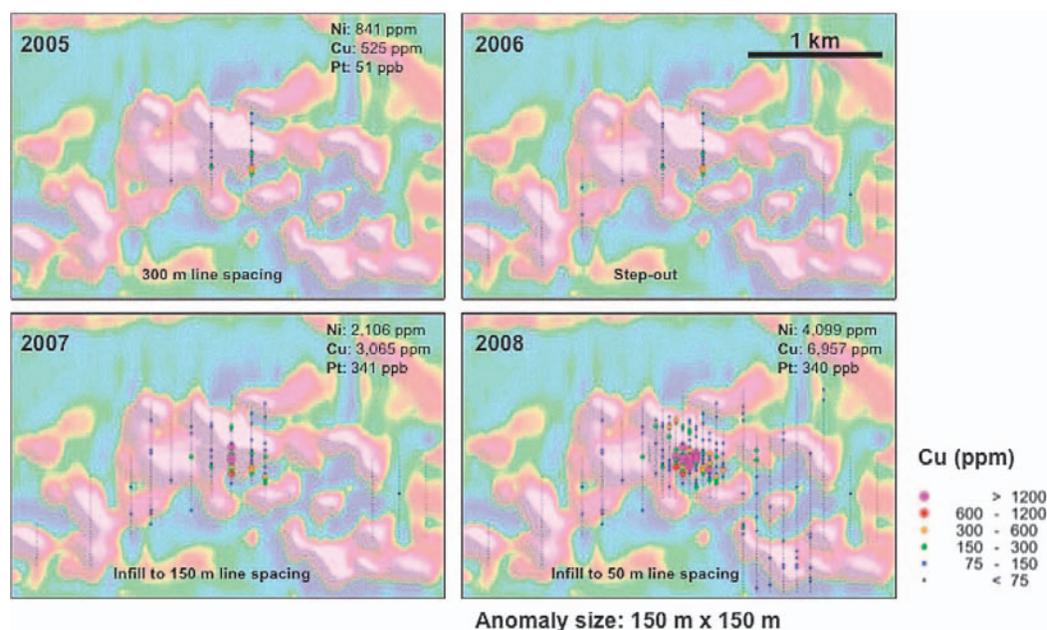


FIGURE 3 Selected results of the base-of-till (BOT) geochemical survey undertaken over the Sakatti deposit (Finland) prior to its discovery (results are overlain on a reduced-to-pole airborne magnetic grid). BOT samples were collected from the basal till layer immediately overlying the bedrock contact. Initial sampling was done at 300 m line spacing along lines perpendicular to the strike of the magnetic body (during 2005 and 2006),

followed by additional sampling, first to a line spacing of 150 m (in 2007) and finally to 50 m (in 2008). As a result of this survey, the 150 m × 150 m large subcropping part of the mineralized body was delineated below the till cover, leading to the discovery of the Sakatti Ni–Cu–PGE sulfide deposit. USED WITH PERMISSION OF ELSEVIER FROM BROWNSCOMBE ET AL. (2015).

drilling of the Cu–Ni–PGE anomaly intersected significant magmatic sulfide mineralization leading to the discovery of the Sakatti deposit.

Another example of successful applied geochemistry was in developing new technologies in isotope tracing and gradients in element concentrations (lithochemical vectors to ore) as a result of integrating element and isotope geochemistry in a study of the Rosario porphyry Cu–Mo subprovince of the Collahuasi district in northern Chile (Fig. 4). Mineralization in the district involved propylitic hydrothermal alteration of granodiorites, diorites, andesites, dacites, and rhyolites, all of which had previously experienced regional lower greenschist facies metamorphism. In low-grade metamorphic terrains, propylitic assemblages that represent the boundary of an ore system can resemble metamorphic mineral assemblages. However, propylitic alteration can be distinguished from other metamorphic mineral assemblages by high whole-rock $\delta^{13}\text{C}$ values and carbon contents that result from the incorporation of magmatic CO_2 during mineralizing events (Fig. 4). The spatial variation in $\delta^{13}\text{C}$ values and carbon contents of outcrop samples from the Collahuasi district were used to delineate zones that correspond exclusively to propylitic alteration surrounding economic deposits, regardless of rock type. When combined with lithochemical data from the same samples, the relative mobilities of elements resulting from primary dispersion defined a compositional gradient that served as a vector toward the mineralization of the Rosario Cu–Mo porphyry deposit (Fig. 4).

FUTURE DIRECTIONS AND TECHNOLOGIES

Recent novel applications of geochemistry in mineral exploration and remediation include the chemical and isotopic composition of surface media (e.g. till, soils, vegetation) to record element migration, new techniques used for real-time (field-based) analyses and for easier laboratory-based

analyses, as well as the development of new approaches to isotope geochemistry, microbial technologies, spectroscopy, and data representation. Among the sample materials currently being examined for tracing element migration are clay minerals in soils (van Geffen et al. 2012); plant matter, such as tree-cores and tree resin; and soil gases (Hale 2010). The novel laboratory analytical techniques of pyrolysis, of electro-thermal vaporization (as a way of introducing samples into ICP instruments), and of faster analysis of isotopic compositions now permit the rapid and accurate analysis of complex materials. Both pXRF and LIBS (TABLE 1) are being employed in various forms to generate real-time data in the field. Synchrotron light-source methods are being increasingly used by geochemists to characterize the speciation and phase associations of ores and the contaminants released as a result of mining activities (Brugger et al. 2010). Research on the interaction between microbes and ore deposits is also a frontier area, which includes identifying microbes through DNA analysis. Microbes, we now know, can mobilize specific ore components and, therefore, have potential for exploration, bio-mining, and remediation.

Portable XRF technology is now well established in the mining and exploration industry and has been validated through initiatives like the CAMIRO (Canadian Mining Industry Research Organization) study (Hall and McClenaghan 2013). With matrix-matched calibration and a proper QA–QC protocol in place, it is possible to generate accurate assay data with the pXRF to allow real-time decisions to be made with reasonable assurances.

LIBS-based field-portable systems are also appearing on the market, and these too will need to be similarly evaluated. The halogens represent a target group of elements in exploration and remediation because they form strong complexes with metals, they tend to be mobile, and they are associated with mineralizing fluids. LIBS is one of the

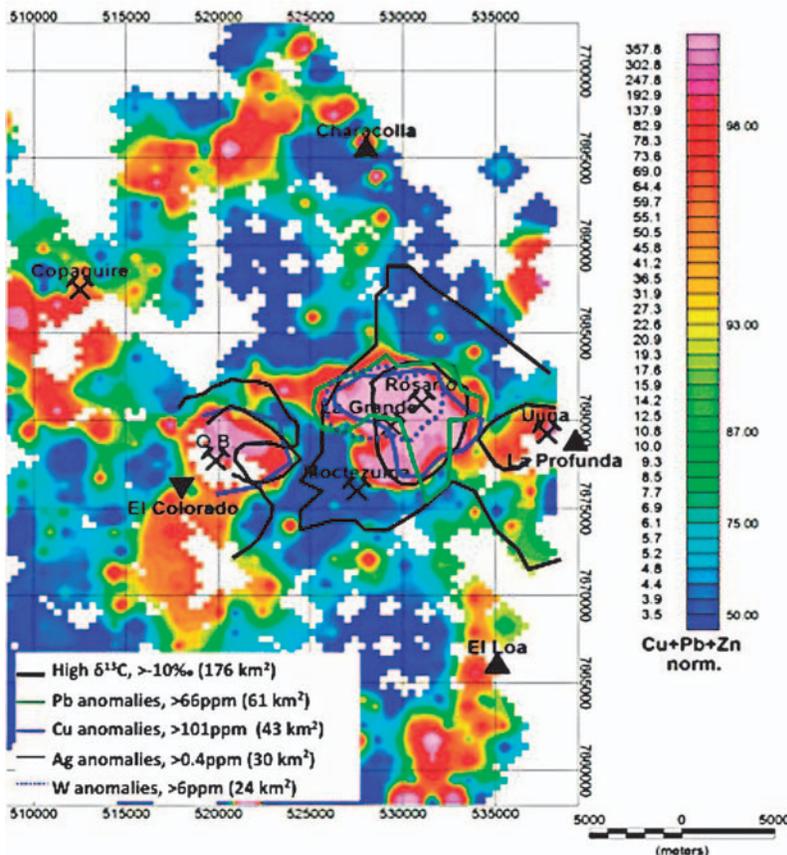


FIGURE 4 Areal extent of anomalous concentrations of pathfinder elements Pb, Cu, Ag and W, and $\delta^{13}\text{C}$ values, in outcrop samples at 2 km spacing from the Collahuasi district (Chile) are shown along with Cu+Pb+Zn concentrations normalized to the median value. The major porphyry Cu–Mo deposits of the district – Rosario, Ujina and Quebrada Blanca (Q.B.) – and the epithermal veins of Moctezuma and La Grande are shown, as are the prospect areas of Characolla, La Profunda, El Loa and El Colorado. High $\delta^{13}\text{C}$ values delineate zones of high magmatic CO_2 component that correspond exclusively to propylitic alteration (Djouka-Fonkwé et al. 2012). Anomalous pathfinder element concentrations and $\delta^{13}\text{C}$ values reflect primary dispersion and define a gradient in anomalous values that serve as a vector toward mineralization.

few techniques that can detect all the halogens. Other field-portable instruments now starting to be routinely used include portable short-wave infrared (SWIR), X-ray diffraction (XRD), and Raman mineral analyzers (TABLE 1). The potential benefits of real-time geochemical data acquisition are advancing with the Lab-at-Rig project (Hillis et al. 2014) that analyzes the chemical and mineralogical composition of drill material as it arrives at the drill-rig site.

The use of isotopes in applied geochemistry is still not normally routine. A partial exception is for environment-related work where commercial analysis of the light stable isotopes in water is available at a number of laboratories. However, analyzing isotopes as part of standard exploration and mining is sporadic and has been hindered by the lack of suitable machines at commercial laboratories. This is starting to change as the analytical techniques of continuous flow isotope ratio mass spectroscopy (CF-IRMS), off-axis integrated cavity output spectroscopy (OA-ICOS), and automated sample preparation systems are advanced (TABLE 1). Similarly, laser ablation ICP-MS techniques

(TABLE 1) have proven useful to exploration; however, cost-effective availability is currently an obstacle to the routine application of this technology to exploration programs.

EPILOGUE

The need to find more economically exploitable mineral deposits is exemplified by the historical use of Cu, a metal critical to the continued advancement of society. Over the past 100 years, Cu production has grown from less than 0.5 million tonnes per year to 18 million tonnes per year. In the past 25 years, we have used half of the copper ever mined. During the next 25 years, we will have to at least double the 600 million tonnes of Cu mined so far, even given the most positive recycling scenarios, to meet growing demands. Thus, the challenge will be to fill the gap between production and consumption of Cu—as well as all mineral commodities—and to do this with minimal perturbation of the total environment. Geochemistry will play a central role in the exploration and management of these resources, and, if applied intelligently, will be a benefit to society. ■

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Environmental Mineralogy: New Challenges, New Materials

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The close links between mineralogy and materials science are leading to major developments in how society deals more effectively with energy and environmental challenges. The fast expanding field of “environmental mineralogy” helps mitigate major environmental issues related to the impact of anthropic activities on the global ecosystem. Focusing on energy-related materials and environmental cleanup, this article shows how minerals inspire us to design new materials for advanced technologies needed for energy production, managing contaminated areas, and disposing of nuclear waste. We illustrate the environmental importance of nanomaterials, non- and poorly crystalline phases, and the interactions between minerals and ubiquitous microbial activity.

KEYWORDS: energy materials, nuclear waste, contamination, heavy metals, uranium, biominerals

INTRODUCTION

Minerals are central to our natural and technological environments. They interact with the biosphere, buffer greenhouse gases (including CO₂), impact soil quality, remediate contaminated sites, and can be used to recycle or dispose of certain industrial wastes (such as nuclear waste). Minerals are also a source of naturally occurring pollutants, such as arsenic, as a result of the breakdown of primary As-containing minerals, e.g. arsenious pyrite and arsenopyrite. On the other hand, trapping pollutants in low-solubility phases and at mineral–water interfaces efficiently isolates toxic components, which can be found contaminating industrial/mining sites (Brown and Calas 2012). Furthermore, it is now universally recognized that minerals play a key role in low-temperature geochemical processes involving living organisms.

Environmental mineralogy is a fast-growing multidisciplinary field, addressing major societal concerns about the impact of anthropic activities on the global ecosystem. This has fostered developments in advanced analytical and theoretical tools, including large user facilities, specialized laboratory instruments, and numerical simulation methods to study the complex chemical and biological processes that impact the environment. The greater element selectivity, spatial resolution, and surface sensitivity provided

by these instruments and methods have led to more robust environmental models.

A unified view of the environmental behavior of specific elements comes from determining their speciation in fluids, in minerals and on mineral surfaces and, more recently, at the biomineral interface. It is now recognized that the traditional boundaries between crystalline minerals, nanophases and nanoparticles, colloids and dissolved species are

artificial, which challenges the current definition of a mineral (Caraballo et al. 2015). Environmentally important minerals include poorly to non-crystalline phases, as well as nanoscale materials. “Amorphous” solids, including glasses and gels, possess short-range order and the mineral–water interfaces present specific 2-D structures leading to unique chemical reactivities that have direct environmental and societal impacts (Brown and Calas 2012). As a consequence, geochemical reactions proceed along a continuum based on well-defined local structures and extending into less well-defined, poorly crystalline and amorphous materials.

In addition to being witnesses of and active agents in our environment, minerals inspire us to design innovative materials for energy conversion and energy storage devices, as well as for novel strategies to manage contaminated areas and toxic waste sites. The crossover between the materials science and mineralogical communities has resulted in new energy- and environmental-related technologies, based on mineral-inspired materials and leading-edge synthesis techniques.

This article illustrates how this new appreciation of minerals, combined with the beneficial exchange between (bio)mineralogical, materials, and environmental sciences, leads to new, socially beneficial, technologies and to new ways to mitigate the environmental impacts of anthropic activities.

MINERALOGY INSPIRES NEW MATERIALS AND TECHNOLOGIES

The approaches used by mineralogists to predict and characterize mineral structures and properties are shared with materials scientists so that mineralogy and the materials sciences have a symbiotic relationship. Crossover between the two fields has inspired new synthetic approaches and materials that are beneficially impacting society.



Cryo-transmission electron microscope image of a bacterial cell surface encrusted by UO₂ and budding a vesicle, after reduction of aqueous U(VI) to U(IV) by *Shewanella oneidensis* strain MR-1. IMAGE FROM SHAO ET AL. (2014)

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For example, hydrothermal synthesis, which is widely used in experimental geology, produces high-quality quartz crystals for precision metrology used in satellite navigation, telecommunications, and global positioning. Synthetic cordierite ceramics, combining low thermal expansion coefficients with high refractoriness, good mechanical strength and open high porosity, are now used for catalytic converters that lower exhaust emissions in automobiles. Natural and synthetic zeolites, prepared using hydrothermal and sol-gel techniques originally developed for geochemical studies, are widely used in catalysis, in gas separation, and in ion exchange applications, which extend to medicine and chemical sensing. Similar sol-gel techniques are now a key method for producing nanoparticle powders, coatings, and composites, which include monolithic low-density phases, mesoporous solids, and inorganic-organic hybrid materials. Sol-gel production of rutile and anatase (both forms of TiO_2) permits control over their properties in pure and doped nanocrystals, leading to a wide variety of uses: in paints and sunscreens, as a photocatalyst for water splitting, for disinfection processes via reactions on the nanoparticle's surfaces, and for the development of light-to-energy conversion and storage.

New technological materials have also been developed as a result of high-pressure mineralogy experiments used to investigate deep planetary interiors (Brazhkin 2007). The laboratory synthesis of diamond and of boron nitride (cubic BN) has led to large-scale industrial production of these and other superhard, high-pressure phases. New technological applications have arisen from discovering that diamond can be deposited as thin films from the vapor phase and be synthesized from hydrothermal solutions, both having astrophysical and geochemical applications. The unique hardness, transparency, and chemical resistance of diamond make it the ideal material for diamond anvil cell experiments used to study minerals and other materials under extreme pressures. Perovskite-structured minerals, which dominate Earth's mantle, provide materials for technologies ranging from energy storage and conversion to communication science. Layered perovskites were the first high-temperature oxide superconductors; now, novel synthetic perovskites that contain organic cations and halide anions are being investigated as light-absorbing materials for photovoltaic applications (Grätzel 2014).

Recently discovered nitride spinels, $\gamma\text{-Si}_3\text{N}_4$ and $\gamma\text{-Ge}_3\text{N}_4$, synthesized in the stability domain of $(\text{Mg,Fe})_2\text{SiO}_4$ ringwoodite, have a wide bandgap of several electron volts, meaning such semiconductor materials could be used for devices requiring higher voltage, frequency and temperature operating conditions and could lead to new optoelectronic materials. Other new nitrides with mineral-related structures have also been discovered using high-pressure synthesis (Salamat et al 2013).

These and many other examples highlight the significant crossover between materials technology and mineralogical research that continues to benefit both fields of study and to have positive environmental and societal impacts.

CARBON NANOMATERIALS: FROM PLANETARY ATMOSPHERES TO NEW ENERGY DEVICES

Graphitic carbon is a widespread and well-known mineral and geomaterial that plays a significant role in determining society's energy and environmental agenda through its use in sorption, catalysis, and battery and fuel cell technology. The 2-D crystal graphene is a single graphite sheet that has remarkable physical properties that are being developed for nanotechnology applications (Lazzeri and Barreiro 2014).

Incorporating nitrogen within graphitic sheets provides chemically reactive sites and allows control over the resulting electronic properties. These new carbon nitrides are also being studied in relation to the complex organic aerosols, or "tholins," produced in the upper atmosphere of Saturn's moon Titan and that contribute to its characteristic reddish haze (Fig. 1A, B). These carbon nitride semiconductors provide redox catalysts that are being developed for sustainable chemical processing (Thomas et al. 2008). Related amorphous to nanocrystalline $\text{C}_x\text{N}_y\text{H}_z$ polymers contain rings of heptazine (C_6N_7) and/or triazine (C_3N_3) linked via $-\text{N}=\text{}$ and $-\text{NH}-$ groups into graphene-like sheets (Fig. 1C, D) that absorb light and that can generate H_2 through photocatalysis of water or methanol (Wang et al. 2009) (Fig. 1E, F). Carbon nitrides can also reversibly intercalate Li^+ between or within the graphitic layers, potentially leading to Li-ion battery electrodes with improved storage capacity (Veith et al. 2013). Nitrogen-rich carbon nanomaterials also appear to offer protection to metal nanoparticle catalysts used in hydrogen- or methanol-burning fuel cells: the N-doped materials retain a higher catalytically active surface area after exposure to many (>500) operational cycles compared with pure carbon supports (Mansor et al. 2014). Attention is now being paid to carbon nitrides of one or just a few layers, analogous to

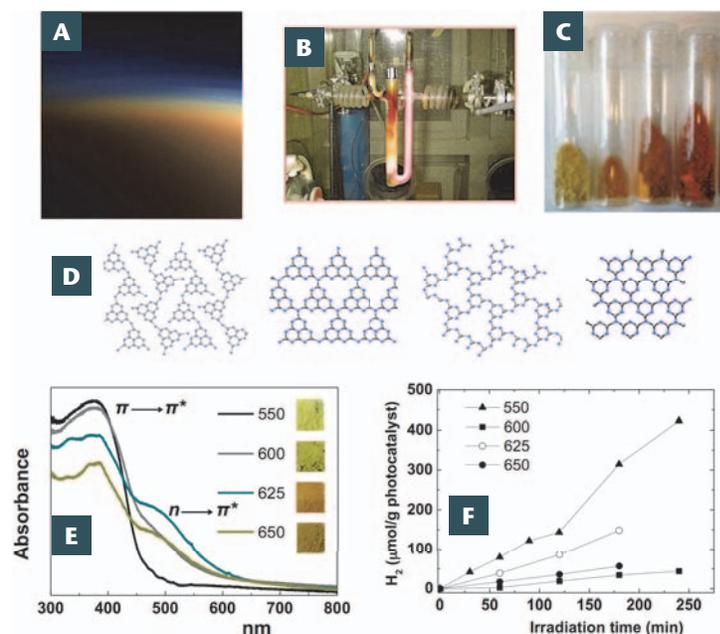


FIGURE 1 (A) Natural color image showing Titan's upper atmospheric haze associated with the presence of suspended aerosols. PHOTO COURTESY OF NASA/JPL-CALTECH (B) A laboratory experiment forming tholins (carbon nitride polymers) to mimic production of Titan's atmospheric aerosols from methane and NH_3 precursors under irradiation (Quirico et al 2008). (C) Samples of graphitic carbon nitride (gCN) produced in the laboratory from different chemical precursors exhibiting varying degrees of condensation within the C-N layers resulting in different electronic and optical absorption properties. These materials are related to the aerosols used to model Titan's tholins. Graphitic carbon nitrides are being developed as new materials for reversible Li^+ uptake as battery anodes for energy storage applications, photocatalysis for solar energy harvesting and conversion, and as fuel cell catalyst supports (Wang et al 2009; Mansor et al 2014). (D) Structural motifs found among gCN materials are based on heptazine or triazine rings linked by $-\text{N}=\text{}$ or $-\text{NH}-$ units with different states of polymerization within the layers that leads to tuning the electronic and surface chemical properties. (E) UV-visible absorption spectra of gCN materials as a function of synthesis temperature and layer condensation. (F) Rate of H_2 evolution with gCN photocatalysts exposed to UV-visible radiation using methanol as a sacrificial agent (Jorge et al 2013).

graphene but with semiconducting properties and higher surface chemical reactivities (Algara-Siller et al. 2014). Along with conductive “inks” produced from C-graphene and nanotubes in various solvents, layered carbon nitride materials will produce new families of paintable electrodes and photochemically active surface coatings. The interplay between geochemical and materials science studies of these remarkable carbon-based nanomaterials is leading to new developments in nanotechnology with implications for energy sustainability and the environment.

GLASS TO GEL TRANSFORMATION AND THE IMMOBILIZATION OF NUCLEAR WASTE PRODUCTS

The radioactive waste that is generated by nuclear power reactors raises complex scientific and societal issues. The main long-term risk is contamination of the biosphere by long-lived radionuclides released after groundwater alteration of spent nuclear fuel (SNF). Over the short term, SNF is usually stored at reactor sites. But long-term geological disposal of SNF involves the use of many types of materials and processes, all with a time-dependence related to the changing composition of SNF over time—a result of the limited half-lives of the fission products and the long half-life actinides that will dominate over the long term. During storage in a geological repository, SNF physical and chemical properties may be modified over time, as a result of radionuclide decay (Ewing 2015). In countries such as France, Russia, Japan, India, and China, SNF is reprocessed, and high-level radioactive waste containing fission and activation products and minor actinides (Am, Np, Cm) is ultimately vitrified in a borosilicate glass (Grambow 2006). Under conditions relevant to a geological disposal environment, the reactions encountered during glass alteration by water include ion diffusion, hydrolysis of the glass structure, formation of a low-porosity gel by sparingly soluble species (mainly Si, Al, Ca), and precipitation of various mineral phases (e.g. smectite-type clays, rare earth element phosphates, zeolites) (Gin et al. 2015). The processes governing the corrosion of nuclear waste glasses and the formation of an alteration layer at the glass–water interface

have been debated for several decades. Contrasting observations can result from different experimental conditions, including pH and composition of the alteration solution, temperature, or glass composition. For example, in closed systems, the glass alteration rate drops by 4 orders of magnitude due to development of a protective layer. In contrast, under open-system conditions, the activity of glass components remains low in the alteration solution, resulting in a high corrosion rate.

The structural relationships among glass components are consistent with the Pauling’s rules observed in minerals and they govern glass stability and chemical durability (Calas et al. 2014). Spectroscopic investigation of the glass–solution interface during alteration has provided a molecular-scale description of the processes operating at the interface and revealed dramatic variations in the local structure of the pristine glass and alteration layer (Fig. 2; Pèlerin et al. 2010). During alteration of a non-radioactive nuclear glass (SON68, the inactive equivalent of the technological R7T7 French nuclear glass) in deionized water at 90 °C, the drastic structural modification of the local environment of Zr, used as a molecular-scale probe of glass structure, indicates that a dissolution–precipitation process has occurred as a result of the hydrolysis of the silicate framework (Fig. 2A). This may explain the observation by transmission electron microscopy of a sharp compositional and structural interface between pristine glass and the glass alteration layer during glass alteration in deionized water (Hellman et al. 2015). However, during alteration under near-saturation conditions with respect to the glass at pH 9, the local structure of the glass is retained, illustrating an in situ condensation process (Pèlerin et al. 2010). This results in lower leaching rates and higher glass durability in the short term. The absence of hydrolysis under these pH conditions is consistent with recent experimental data on glass alteration (Gin et al. 2015). In contrast to Zr(IV), cations such as Fe(III) or Al(III) do not participate in the preservation of the silicate framework building the alteration layer (Fig. 2B). A major question remains concerning the compositional dependence of both the initial alteration rate and the residual corrosion rate

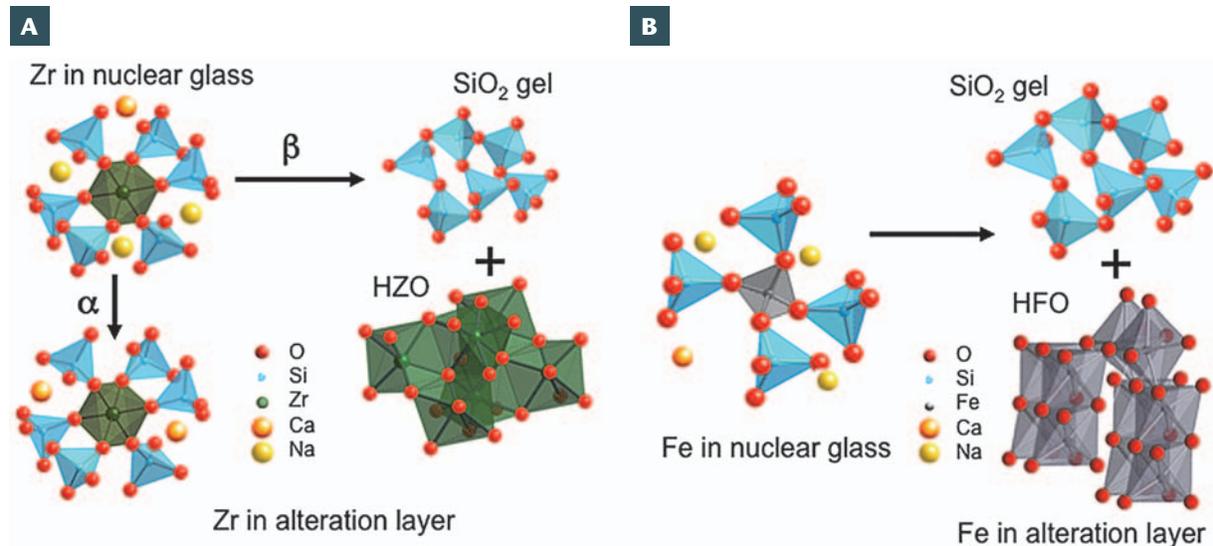


FIGURE 2 Modification of the local structure around Zr (A) and Fe (B), which are used as structural probes during the alteration of an inactive borosilicate nuclear glass, SON68. (A) In the pristine nuclear glass, octahedral Zr (green atoms) is in a networking position in the glass network, with well-defined Zr–O–Si linkages. During glass alteration under silica-saturated conditions (α), the local structure around Zr(IV) is retained in the alteration layer, a direct illustration of an in situ condensation process. During alteration in deionized water (β), the Zr–O–Si linkages disappear.

Hydrous zirconium oxides (HZO) clusters (7-coordinated Zr) and silica gel domains coexist in the alteration layer, as a result of a dissolution–precipitation process. (B) In the pristine nuclear glass, tetrahedral Fe(III) (grey atoms) is a network-former. During alteration, either in silica-saturated conditions or in deionized water, Fe(III) converts to an octahedral coordination, leading to hydrous ferric oxides (HFO) coexisting with a silica gel in the alteration layer.

over the long term: the long-term stability of a nuclear-waste glass depends not only on the leaching processes at the glass–solution interface but also on the long-term stability of the alteration layers. New types of nuclear waste will be generated by the use of mixed oxide (plutonium/uranium) nuclear fuel (MOX) and other alternate nuclear fuels, and by future generations of nuclear reactors, such as the GEN IV. Understanding and predicting the long-term behavior of nuclear wastes, either through direct storage of SNF or the disposal of vitrified matrices resulting from spent fuel reprocessing, will require further research on the complex interactions between these man-made materials, the hydrosphere, and the biosphere.

MINERAL INTERACTIONS WITH THE BIOSPHERE: ENVIRONMENTAL APPLICATIONS

Microorganisms are known to affect the evolution of minerals, rocks, and ore bodies. They also act as biochemical “factories” for energy production and are useful in environmental waste management. Some microorganisms incorporate protein-based mechanisms for mediating redox reactions in their anaerobic metabolic cycles, leading to the production of methane or hydrogen. This property can now be industrially harnessed in biofilms to provide microbial fuel cells for environmentally sustainable energy production. Proteinaceous conducting “nanowires” extend from the surface of some bacteria and allow them to deliver electrons at distances up to several hundreds nm from the bacterial cell and so play a role in electrical transport and energy storage (FIG. 3A). The bacteria are also capable of catalyzing the reductive precipitation of toxic elements (FIG. 3B), including metal contaminants. Precipitates bound to extracellular polymeric substances (EPS) or membrane vesicles (Shao et al. 2014) improve survival rates of bacterial populations that are capable of detoxifying the cell environment at the same time as they immobilize toxic elements by producing solid (nanoscale) phases. The interplay between biology, geochemistry, materials science, and environmental science constitutes one of the frontier interfaces of modern science that impact on human welfare.

A main avenue by which microbial processes are being harnessed for applications is through environmental remediation. Contamination of the subsurface with toxic metals as a result of natural processes, mining, ore processing, and other industrial activities can be extensive, making conventional remediation approaches (i.e. excavation or pump-and-treat) impractical. However, stimulating the indigenous microbial community by the addition of a source of electrons (e.g. molasses), one can establish reducing conditions and promote the enzymatic or abiotic reduction of a redox-active metal. This application is particularly relevant in the case of uranium or chromium whose reduced forms are expected to be immobilized and to persist as an in situ waste. Bioremediation of sites contaminated with Cr(VI) has been attempted with amendments of organic matter that stimulate metal-reducing bacteria. The reduction of Fe(III) by *Shewanella alga* (strain BrY) results in aqueous Fe(II) that subsequently reduces Cr(VI) to Cr(III) and oxidizes Fe(II) back to Fe(III) (Hansel et al. 2003). The resulting Fe(III)–Cr(III) hydroxide $[\text{Fe}_{1-x}\text{Cr}_x(\text{OH})_3 \cdot n\text{H}_2\text{O}]$ is insoluble and effectively sequesters chromium. As Fe(III) reduction proceeds further, the fraction of Cr in the hydroxide increases, ultimately producing $\text{Cr}(\text{OH})_3 \cdot n\text{H}_2\text{O}$, which is slightly more soluble but still represents a sink for Cr.

Bacteria in the genus *Shewanella* have the unusual ability to transfer electrons via extracellular electron transfer (EET), which enables them to carry out the remarkable feat of respiration using solid mineral phases. From an environmental perspective, *Shewanella* catalyzes the reduction of Fe(III) oxy/hydroxides and causes their transformation to magnetite or other Fe(II)-bearing minerals; biologically produced magnetite can then impact the mobility of metal/metalloid contaminants in the subsurface. This can be illustrated by the oxidation of the more toxic As(III) form of arsenic to the less toxic As(V) by biogenic magnetite resulting from the reduction of lepidocrocite by *Shewanella putrefaciens* (Ona-Nguema et al. 2010). Arsenic oxidation results from a reaction initially involving Fe(II) oxidation by molecular oxygen, which leads to the formation of hydroxyl radicals or other highly effective oxidants (e.g. $\bullet\text{O}_2^-$ and H_2O_2). These can then oxidize As(III) to

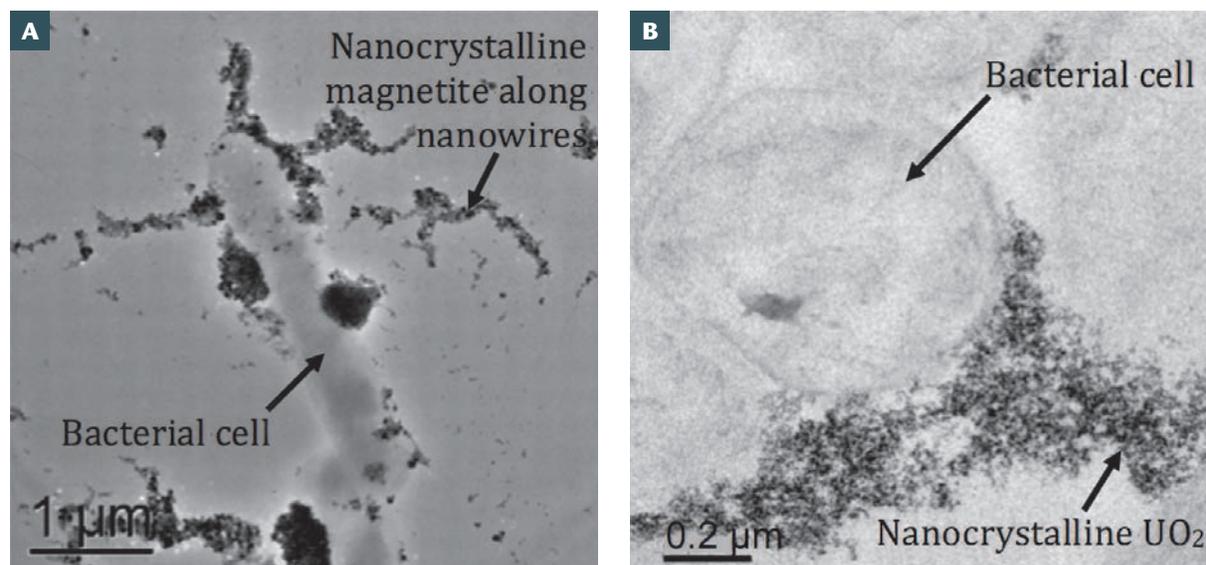


FIGURE 3 (A) Transmission electron microscope (TEM) images of whole mounts of *Shewanella oneidensis* MR-1 bacterial cells incubated in an aqueous suspension of silica hydrous ferric oxide. Nanocrystalline magnetite precipitates along extracellular features (i.e., nanowires) due to electron transfer facilitated by the

bacteria. IMAGE COURTESY OF GORBY ET AL. (2006). (B) TEM image of thin section of *Shewanella oneidensis* MR-1 with nanocrystalline UO_2 precipitates resulting from the reduction of aqueous U(VI) by the bacterium.

As(V) which can in turn adsorb onto the iron (hydr)oxides produced during the oxidation reaction. There are many examples of *Shewanella* and other metal-reducing bacteria impacting on the mobility of metal contaminants in ways that are beneficial to the environment.

Microorganisms, such as bacteria, are, of course, already present at highly contaminated sites, often bound to mineral surfaces by extracellular polymeric substances in the form of biofilms, and they can play an important role in the speciation of contaminants. Bacterially mediated biomineralization of a contaminated area may result from local modification of chemical conditions (e.g. pH, redox) or from passive mineral precipitation in the presence of organic matter. Acid mine drainage provides examples of bacterial mitigation of inorganic pollutants. For example, spatial and seasonal variation in microbial communities correlates with distinct trapping of arsenic by different bacterial strains. Fe-oxidizing bacteria and As-oxidizing bacteria promote the precipitation of Fe- and As-containing mineral phases, mostly in association with extracellular polymeric substances (Benzerara et al. 2011).

In the nuclear fuel cycle, the legacy of waste from uranium mining, milling, and processing has led to concerns about potential contamination in densely populated areas unless improved storage methods are developed. The type of reducing environments that are encountered in organic-rich soils, including peat horizons, preferentially concentrate uranium. Microbial reduction of U(VI) results in two potential products (Bernier-Latmani et al. 2010). One of these is uraninite, as 5 nm-size particles that effectively immobilize U(IV) and are relatively resistant to re-oxidation. The second is an insoluble “noncrystalline U(IV) phase” associated with bacterial biomass, the structure of which remains ill-defined. This latter product can occur in laboratory sediment columns, alpine meadows, or wetlands

(Wang et al. 2013). Its continued presence in sediments post-remediation results from the cooperative action of sulfate- and metal-reducing bacteria (Bargar et al. 2013). The “non-crystalline U(IV) phase” is more labile than UO_2 (Cerrato et al. 2013) but represents, in most cases, a net uranium sink under reducing conditions. However, there is evidence that uranium can also associate with iron-rich organic-matter colloids of microbial origin, forming suspensions of mobile U(IV)-bearing particles (Wang et al. 2013). The string-shaped organic matter in these colloids includes iron-bearing nanoparticles (Fig. 4), as well as uranium. These species defy the common notion that U(IV) is always an immobile phase in the environment.

By directing electrons away from the bacterial cell, *Shewanella* and other species produce electrical currents that can be exploited in man-made microbial fuel cells. These devices harness the electrons produced by the oxidation of organic matter to generate electricity for a wide range of applications. Although the level of electrical current is low, microbial fuel cells can be used to power deep-water sensors, measure biological oxygen demand, or produce hydrogen from wastewater and other biomass resources (Ge et al. 2014). Furthermore, newly described urine-powered microbial fuel cells could represent a new technology for sending distress signals (Winfield et al. 2015).

The mechanisms of electron transfer tens of microns away from the cell surface include the production of long nanowires that represent extensions of the outer membrane and periplasm (Pirbadian et al. 2014). These structures include multiheme cytochromes that are responsible for extracellular electron transfer and suggest future possibilities for bionanotechnology to construct biological nanowires.

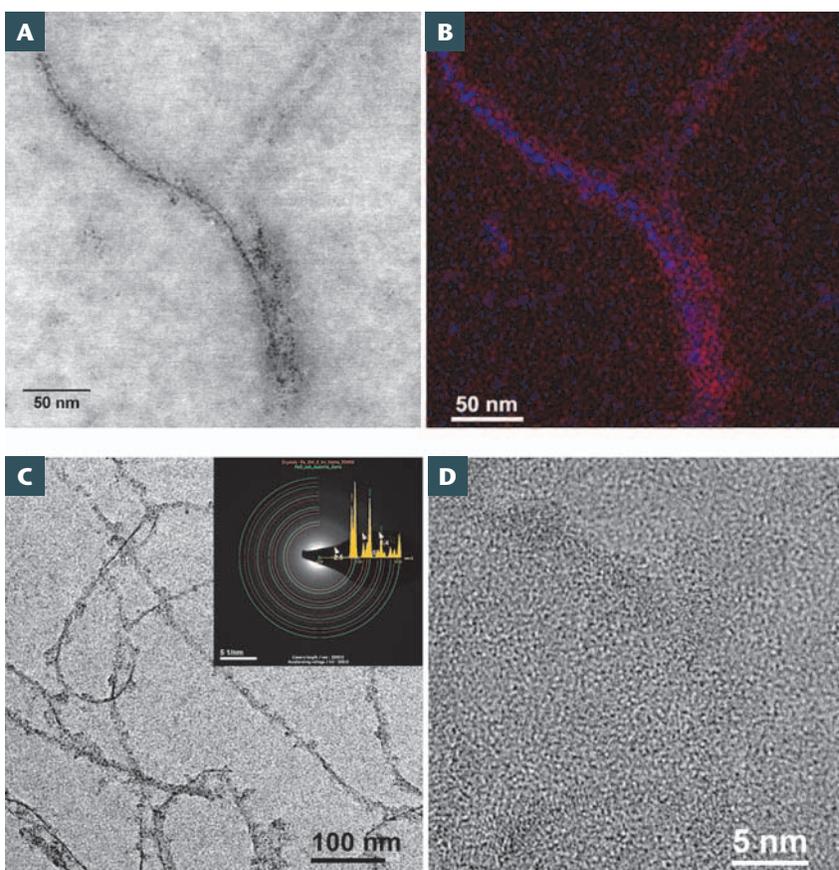


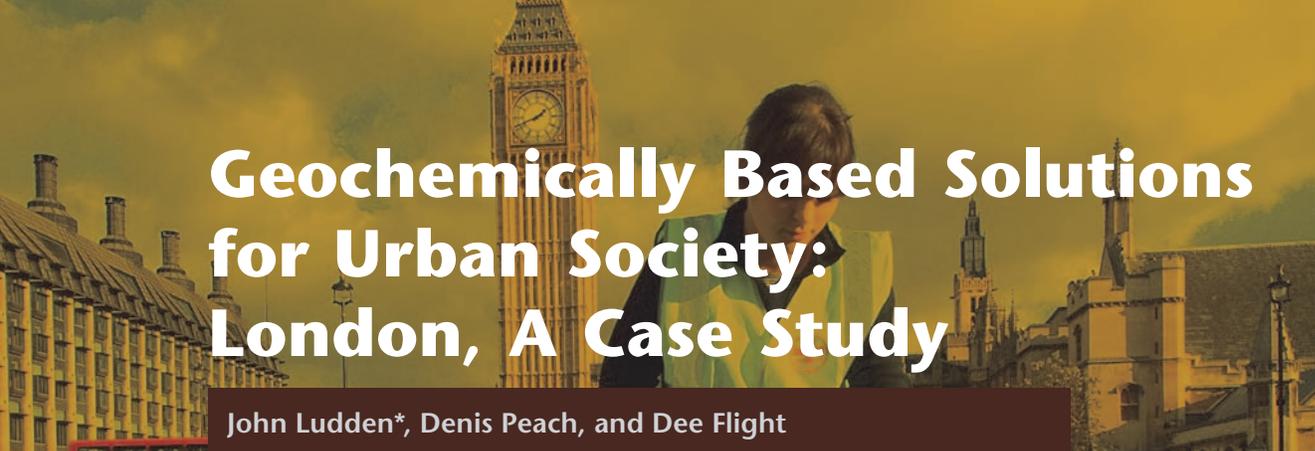
FIGURE 4 Transmission electron microscope (TEM) observations of U-bearing colloids in porewaters. **(A)** Scanning TEM image of U-bearing colloids in porewater. **(B)** The corresponding iron (Fe, blue) and carbon (C, red) energy dispersive X-ray spectroscopy (EDS) map of Figure 4A. **(C)** TEM image of U-colloids from the same sample as A and B; **INSET:** corresponding selected area electron diffraction pattern interpreted as a combination of trigonal $Fe(OH)_2$ and cubic FeO phases. **(D)** High-resolution TEM image of small U-bearing crystallites. Point EDS analyses on similar colloids show low, but statistically relevant, U concentrations in association with Fe and C (Wang et al. 2013).

CONCLUDING REMARKS

Minerals are key players in the environmental and technological issues that are important to modern society, especially when considering the importance of new “phases” such as gels and nanomaterials and the omnipresent reactivity of mineral–water interfaces, because such materials are now, or have the potential to become, exceptionally useful. Biological activity leads to the formation or alteration of mineral phases in nearly all environmentally relevant situations. Mineral–microbe interactions are being harnessed and developed for new energy technologies and for environmental cleanups. Mineralogical research has led the way in developing new approaches for materials synthesis and for in situ characterization techniques, while, at the same time, inspiring innovative materials based on structure–property relationships. In return, advances in materials research impact on environmental studies and widen our knowledge of mineral behavior. This symbiotic relationship is both healthy and necessary for our science and our students, who acquire experience and flair for mastering complex systems and problems in the Earth and environmental sciences.

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Geochemically Based Solutions for Urban Society: London, A Case Study

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Geochemical data and models can provide a baseline by which to compare changes in the composition of surface waters, groundwater, the atmosphere, soils, and sediments in the coastal megacity of London. The usefulness of geochemical data is dependent on effective communication, which can be challenging. Geochemical tools and approaches can provide evidence to underpin decision making as well as solutions to environmental problems in cities. Geochemists must move beyond simple provision of evidence to describing a solution and then convincing politicians to put this solution into practice.

KEYWORDS: London, geochemistry, soils, water, atmosphere, communicators

INTRODUCTION

As Earth and environmental scientists, our focus is almost exclusively on providing evidence, but not specifically on offering solutions for environmental pollution which require political support. We can provide the boundary conditions (baselines) to a city, such as the weather, river flow, tides, and underlying geology. However, to truly understand the impact of a city on its environment, we must integrate these data with social, engineering, and economic factors in order to provide feasible scientifically based responses to the evidence and to enhance quality of living in megacities. As London (UK) is extremely well monitored and has a history of long-term measurements, we can use London as a scalable case study to examine how a city affects the Earth system. This, of course, includes approaches to de-convolute that impact and get back to a true understanding of what is a baseline and how useful the concept of a baseline might be.

London, which sits on the River Thames, has been settled since early Roman times, and, as such, it bears the legacy of its history and of associated industry and contamination. London clearly demonstrates the concept that cities obey scaling relations with population size, characterizing, as Bettencourt et al. (2007) identified, rates of innovation, wealth creation, patterns of consumption, and human behaviour, as well as the properties of urban infrastructure.

Most cities are continuously growing – a phenomenon known as urbanization – and, as Bettencourt et al. (2007) say, ‘as population grows, major innovation cycles, which refine and redefine the quality of livelihoods, must be generated at a continually accelerating rate to sustain growth and avoid stagnation or collapse’. We can, thus, expect the metropolis of London to continue to grow and prosper. London is a city of ~8.5 million people living in

1570 km² with a gross domestic product of ~£600 billion and, as such, requires continued environmental quality control.

London provides a test case of how a city can live within its landscape. Although ‘urban geochemistry’ (see *Elements*, vol.8, no.6 December 2012) has mainly focused on the problems of environmental pollution, in this article we present some of the issues that are largely a management problem for city planners. We also discuss how we can use information that is based

on a geochemical assessment of London (and other cities) to make living in cities safer, better, and sustainable.

THE IMPORTANCE OF LONG-TERM RECORDS AND THE ROLE OF GEOCHEMISTRY

There are extensive geochemical records, stretching back many decades, on the River Thames and its tributaries; on London’s local atmospheric conditions, soils, and groundwater; and on the Thames Estuary and its sediments. For example, herbage from 1945 to 1990 is stored in Rothamsted Research Station (Harpenden, UK). This stored material acts as a perfect archive of nuclear accident fallout (as from Chernobyl, Russia) from isotopes such as ¹³⁷Cs and ²³⁹Pu, the specific activities of ²⁴⁰Pu (Bq/kg), and of the ratios ²³⁸U/²³⁵U and ²⁴⁰Pu/²³⁹Pu. Research using this archive provided evidence, for the first time, that plutonium contamination originating from America’s Nevada Desert atmospheric weapon tests in 1952 and 1953 extended eastwards as far as north-western Europe (Warneke et al. 2002). As such, this baseline can be used to validate or dismiss claims of local radioactive fallout, such as the alleged nuclear pollution of a wide area around the Royal Air Force Station Greenham Common (Berkshire, UK). While not elaborating on this particular case, the existence of these archives and the ability of geochemists to produce high-quality isotope data proved essential in showing that *local* radioactive fallout was not the cause of the plutonium contamination. This is but one example of the power of defining a baseline composition. Clearly, a city such as London would have several baselines: pre atomic bomb testing, pre industrial revolution, pre large-scale use of nitrate fertilisers, pre extensive use of diesel in vehicles. Environmental impacts, of whatever sort, must be defined relative to appropriate baselines.

The Thames has a record of nitrate concentration measurements that goes back to the mid-19th century (Howden et al. 2011), which is valuable in assessing the long-term nitrate input from agriculture. With 60% of its baseflow coming

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from groundwater knowing how the Thames waters are affected by the delayed input from nitrate-containing groundwater aids in our ability to predict future nitrate levels and to meet requirements imposed by governments.

Communicating data analysis, so as not to alarm the population, is a challenge. Moreover, deciding how to impart critical information that may have an impact on the population while at the same time keeping the information in context with respect to norms and measurement uncertainty is not easy. It might be said that communicating the importance and value of our science to non-specialists has become a science in itself.

As stated earlier, geochemists typically provide the evidence and not the solution. They collect data and offer analytical options that can influence a government's policy-making process at all levels. The three examples below show how geochemical knowledge has impacted society and a region's economy, but does not necessarily provide the answers or solutions to the societal problems highlighted by this knowledge.

1. Air pollutants reduce human lifespan in the UK by an average of 8–14 months and by up to 9 years for the most vulnerable groups. In addition, health costs are estimated to be comparable to those of alcohol and drug misuse (COMEAP 2010).
2. Nitrogen pollution costs each person in Europe around £130–£650 (€150–€740) a year (Sutton et al. 2011).
3. The EU Water Framework Directive (2000) assessment of the status of groundwater bodies (Environment Agency 2009) indicated that over 40% were failing to achieve their environmental objectives; 60% of these failures were due to agricultural sources of nitrate. The second largest cause of status failure is pesticides.

London, our case study, is polluted at variable levels and, though the worst polluting activities are now largely past, the pollution itself is still found in the pore waters of London's Chalk aquifer, in river and estuarine sediments, and in local soils. Historic pollutants can be mobilised through bad planning and engineering errors. European norms and similar guidelines need to take account of regional variability and historical pollution. Society today is potentially creating problems for the future with rising levels of aerosol use, rare-element waste products, and a host of unknown effects such as may be produced by the variety of engineered nanoparticles in consumer products that are being increasingly introduced into urban settings.

THE THAMES BASIN

The Thames Basin covers just over 16,000 km² and, with London as the UK's capital at its heart, it is a river basin supporting over 13 million people in a restricted catchment. The River Thames rises from the Jurassic limestone of the Cotswold Hills in Gloucestershire County and flows approximately 235 km to its tidal limit at Teddington Lock in London. At this point, ~60% of the river flow is baseflow (i.e. the amount of water contributed from groundwater systems). Although the UK is considered a wet country, the Thames Basin around London is one of the driest in the country, receiving an average of 690 mm of rain compared to the national average of 897 mm. About 40% of the public water supply in the Thames Basin comes from groundwater derived from the basin's Chalk aquifer, which is its principle aquifer (Environment Agency 2009; Bloomfield et al. 2011)

The geology of London is shown in FIGURE 1. The city is built largely on river terraces, which are underlain by Palaeogene sands and clays (Royse et al. 2012). The Upper Cretaceous Chalk Group (green in the figure) underlies the basin as a whole and has structurally controlled its development. From borehole and geophysical data, the British Geological Survey (BGS) has been able to provide a 3-D reconstruction of the geology (e.g. Aldiss et al. 2012). This geological model is one of the most advanced for any major city. Of particular importance is the detailed reconstruction of the 40–60 m of sediments that overly the Chalk Group: this is critical in defining not only infrastructure, such as rail construction projects and the sewer and drainage systems, but also controlling groundwater flow and pollution pathways in the subsurface and for modern utilities such as the installation of ground-sourced heating systems.

This geological model provides detailed information for ongoing engineering and construction works in London, and the geology also controls the baseline geochemistry of the soils.

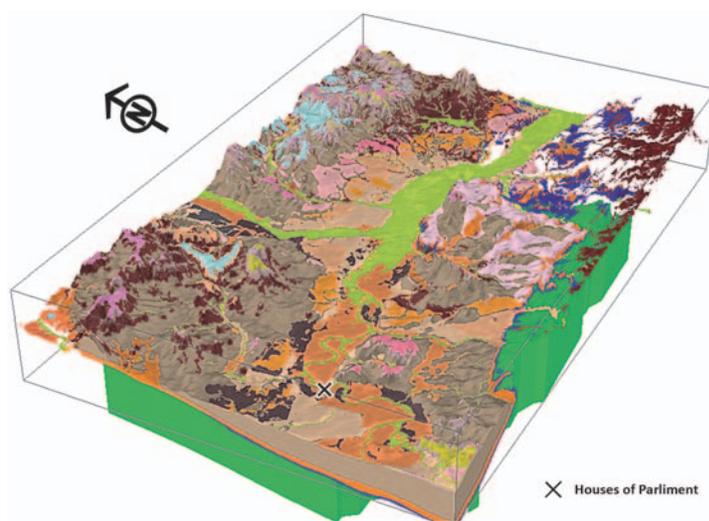


FIGURE 1 Three-dimensional geological map of London (UK) viewed looking from the west across London towards the Thames estuary in the east. For detailed discussion, see Royse et al. (2012) and Mathers et al. (2014). From depth to surface, the Chalk Group (dark green) is overlain by the Thanet Sand Formation (dark blue), the sands, silts and clays of the Lambeth Group (orange), and the London Clay Formation (beige). The other coloured overlayers (pink, yellow, tan, and brown) are various clay and gravel formations and glaciofluvial deposits. REPRODUCED WITH THE PERMISSION OF THE BRITISH GEOLOGICAL SURVEY ©NERC; ALL RIGHTS RESERVED

THE SOILS OF LONDON

The BGS London Earth survey (BGS 2011) collected soil samples at a density of four sites per square kilometre, comprising over 6000 sample sites (sampling density shown in FIG. 2) across the entire London area. At each site, over 50 inorganic chemical elements and properties were measured, a selection of which are now available online (mapapps.bgs.ac.uk/londonearth/londonearth.html). The survey used a systematic and unbiased approach that was independent of land usage or of contaminated sites. This ensured that the survey measured the *baseline geochemistry*, but not necessarily the unmodified original soil compositions. This type of mapping ensured robust results that could be compared to other citywide and national surveys and could, in theory, provide insight into the environmental impacts of urbanization and industrialization, as well as characterizing the geochemical baseline of the UK's most populous city.

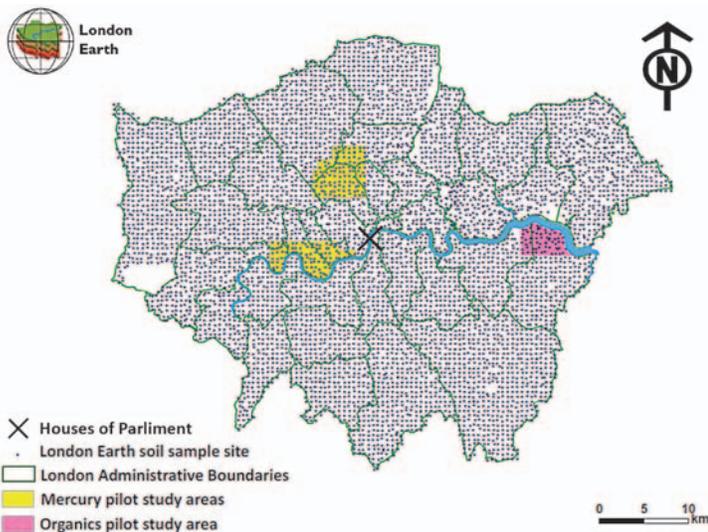


FIGURE 2 Points are locations of top soil samples from the London Earth Project. Pink represents a study area for polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) (see Vane et al. 2014). Yellow represents a mercury pilot-study area. USED WITH PERMISSION FROM THE BRITISH GEOLOGICAL SURVEY (BGS 2011)

It is possible to deconvolute geological from anthropogenic signals. FIGURE 3 portrays the composite chemistry of silicon, aluminium, and calcium and, if superimposed on the geological model in FIGURE 1, neatly divides the chalk and London clay bedrock and allows identification and quantification of the parent material to the soils. Thus, the 'geogenic' signatures that will dominate rural soil chemistry can also be detected in London's urban region. As described by Appleton et al. (2013), soil parent geology explains ~20–33% of the variance of most elements. Interestingly, it is still quite possible to see that the primary control of the parent rock has not been destroyed even in a major urban centre that has been subjected to intensive urban development, destruction, and redevelopment over many hundreds of years.

The variance of some other elements – including As, Cr, Ba, Pb, Sb, Sn and Zn – is influenced by a mixture of geogenic control (generally <20%) and anthropogenic control (80%). FIGURE 4, for example, shows the distribution of Pb in soils across London. Centrally located highs are focused on high-density population centres and are most likely related to the use of leaded fuel. Other anthropogenic sources are likely to be locally important (e.g. leaded paint); London is ~5 times higher in this latter regard than local rural areas.

As geochemists, we should ask ourselves how our data is used or understood by the general public. As the data are now freely available to the general public and to government and local councils, our biggest challenge is to communicate to the public the meaning of the data we have collected and analysed. Simple messages such as converting units into a form easily understood by the public – '5 mg/kg is equal to 5 grains of sugar in a one kilo bag of sugar' – are important for ensuring public understanding. Equally important is communicating the errors associated with the analyses and averaging processes, and informing the public how elements may be processed by the human body. Geochemists must work with specialists in other fields (e.g. physicians, politicians, media experts) to find the best way to communicate this important information.

London's soil geochemistry data will help to define the background concentration of over 50 elements, including potentially harmful elements such as lead (Pb), arsenic (As),

and nickel (Ni) in soils of the urban and developed areas. In general, geochemists make datasets on the environment available so that individuals, local councils, developers, and organizations can make informed decisions about environmental and health risks (Anders et al. 2013). This information may also prompt local authorities to do follow-up studies.

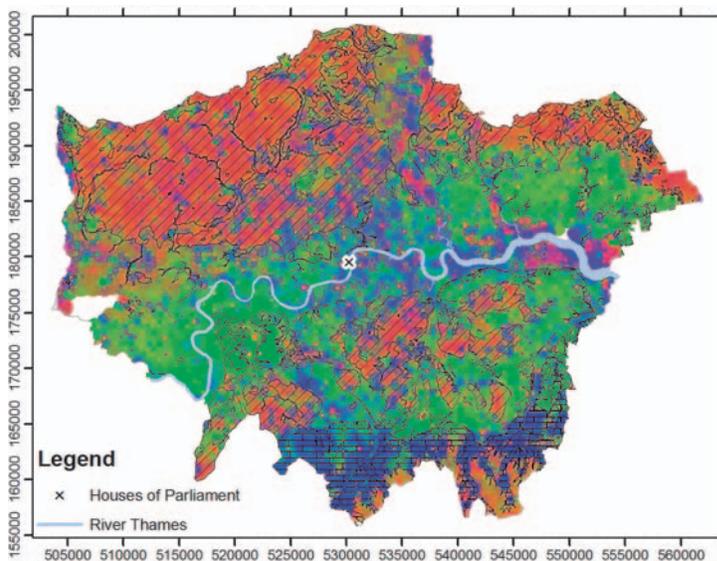


FIGURE 3 London's topsoil geochemistry as taken from the British Geological Survey's Geochemical Baseline Survey of the Environment (G-BASE) project. Regional topsoil samples were collected at a depth of ~5–20 cm with a sampling density of one sample per 2 km² (Johnson et al. 2005). In the London urban area, soil samples were collected from open ground on a 500 m grid at a density of approximately 4 samples per km² (BGS 2011; Flight and Scheib 2011). Sample preparation, analytical methods, and quality control procedures are described in Allen et al. (2011) and Johnson (2011).

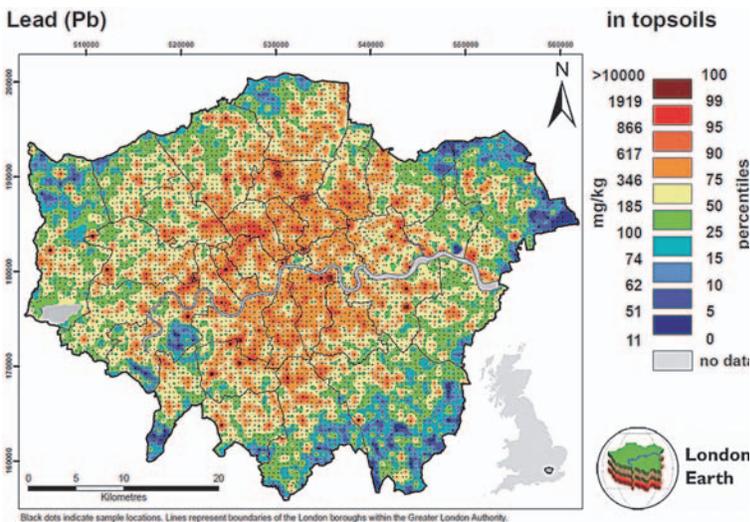
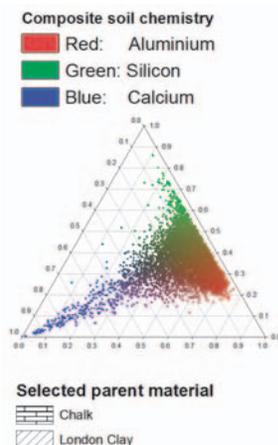


FIGURE 4 Map of lead (Pb) distribution in London's topsoil as taken from the London Earth project.

A significant result of geochemically analysing the soils of London has been simply identifying and locating the polluted areas and pollution pathways, most of which are a legacy of past industrial activities. Hopefully, planners will take this information into account when deciding whether to leave a particular site in its current state (i.e. brown-field), whether to go through with complete site remediation, or whether, for example, to avoid dredging certain parts of the Thames and risk sediment remobilization in estuarine and riverine areas.

NITRATES IN THE RIVER THAMES AND THE 'NITRATE TIME BOMB'

The Thames Basin is in a chalk-dominated catchment area that exemplifies all of the problems pertinent to groundwater, including groundwater flooding and contamination issues. Nitrate concentrations for the Thames River at Hampton have records dating back to 1868 (Howden et al. 2011). These form the basis for modelling nitrate export from the Thames Basin and offer some interesting observations, e.g. nitrate export was 50 kg ha^{-1} prior to WWII but has now tripled, as shown in FIGURE 5A, in post-war years because of the increased use of fertilizers.

High nitrate in water is an economic and human health problem that often leads to water eutrophication. High-nitrate concentrations in drinking water may also reduce the ability of human blood to carry oxygen and,

in the very young, may cause 'blue baby syndrome' (Bryan 2006). The costs of nitrate treatment for the UK water industry rose from £16 million (\$25 million) per year in 2000 to £58 million (\$90 million) per year in 2005 (DEFRA 2006). The domestic and industrial water supplies to London comes from the river and groundwater. In dry weather and droughts, all the water in the river originates from groundwater. However, the river water may have been used and recycled (e.g. treated sewage effluent) several times on its journey from the Cotswold Hills through Oxford and Reading and into London.

Given that the Thames has a strong groundwater influence, remediation of the river depends on the rate of nitrate removal through biological and physical processes in the groundwater system. This is shown in FIGURE 5B where the nitrate input function is described. The black dots show individual pore-water nitrate concentrations from 300 cored boreholes in the BGS database. These concentrations have been back-plotted to give nitrate concentrations at the base of the soil zone at their year of recharge, which has been calculated using depth in the profile and the estimated undersaturated zone travel time of peak nitrate. The red solid line shows nitrate input spans derived from literature data; the blue crosses show average nitrate concentration for a given year calculated from the pore-water data. The nitrogen application rates ($25\text{--}70 \text{ kg N ha}^{-1} \text{ y}^{-1}$) indicated in FIGURE 5B reflect the historic different levels of industrialization and the introduction of measures to reduce the fertilizer application rate.

Wang et al. (2012) define the nitrate concentrations in groundwater as a 'nitrate time bomb' that could affect not just London but the UK as a whole. They describe a simple process-based geographical information system (GIS) model that simulates nitrate transport in the unsaturated zone of rock and soil and that predicts the arrival time for peak nitrate loading for the UK's water table. This GIS model links the nitrate input function (the temporally varying but spatially uniform leaching of nitrate from the base of the soil) to the factors of unsaturated zone thickness and lithological dependence rate of nitrate transport through the saturated zone and so makes an estimate of the arrival time of nitrate at the water table.

Restoring surface nitrate concentrations in the London region to values typical of the pre-intensification period (i.e. pre-1940s) would require massive basin-wide changes in land use and management approaches that would compromise food security and take decades to be effective. This is clearly not practical. However, groundwater modelling and understanding nitrate baselines will be essential to inform future policy decisions on London's long-term land management and water use.

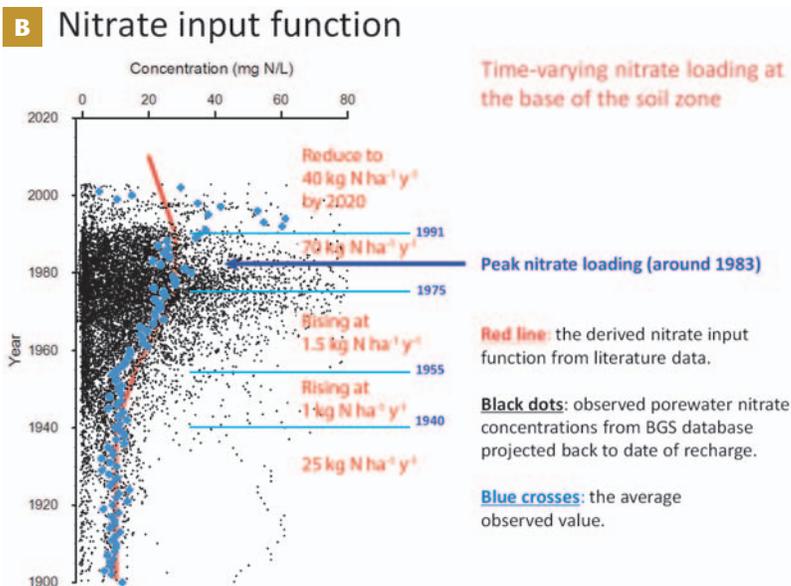
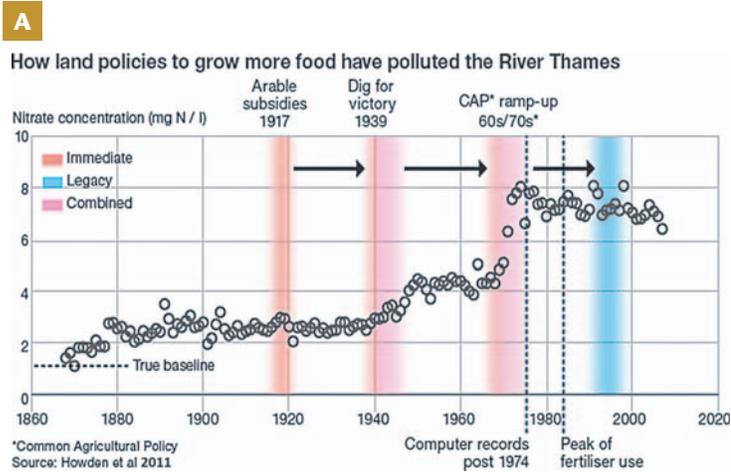


FIGURE 5 (A) Nitrate concentrations in the River Thames as measured at Teddington Lock since 1868 (Howden et al. 2011) showing how land policies over the last 100 years have impacted on pollution levels. (B) Application of nitrogen fertilizers increased from pre-WWII rates of $25 \text{ kg N ha}^{-1} \text{ y}^{-1}$ to $\sim 70 \text{ kg N ha}^{-1} \text{ y}^{-1}$ in the early 1980's. Nitrate levels (black dots) in groundwater from 300 wells across the UK reflect this increase as shown by the nitrate input function (red line) and average observed levels (blue crosses). Wang et al. (2012) estimate that peak nitrate levels have not been reached in the water table, suggesting a future 'nitrate time bomb' that will negatively impact groundwater quality.

ATMOSPHERIC POLLUTION IN LONDON (THE CLEARFLO EXPERIMENT)

Atmospheric conditions in London, in contrast to legacy problems derived from polluted soils and river sediments, depend in part on the current use of fuels and on present industrial processes. And, these atmospheric problems are increasingly in the public eye. For example, on 5 March 2015, the *London Evening Standard* ran the following article: 'Toxic London: Shock Figures Show That We're Breathing the Filthiest Air in Britain? Top Pollution Hotspots are Marylebone and Park Lane From Park Lane to East Ham, the City's Air is Filthy'. This headline was based on high NO₂ levels that had arisen due to a temperature inversion. People are concerned as they see and feel this as a direct effect on their health.

To monitor and react to London's potentially poor air conditions, the ClearfLo experiment (Clean Air for London) was set up (www.clearflo.ac.uk). This was designed to provide long-term integrated measurements of the meteorology, composition, and particulate loading of London's urban atmosphere. Measurements were made at street level and at elevated sites, complemented by modelling to improve predictions for air quality. This experiment took place during the winter of 2012 and during the London summer Olympics.

For the first time in London, or any major city, the ClearfLo experiment aimed to:

1. Establish an infrastructure to measure meteorological conditions, gaseous composition, and particulate loading
2. Determine the meteorological processes that control London's urban boundary layer; the atmosphere in which most of the planet's population now lives
3. Determine the chemical processes that control the concentrations of ozone (O₃) and NO₂
4. Determine the chemical and physical processes that control the size distribution and chemical composition of particulate matter and identify its sources
5. Evaluate the strengths and weaknesses of air quality models

The ClearfLo monitoring and measuring infrastructure was installed at multiple heights above the ground surface: from street level to tower tops. The data collected, analogous to the soil/sediment geochemical data, allowed the identification of what was urban background and what was an anomaly. The measurements were complemented by numerical atmospheric simulations.

The first results from ClearfLo were described by Lee et al. (2014) and Bohnenstengel et al. (2015). FIGURE 6 summarises a model, centred on London, of mean NO_x concentrations gridded at 12.5 m above ground and compared for winter and summer periods. This model emphasises the vertical structure and evolution of the urban boundary layer and incorporates the chemical controls on atmospheric NO_x and O₃, in particular the composition and role of particulate matter. The model results clearly define the seasonality of London's air quality and also confirm the poor atmospheric conditions of the city.

DISCUSSION: WHAT IMPACT ARE WE MAKING?

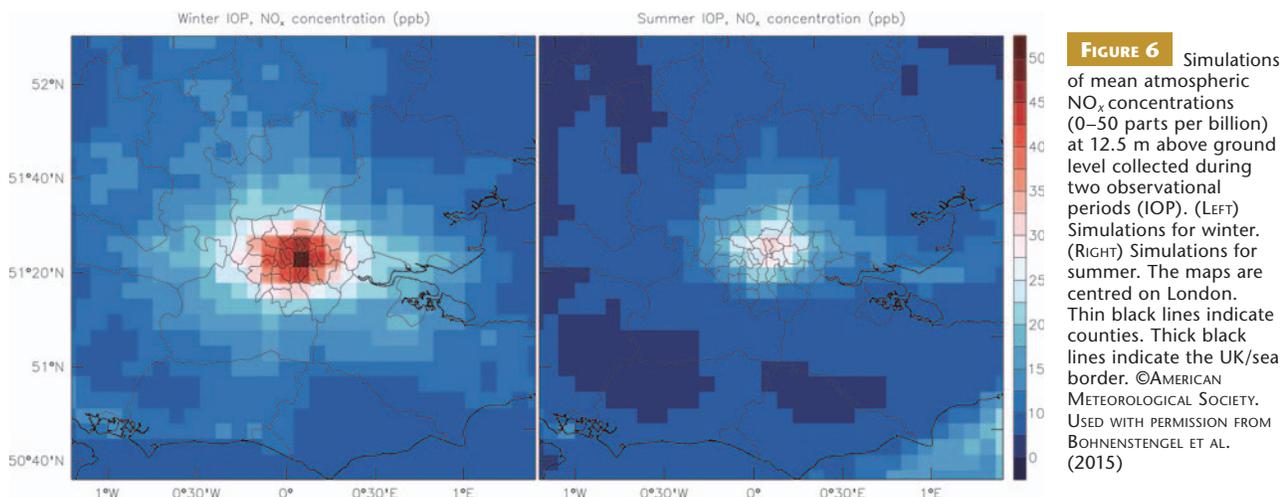
In a previous issue of *Elements* that focused on urban geochemistry, Wong et al. (2012) neatly laid out the challenges for urban space. These included dealing with atmospheric pollution, waste management (discharge and landfill), runoff (roadway, surface and greenspace), infrastructure failures (sewage, subway seepage), and groundwater and heat abstraction. In this article, we have addressed some of the problems described by Wong et al. (2012) by highlighting current work on London's soils (the London Earth project), its hydrology and geohydrology (the so-called 'nitrogen time bomb'), and its atmospheric contaminants (the ClearfLo project).

Urban areas are increasingly a platform for scientific research and require us, as scientists, to move from our own evidence-gathering to working with other specialists so as to provide robust solutions to the problems involved with biodiversity and conservation, contaminated land studies, urban-rural land-use planning, and how contaminated environments affect human health.

We must establish real-time monitoring systems that are carefully placed at arm's length from government and the commercial world. Monitoring should be transparent, and authoritative data should be used to reassure the public that we are able to 'whistle blow' and, when needed, force authorities to intervene, remediate, or shut down operations, however commercial or critical. Yet at the same time, we must educate the stakeholders who will want to interpret the geochemical data.

We know that our cities are polluted. Legacy issues, for example, indicate the following:

1. The worst is largely past, but the pollution is still present in the groundwater, in river and estuarine sediments, and in the soils from where it can be mobilised through bad planning and engineering errors.



- European (and other) norms need to take account of regional variability and historical pollution and modelling studies, such as that indicated for the 'nitrate time bomb'.
- That we may be creating new and ongoing problems with aerosols, nanoparticles of rare elements and other critical metals and of unknowns.

CONCLUSIONS

London provides an excellent test case by which to examine a wide range of urban geochemistry that, in one way or another, affects the lives of those living there. It is environmental scientists who define the boundary conditions to life in this or any city. However, we do not provide solutions to any problems arising. Is it possible for us to work with the social and economic sectors and build models on how best to *live with* the city and understand the feedback mechanisms between work, play, and the city?

Can we use geochemical and other environmental data to build impact into infrastructure models, financial models, population models, ecological models, and water and air quality models? To an extent, some of the legacy issues are best identified and then left untouched (placing a virtual

'Do Not Disturb' sign on some of the metal pollutants in sediments in estuaries and rivers), although communicating the risks of managing these hazards to the public and town-planners is a major challenge.

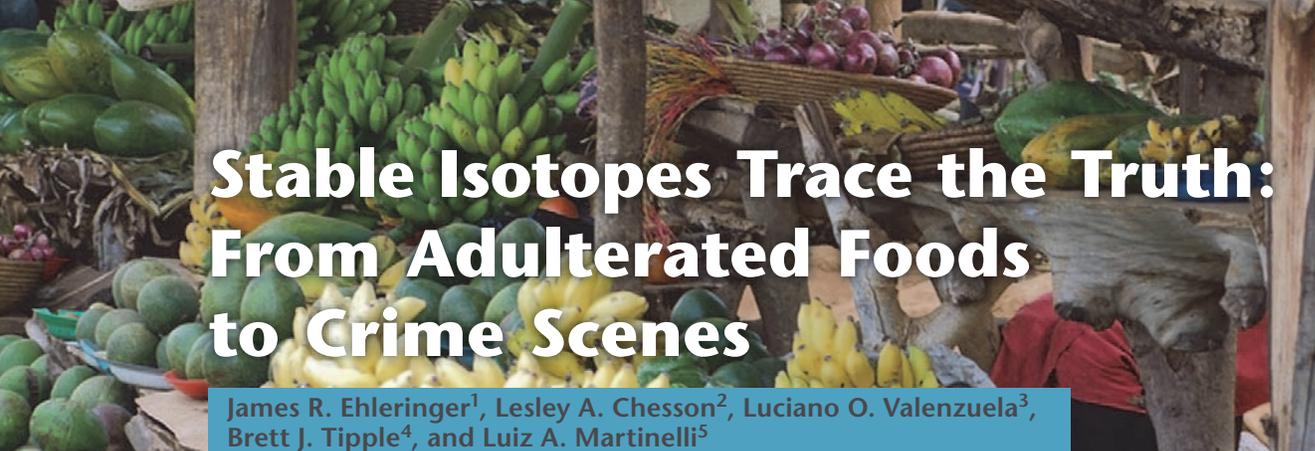
London, and cities like it, will grow and evolve, and environmental scientists will need to rise to that challenge to make sure our cities remain places where people and businesses can thrive. Given the wealth of environmental information in the London urban area, can we now model the environmental impact of the city on its catchment area and then scale this to other cities around the world? If so, we could develop a best practice for managing the legacy of centuries of environmental damage in any city.

ACKNOWLEDGMENTS

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Stable Isotopes Trace the Truth: From Adulterated Foods to Crime Scenes

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Stable isotopes are valuable biogeochemical markers for solving problems faced by society today, such as distinguishing authentic from adulterated foods and beverages or tracing the origins of illicit drugs. Hydrogen and oxygen isotopes in water exhibit distinct continental patterns (isoscapes), which provide useful region-of-origin information. We ourselves reflect the stable isotope ratios of the water we drink and the food we eat: our hair records any isotopic changes to our diets, which can often be related to location. This latter aspect can be of interest to law enforcement in determining the origins and travel histories of unidentified murder victims.

KEYWORDS: biogeochemistry, stable isotope, food, law enforcement, humans

INTRODUCTION

Changes in stable isotope abundances in materials are nature's recorder of many aspects of climatology, geology, hydrology, biology, and anthropology. Whether through successive layers in lake sediments, individual segments along a human hair, or annual layers in an ice core, a sequence of isotope ratios, once deciphered, leads to a quantitative understanding of patterns, processes, and history (Bowen 2010). The results of stable isotope fractionation appear as differences in the relative abundances of heavy-to-light isotopes of an element within the constituent molecules. For society today, the analysis of stable isotopes serves as a valuable, and diagnostic, biogeochemical tool when applied to water, food, human diets, travel movement patterns, and manufacturing methods (Fig. 1). Stable isotope analyses have been applied in medicine (O'Brien 2015) and as a tool to trace pollution (Elsner et al. 2012).

The subtle, but significant, changes in the hydrogen, carbon, nitrogen, oxygen, and sulfur stable isotope compositions of the water we drink and the foods we eat become reflected in our hair (Valenzuela et al. 2012; Nechlich 2015), which can thereby record geographic and dietary information (Ehleringer et al. 2008; Thompson et al. 2014; Chesson et al. 2014). Human hair becomes a linear recorder of our

diets and geographic origins; this leads to applications that include the investigation of historical practices, modern dietary patterns, and even forensic cases (Ehleringer et al. 2008; Thompson et al. 2014). Furthermore, even slight differences in how a chemical is manufactured or the substitution of ingredients from one source of raw materials to another can be recorded in the isotope ratios of

organic molecules of the product itself. And this can lead to useful insights into the origins, authenticity, and verification of a food product (Chesson et al. 2014).

HOW AUTHENTIC IS YOUR FOOD?

"Adulteration" is the illegal substitution of one ingredient or product for another, often driven by a desire for increased profits. In many aspects of food security, stable isotope biogeochemistry has become a critical tool in determining food and beverage authenticity (Simon et al. 2005). Here, the large differences in carbon isotope ratios between the two major types of photosynthesis in plants (C3 and C4: plant groups named for either the 3-carbon or the 4-carbon molecule present when they initially convert atmospheric CO₂ to organic carbon) become a diagnostic tool (Ehleringer and Sandquist 2014). A common adulteration approach is adding sugars from corn or sugar cane (both C4 plants) into either honey or maple syrup (both from C3 plants) to cheaply increase product volume (Guler et al. 2014). But because honey and maple syrup come from C3 plants and have carbon isotope ratios of -28‰ to -23‰, the addition of corn or sugar cane, with carbon isotope ratios of -14‰ to -10‰, results in a significant and detectable change in the expected carbon isotope ratio of the honey or syrup. The attempted importation of adulterated foreign honey to the United States is pervasive, which has led to federal guidelines that describe the acceptable ranges of carbon isotope values and allow authorities to differentiate between authentic and adulterated honeys.

Carbon isotopes can also be used to distinguish between other types of authentic and adulterated foods and beverages, such as beer (Brooks et al. 2002) and the sources of caffeine (Zhang et al. 2012). It seems that when there is an economic opportunity, producers will augment beverages with corn and cane sugars to extend their products to make them sweeter than they would be naturally or else to substitute cheaper synthetic ingredients for the more expensive naturally occurring compounds.

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FIGURE 1 Stable isotope analyses are applied to many aspects of human society. These range from tracing the food and water we drink, verifying the claimed growing regions where our food is produced, recording via our hair where we have been, and checking the authenticity of the products we use. PHOTO CREDIT: COMMONS.WIKIMEDIA.ORG

While carbon isotopes have been used to detect food adulteration, nitrogen isotopes are commonly analyzed to distinguish organic from nonorganic fertilizers used in the production of vegetable crops (Chesson et al. 2014). Vegetables raised with synthetic fertilizers often have nitrogen isotope ratios of between +3‰ and +5‰; plants raised on organic fertilizers are expected to have higher nitrogen isotope ratios between +10‰ and +20‰. A popular undergraduate student exercise is to visit stores and local farmer's markets to see which of the vegetables advertised as organically grown really have nitrogen isotope ratios consistent with those expected from plants grown with organic fertilizers.

For each of the food items mentioned above, the carbon and nitrogen isotope ratios are faithful recorders of food history and serve as a more quantitative means of verifying authenticity than simply using bar codes or package labels. Protecting consumers from fraud has always been a challenge. However, stable isotopes provide government and industry with a means by which to identify fraud.

WAS TONIGHT'S DINNER GROWN LOCALLY?

Eating locally grown foods is an increasing trend in Western societies, and consumers are often willing to pay more for local produce. But how can one be sure that a vegetable, fruit, or animal meat was produced locally, as opposed to having been transported in from afar?

Geographic Origins Revealed through Isoscapes

Think of a continental landscape where the different geographical regions are characterized by the stable isotope ratio of the geology, hydrology, or biology of the region. This is the isotopic landscape, or "isotope" context where the hydrogen and oxygen isotope ratios of local water act as a tool to distinguish between different geographical regions (Bowen 2010). How does this work?

Heavier isotopes of water (^2H , ^{18}O) are less stable in the vapor form and therefore more likely to precipitate from clouds than the lighter isotopes (^1H , ^{16}O). This leads to a spatial gradient in water isotope ratios. As most drinking

waters are largely derived from precipitation or recently recharged groundwaters, we find that there are pronounced spatial patterns in the stable isotopes of tap waters across a geographic region based on this rain-out effect. For example, cold, winter precipitation in the United States largely originates as storms from the eastern Pacific Ocean while warm, summer precipitation also draws in moisture from the Gulf of Mexico. As a result, we see distinct tap water isotope-ratio gradients defining geographic bands or zones (Fig. 2A), allowing us to isotopically distinguish between various regions of the United States. The isotope fractionation during precipitation affects both hydrogen and oxygen isotopes similarly, so either could be used to generate water isoscapes.

Our Foods Record Regional Isotope Biogeochemistry

The hydrogen and oxygen isotope ratios of local waters enter our bodies in many ways: tap water, bottled water, milk, fruit or vegetable juice, bottled or canned alcoholic and nonalcoholic drinks, and brewed beverages (Chesson et al. 2010a,b). The spatial gradients in water isotope values provide a quantitative tool and a type of geographic mapping system for determining if a beverage is of local origin or whether it was imported from a separate and isotopically distinct region. For instance, is the wine at dinner really from the Napa Valley of California or did it originate from another region or country? Is the bottled water served at lunch local, regional, or imported?

The hydrogen and oxygen isotopes of water serve as the raw material used to build proteins within our hair, nails, muscles, bones, and teeth and also within the "flesh foods" we eat daily. As a consequence, the hydrogen and oxygen isotope ratios of beef, chicken, eggs, freshwater fish, and pork reflect the local isotope ratios of water for the region in which these protein sources were grown (Fig. 2B). A survey of milk and meat sources in restaurants across the United States revealed a tendency of local restaurants to serve regionally produced foods. In contrast, the national chain restaurants tended to provide foods not of local origin and in some cases foods were transported large distances or even imported (Chesson et al. 2010a,b; Martinelli et al 2011).

Stable isotope analyses provide consumers with a tool that allows them to make a choice: foods of local origin or foods transported in from another part of the country (Chesson et al. 2009). Consider, for example, hamburgers that were purchased at different restaurants in Salt Lake City, Utah (location shown as black dot in Fig. 3). When these hamburgers were analyzed, the protein's hydrogen and oxygen isotope ratios fell into two distinct groupings. FIGURE 3 shows possible cattle-raising regions for hamburgers purchased from local restaurants as well as national chain restaurants. Local restaurants tended to have protein consistent with being regionally raised, whereas hamburgers from national chain restaurants tended to have isotope ratios expected for cows that had been raised farther away. FIGURE 3 shows all of those regions that were isotopically consistent with the observations. Because beef cattle are actually raised in only a subset of these possible locations, then overlaying those locations would further reduce the scope of possible geographic origins of beef sold in the different restaurants.

Stable isotope analyses also serve as valuable diagnostic tools for characterizing foods that are from protected domains of origin, which include many of the more desirable wines, cheeses, hams, and olive oils.

YOU ARE WHAT YOU EAT AND DRINK

Hair serves as a wonderful linear recorder of human diet (Thompson et al. 2014). Growing at a rate of about 1 cm per month, hair provides a continual record of diet and drinking water behavior even if we want to deny specific eating habits or movements. So, your mother was right, “You are what you eat and drink.”

The carbon and nitrogen isotope ratios found in all animals reflect their food resources. Because foods are consumed as the macromolecules of protein, fat, and carbohydrate, there is little carbon isotope fractionation between the food resource and the tissues produced by animals consuming those foods. This holds true even when we consider animals along the entire length of a food chain—including humans, at the top of the food chain.

However, for nitrogen isotopes there is approximately a 3‰ fractionation between animals and their food resources at each trophic level (i.e. their position in the food chain), reflecting fractionation events that occur when animals excrete nitrogen (as urine). Thus, there are increasing differences in the nitrogen isotope ratios of animals along a food chain, with animals at the top of the chain having the highest nitrogen isotope ratios (Post 2002). This insight allows us to study ourselves (humans) and our diets. Within humans, we see similar patterns: vegans, vegetarians, and omnivores can be distinguished through characterization of nitrogen isotope ratios of their hair (Thompson et al. 2014). When we use isotope analyses to study broad patterns between Europeans and North Americans, we find absolutely no differences in the population-level distribu-

tions of nitrogen isotope ratios (Valenzuela et al. 2012). Most individuals appear to be omnivores, and there is no difference in the occurrence of vegans or vegetarians in the populations of the two continents. On average, Europeans and North Americans eat at the same trophic level.

Dietary Differences Between Continents

What has been remarkable to discover is that even with the emergence of global supermarket diets, individuals from different continents often show very distinct and different carbon and sulfur isotope ratios (Martinelli et al. 2011; Valenzuela et al. 2012). Sulfur isotopes appear to reflect the relative contributions of marine versus nonmarine proteins (Nechlich 2015). The carbon isotope ratios of proteins from terrestrial sources reflect animals that were raised on either C3 or C4 plants. Because it is common in North America for beef, eggs, and pork to come from concentrated animal feeding operations where corn is the major food source, it is not surprising that the carbon isotopes of North American protein foods reflect a strong C4 carbon isotope ratio (Jahren and Kraft 2008). In contrast, European animals are more often field raised where the predominant forages are C3 grasses.

The difference in carbon isotope ratios of dietary protein is so large that there is virtually no overlap in the carbon isotope ratios of hair from individuals living in Europe versus those in North America (Valenzuela et al. 2012). Thus, we can use this isotopic separation to distinguish an international visitor from a local resident.

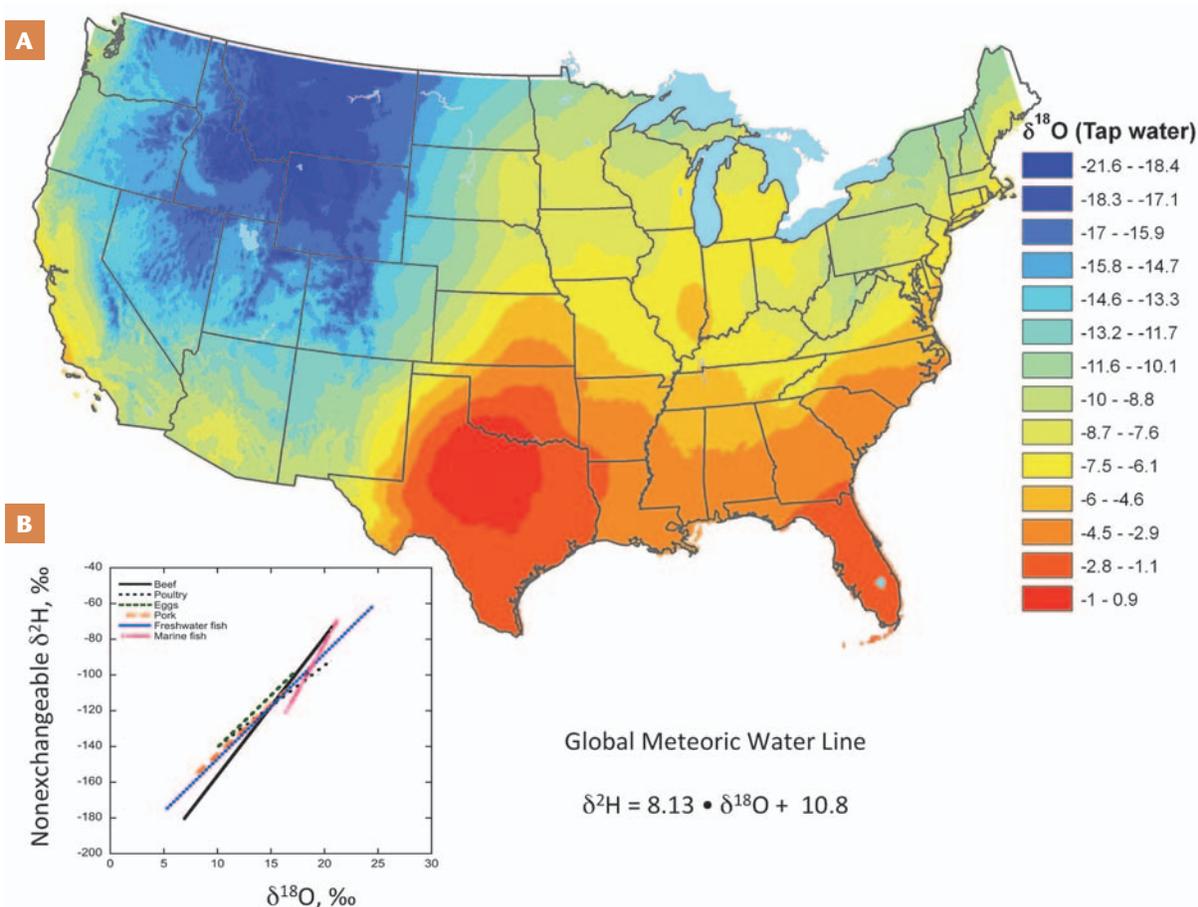


FIGURE 2 (A) An “isoscapes,” or geographical depiction, of oxygen isotope ratios in the drinking waters across the United States (ADAPTED FROM BOWEN ET AL. 2007). The equation for the Global Meteoric Water Line describes the relationship between

hydrogen and oxygen isotope ratios in precipitation. (B) A plot of the stable isotopes of nonexchangeable H and O atoms in various protein sources common in our diets (ADAPTED FROM CHESSON ET AL. 2011)

CASES SOLVED WITH ISOTOPES

Stable isotope analysis is now making its way into the US judicial system as an investigative tool. As such, it will receive the same level of scrutiny as any other analytical approach applied to legal matters (Ehleringer and Matheson 2010). We next explore some recent cases along these lines.

Graves Speak of the Past

The dead can speak from the grave using the language of stable isotopes. Corpses and skeletons from the past can provide key information on their once-living dietary practices and travel histories. A well-known example is that of Ötzi, the “Iceman” discovered by hikers in the Ötztal Alps (on the border between Austria and Italy) in 1991. Ötzi is one of the best-preserved natural mummies in the world, and many of his remains (hair, teeth, bones) have undergone stable isotope analysis.

The carbon and nitrogen isotope ratios of Ötzi’s hair suggest he ate a vegetarian diet of primarily C3 grains in the weeks before death (Macko et al. 1999). The oxygen isotopes of Ötzi’s teeth, which were incorporated into the enamel during initial formation, suggest that the Iceman spent his childhood approximately 60 km south of the site of his discovery (Müller et al. 2003). Isotopes in adult bones are incorporated at a later stage of life than in teeth. Differences between the isotopic composition of his teeth and bones indicate Ötzi was migratory during adulthood. The analysis of strontium was also useful in constraining his origins because strontium isotopes vary with local geology. Strontium is taken up passively and without fractionation as part of drinking water and in the food eaten, so strontium isotopes in biological tissues reflect the local bedrock. Thus, strontium isotopes become a second marker for geographic location.

Another example of stable isotopes as a forensic tool involves a man well-known before death: King Richard III of England. Killed in battle in 1485, his body was hastily buried without ceremony, the burial site remaining lost for more than 500 years. It was not until 2012 that his remains were recovered during an excavation to construct a car park in Leicester (UK). Analysis of residual DNA confirmed the identity of Richard III, but it was stable isotope analyses that revealed details of his lifestyle (Lamb et al. 2014). Enriched nitrogen isotope ratios of his bones and enriched oxygen isotope ratios of his teeth have been interpreted as indicating that his diet was richer later in life than in childhood, reflecting consumption of more meat and wine as an adult.

Bones and teeth also provide dietary information through carbon isotopes. As described previously, a North American diet is heavily reliant on C4 plants (corn, sugar cane); in contrast, a Southeast Asian diet typically includes more reliance on C3 plants. As war-zone human remains are occasionally recovered in Vietnam, the bone tissues are first analyzed isotopically to determine their carbon isotope ratios. In these cases, differences in carbon isotope ratios in bone tissues of remains from these regions are applied to determine if a set of remains are more likely to be from a US serviceperson or an indigenous local (Bartelink et al. 2014).

Sequential stable isotope analysis of hair can provide more information than the “snapshots” in time provided by measurements of teeth and bones. Because hair acts like a linear tape recorder as it grows, it is possible to construct chronological histories for individuals that span weeks to months, depending on lengths of the hair strands. For instance, Incan civilization children from Peru, who were to be sacrificed for religious purposes, were first fed rich diets in an effort to provide an offering that would please

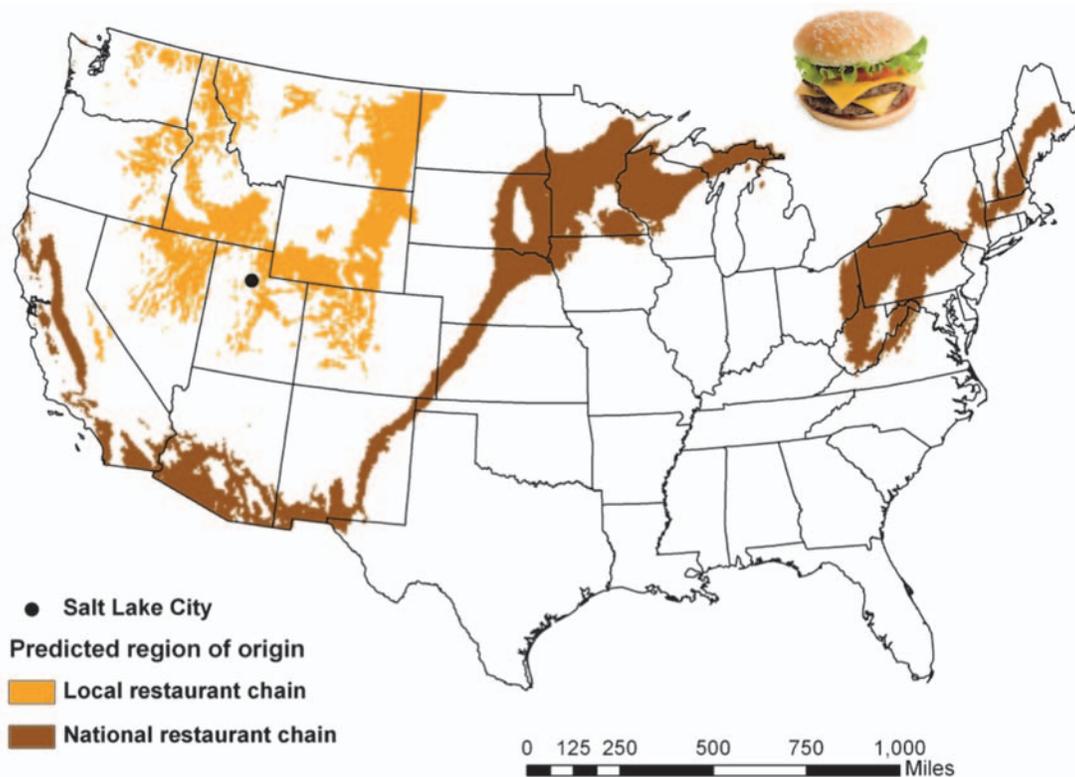


FIGURE 3 Possible geographic regions in which the beef in hamburgers from a local restaurant and from a national-chain restaurant in Salt Lake City (Utah) could have been raised. The geographic origin of the meat is determined from the

isotope shown in FIGURE 2 using the relationship between the oxygen isotope ratios of water and beef. LA Chesson (unpublished data).

the gods. Carbon isotope analyses of hair from sacrificed and mummified children show that in the year preceding their sacrifice, at the highest peaks of the south Central Andes, these children went from diets with limited corn to a diet that was rich in corn (Wilson et al. 2007).

Unraveling Other Mysteries and Crimes

Applying stable isotope analyses to assist law enforcement on cases with unidentified murder victims represents a contribution that has gained wider attention from biogeochemical sciences in recent years. The American crime drama *CSI: Crime Scene Investigation* is a popular television series, and millions of viewers are fascinated by the power of the show's analytical methods to solve mysteries. Yet few consider that the acronym CSI could just as easily be "Cases Solved with Isotopes."

Hair is a common piece of crime-scene evidence, and stable isotope analytical methods have applications in identifying murder victims and combating human trafficking and illegal immigration because travel histories for individuals can be established (Ehleringer et al. 2010). As noted earlier, the oxygen isotope ratios of hair act as a linear recorder of drinking waters and so becomes a recorder of an individual's geographical history or travel movements.

Consider the case of "Saltair Sally", initially an unidentified female buried near the freeway in the desert west of Salt Lake City, Utah (Fig. 4). The oxygen isotope ratios of her hair suggested that Saltair Sally was a traveler. Yet this same isotope record showed isotope values that were consistent with her being a resident of Salt Lake City (Region 1 and blue dot in Fig. 4). Despite her apparent residency in the Salt Lake City region, no one came forward to identify her as a missing person. She was simply unidentified for many years. Where to go next in this investigation? New clues were needed. When stable isotope analyses were applied, two other isoscape regions were identified as possible locations where Saltair Sally lived or had visited prior to her death (Regions 2 and 3 of Fig. 4). Perhaps Saltair Sally had

traveled to these regions to visit family members. Working on this hunch, Detective Todd Park (Salt Lake Unified Police Department) sent inquiries to the major cities within these isoscape regions. In August 2012, he received a positive response¹. An individual last seen by her family in the Seattle area a year before Saltair Sally's discovery matched the timeline reconstruction shown in FIGURE 4 (Seattle is represented by the yellow dot). Subsequent genetic analyses confirmed that Saltair Sally was no longer an unidentified decedent, but was actually Nikole Bakoles. Stable isotope analyses confirmed that she visited her mother about a year before her death (Region 2 in Fig. 4). Thus, stable isotopes had proved useful in assisting with what is now an active homicide investigation. The literature is filling with additional examples of how stable isotopes analyses are being applied to investigations of other unidentified persons' cases.

A Tool Applied to Sourcing Drugs

The source of illicit drugs, such as heroin and cocaine, can also be determined, or at least ruled out, using stable isotope ratio analyses. Unique combinations of carbon and nitrogen isotope ratios provide regional information of benefit to federal agents, allowing the agents to determine from which region illicit drugs originated (Ehleringer et al. 2000). Within the US Drug Enforcement Administration, stable isotope analyses are now used to identify cocaine that has originated from various regions in Central and South America. One particularly striking and unusual example for this application of stable isotopes is not of cocaine but instead involved heroin.

1 www.sltrib.com/sltrib/news/54649101-78/bakoles-saltair-detectives-police.html

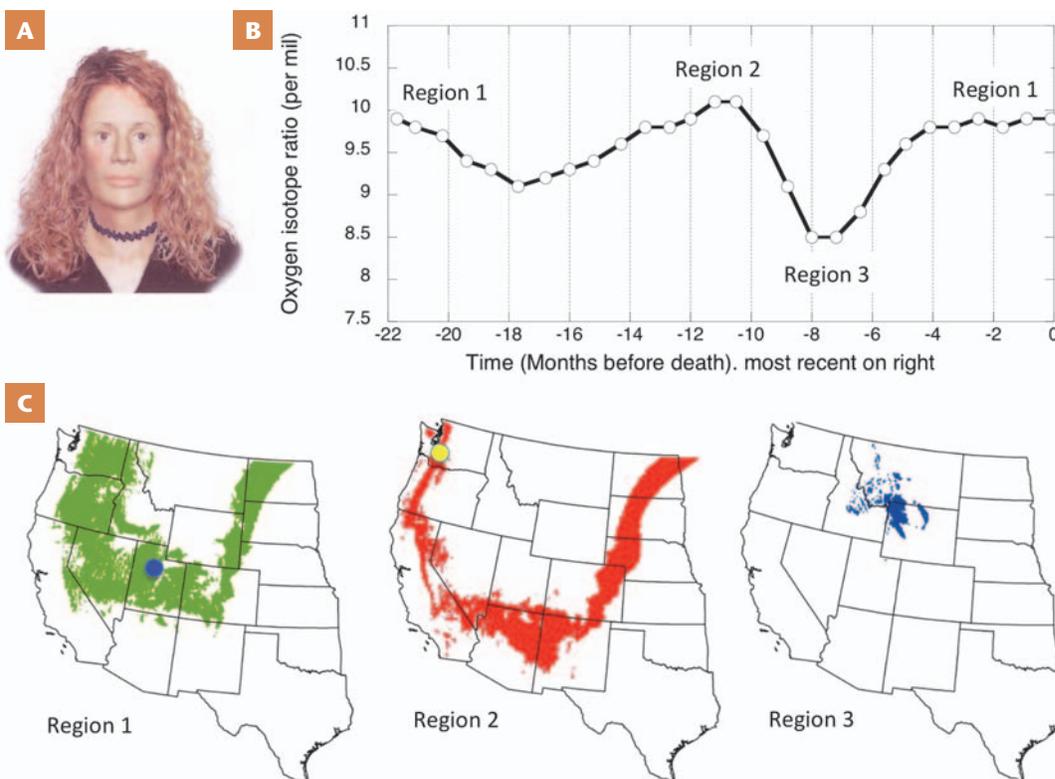


FIGURE 4 (A) An artist's sketch of "Saltair Sally". (B) A plot of the changes in the oxygen isotope ratio of Saltair Sally's hair over the last 22 months of her life. (C) The isoscapes of three geographical regions where Saltair Sally had traveled prior to her death (Remien et al. 2014) are based on the tap water isoscape shown in FIGURE 2 and the relationship between the oxygen isotope ratios of tap water and hair. The blue spot on isoscape Region 1 is Salt Lake City (Utah) from where Saltair Sally's body was recovered. The yellow spot on isoscape Region 2 is Seattle (Washington) where she was originally from.

In 2003, a large amount of heroin was seized from the North Korean cargo ship, the *Pong Su* (Casale et al. 2006). Australian officials confiscated heroin from the cargo ship as well as from off-load sites on Australian soil. When these heroin samples were isotopically characterized, they were all found to have stable isotope ratios significantly different from any of the known poppy growing regions used in heroin production (i.e. Mexico, South America, Southeast Asia, Southwest Asia). Both the combination of stable isotopes and alkaloid compositions of the heroin were unlike any samples seized before or of any authentic samples previously analyzed by Australian or United States investigators. The origin(s) of the *Pong Su* heroin remains a mystery to this day, but several regions could be ruled out on the basis of the isotopic analyses. Authorities are

currently awaiting heroin samples collected from a poppy-growing region in Asia where the isotope ratios and alkaloid profiles are similar to the *Pong Su* samples.

ON THE FUTURE BENEFITS OF STABLE ISOTOPE BIOGEOCHEMISTRY TO SOCIETY

As we move into an era of increased capacities to analyze specific compounds, human metabolism, and spatial patterns across the globe, the possibilities for stable isotope analyses to benefit society seem boundless. We are already seeing these contributions in relation to health, understanding our environment, and clarifying matters on the food we eat. As stable isotope analyses are applied to more situations, society will continue to benefit from this valuable biogeochemical tool. ■

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Metal Stable Isotopes in the Human Body: A Tribute of Geochemistry to Medicine

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Metalloproteins play essential roles in biology and medicine. Calcium is a major component of bones, while electron and oxygen transport in the body relies on iron and copper. Isotope fractionation of metal stable elements uniquely reflects specific biochemical pathways. Variations in these isotope ratios from normal levels in body fluids can be used as reliable markers of pathological conditions. Metal stable isotope fractionation reflects the energetics of bonding, is amenable to theoretical calculations and is fast becoming a powerful medical diagnostic tool. Examples include how calcium isotopes can be used to monitor bone loss, how iron isotopes can react to genetic disorders, and how copper isotopes can help track cancer progression.

KEYWORDS: metallomics, stable isotope fractionation, medical isotopes, bone loss, cancer, biomarker

INTRODUCTION

Medical uses for the conventional stable isotope systems of C, H, O, N, and S, are very limited because these elements are ubiquitous and, as such, are not specific (diagnostic of) any particular biological process. However, elements such as the alkaline earth metals (Ca, Mg) and transition metals (e.g. Cu, Zn, Fe) appear more promising as medical diagnostic tools precisely because they *are* often more specific in biological functions and because their turnover rate in the body is relatively short. This is, for example, the case for iron in the heme molecule, which is a large heterocyclic organic ring porphyrin and a component of hemoglobin, which itself is a metalloprotein used by the body to shuttle oxygen and carbon dioxide around in the bloodstream. Likewise, copper plays a major role in moving iron from organs and tissues into the bloodstream. Calcium, as we saw in the previous issue of *Elements* (v11n3), is an essential component of bone apatite. Herein, I will review some appealing, and intriguing, applications of stable metal isotopes to medicine.

Whenever the word “isotope” is overheard in a medical context it often evokes thoughts of radioactive isotopes, such as technetium-99m (radioactive, metastable, Tc-99) or cobalt-60, used for radiotherapy. The public might also associate medical uses of isotopes with nutrition studies in which enriched stable isotopes are added to a diet to monitor the transit of a particular element. Both these uses of isotopes are invasive in the sense that they interfere with the natural metabolism of the patient, even if only to a trivial degree.

To understand stable isotopes in medicine and why their use differs from radioactive isotopes, we first need to establish a few concepts. The abundances of stable metal isotopes, which are *naturally* present in the body

of humans and other organisms, tend to vary. This is known as the *isotope effect*, a term that describes the mass-dependent variations of natural isotope abundances for a particular element. The isotope effect is a consequence of the Heisenberg uncertainty principle on the distribution of energy levels of molecular vibrations. The energy of the lowermost vibrational energy state depends on the mass of the atoms involved in bonding, a characteristic that is at the heart of the isotopic variability of a given element between different parts of a biological system.

Isotope fractionation is the general term referring to differences in isotope abundances. It can be explained in a simple way: heavy isotopes vibrate more slowly than their lighter kin, and, because bond energy is proportional to vibrational frequencies, heavy isotopes tend to preferentially occupy the lowermost energy levels. At high temperatures, this tendency is opposed by the second law of thermodynamics, which works to randomize the distribution of isotopes across energy levels. At ambient temperatures, however, the total energy is minimized when heavy isotopes concentrate into the “stiffest” bonds, i.e. those with the lowest and, therefore, most stable energy levels (Bigeisen and Mayer 1947). For a given element, the strength of a particular bond is expected to be higher for ions with higher charges and where bond energy is shared between fewer partners. Heavy isotopes will favor bonds that involve elements in high oxidation states (as for Fe³⁺, Cu²⁺) and that are in structural sites with small coordination numbers.

Kinetic effects may also play a role. The fact that lighter isotopes have smaller activation energies allows them to react faster: kinetic effects are thought to be a cause of biologically mediated isotope fractionation (Gussone et al. 2003), but they would require either non-steady state conditions or the existence of competing reaction pathways (Fig. 1).

Why has it taken so long for metal isotopes to be applied to biology and medicine? Calcium isotopes benefited from decades-long experience with thermal ionization mass spectrometry (TIMS) (Skulan et al. 1997). But it was only in the late 1990s that the development of multiple collector inductively coupled plasma mass spectrometry (MC-ICPMS) made it possible to precisely assess the isotopic variability of metals such as Cu, Zn, and Fe in biological material (Maréchal et al. 1999; Zhu et al. 2000). For example, using MC-ICPMS, isotope fractionation of Fe, Cu, and Zn was observed between body parts and fluids of

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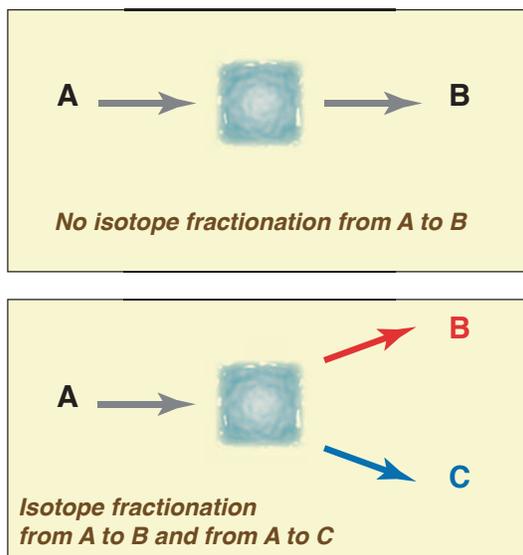


FIGURE 1 (TOP) At steady state, each individual isotope of each element is conserved during its transit, hence the cell or organ (represented by the blue square) is reduced to a single input and a single output that does not modify isotopic abundances. (BOTTOM) When two pathways compete for an element, A to B and A to C, its individual isotopes become fractionated by the cell or organ.

humans, sheep, and mice at the per mil level (Walczky and von Blanckenburg 2002; Balter et al. 2010, 2013; Moynier et al. 2013).

Let us try to find some guidelines on how to apply stable metal isotopes to medicine, a scientific field I suggest we refer to as *medical isotope metallomics*. The hassle of experiments makes it impractical to acquire, in the foreseeable future, the large amount of isotope fractionation data required for the very large number of medically relevant compounds. These data must, therefore, be computed by theoretical methods, typically by ab initio techniques such as density functional theory, which allows the electronic structure of atoms and molecules to be computed from first principles. The results are usually reported on the “ln β ” scale, which may be thought of as ranking the relative appetite that different bonds have for heavy isotopes over their lighter relatives. The ligands that most frequently bond with metal ions involve certain inorganic anions (Cl^- , OH^- , HCO_3^- , SO_4^{2-} , PO_4^{3-}), functional O^- anions (such as lactates $\text{CH}_3\text{CH}(\text{OH})\text{COO}^-$), and covalently bound atoms (such as S in cysteine or N in histidine, two of the most common amino acids). The attraction of metals to charged particles may be conveniently illustrated by their ionization energy or by their electronegativity (Fig. 2): bonds with O (or OH) and N (or NH_2) are expected to be much stronger than bonds with S, whereas bonds with Zn should be stronger than equivalent bonds with Ca. Isotopic variations in body fluids and organs should, therefore, follow rather simple principles: heavy isotopes should prefer bonds with OH^- , HCO_3^- , PO_4^{3-} over Cl^- ; histidine over cysteine; and Fe^{3+} and Cu^{2+} metalloproteins should be isotopically heavier than those containing Fe^{2+} and Cu^+ , respectively.

CALCIUM STABLE ISOTOPES IN THE BODY: A MEDICAL DIAGNOSTIC TOOL FOR BONE DISEASES

Ninety-nine percent of calcium in our bodies resides in our bones in the form of hydroxylapatite, which is continually being renewed over our entire life. An average adult has a healthy balanced Ca diet of ~1 g per day (Matkovic

and Heaney 1992), which corresponds to an overall bone turnover time of a few years. As a consequence, the much-feared condition of bone loss is a dynamic process. The bone-building cells (osteoblasts) produce collagen fibers on the outer part of new bone material. Alkaline phosphatase, an enzyme located in the membrane of osteoblasts, liberates phosphate from phosphate esters, such as β -glycerophosphate (Chung et al. 1992), which allows apatite precipitation and mineralization. Bone demolishers (osteoclasts), on the other hand, are responsible for resorption, which returns Ca and phosphate to the bloodstream, a process regulated by parathyroid hormone. Lack of Ca regulation results in arterial calcification, a common disease of the elderly and of patients on dialysis. In the bloodstream, Ca^{2+} ions exist in three forms: free ions (50%); bound to albumin (40%); and bound to proteins (10%). Free Ca is one of the most tightly regulated parameters in the body, and parathyroid hormone regulates concentrations in the cell-free liquid fraction of the blood (serum) by stimulating bone resorption and Ca reabsorption by the kidney. The soft cysteine that is present in albumin, which would favor isotopically light Ca isotopes relative to the free-ion pool, does not seem to bind significantly with Ca^{2+} (Kragh-Hansen and Vorum 1993).

Calcium was the first non-conventional element for which variations of its six isotopes were investigated (Skulan et al. 1997). Calcium isotopes are routinely analyzed by two methods: thermal ionization mass spectrometry (TIMS) and multiple-collector inductively coupled plasma mass spectrometry (MC-ICPMS). Two main results have emerged from all the analyses. First, Ca becomes isotopically lighter as it moves through the food chain. Second, bone Ca is isotopically light (Skulan and DePaolo 1999; Reynard et al. 2010), which may come as a surprise because, as predicted from the electronegativity scale, heavy Ca isotopes should favor PO_4^{3-} over carboxylate and carbonyl groups. Bone deficit in heavy Ca isotopes inevitably reflects Ca binding with soft ligands, while the combination of Ca^{2+} with

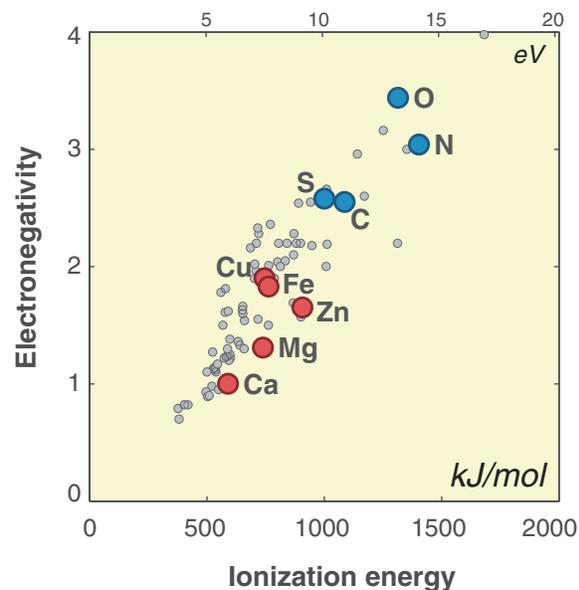


FIGURE 2 Graph of an element’s electronegativity versus ionization energy. The strength of the bond can be roughly estimated using the energy of the first ionization potential or using the element’s electronegativity: higher energy/potential = stronger bonds. Strong bonds preferentially incorporate heavy isotopes. This is the case for nitrogen, as in the amino acid histidine, and oxygen, as in lactate. In contrast, sulfide bonds, as in the amino acid cysteine, tend to preferentially incorporate light isotopes. Red dots represent metals for which isotope compositions are sought. Blue dots represent ligand-forming elements.

phosphate liberated by phosphate esters into the highly insoluble hydroxylapatite must be delayed until final delivery of P and Ca to the bone.

Bed-rest studies in which calcium isotopic variations were monitored (Heuser and Eisenhauer 2010; Morgan et al. 2012) were motivated by the frequent observation that astronauts suffer bone loss during space flight (Fig. 3). It was known that Ca in urine increases and becomes isotopically lighter with time, suggesting that Ca is being liberated by osteoclasts from the bones into the blood stream (Permyakov and Kretsinger 2011). Increased loss of isotopically light Ca among patients may reflect the way that bone is being mineralized as a response to changing proportions of free Ca to albumin-bound Ca. This loss may also be caused by an increased loss of bone Ca, which is recognized to result from enhanced expression of another calcium-binding protein, sclerostin, during bed rest (Spatz et al. 2012).

Calcium isotopes can be used to quantify the Ca fluxes in and out of the bones without having to resort to adding isotope tracers to a diet (Skullan and DePaolo 1999; Heuser and Eisenhauer 2010). This is also relevant to the study of Ca in osteoporosis, a condition particularly common in aging women.

IRON STABLE ISOTOPES IN THE BODY: A TRACER OF HEREDITARY DISEASES

The role of iron in human biology is particularly important because Fe(II)-bearing hemoglobin is the prime carrier of oxygen in the blood. Other iron stores are present in the liver and the kidneys, largely as Fe(III) ferritin, a ferrihydrite analog wrapped in a protein shell.

Iron has two oxidation states: Fe(II), which is ferrous iron; and Fe(III), which is ferric iron. Ferric iron binds with many inorganic and organic ligands, and Fe(III) hydroxide is highly insoluble. Iron has three major isotopes— ^{54}Fe , ^{56}Fe , and ^{57}Fe —and one minor isotope, ^{58}Fe . The pioneering study of Walczyk et al. (2002) demonstrated that there is a large variability in Fe isotope distributions between organs and body fluids. The important observation that blood Fe becomes isotopically heavier after bloodletting was interpreted to indicate that Fe is quickly retrieved from the liver and kidney to replace the lost blood iron (Hotz et al. 2012; Krayenbuehl et al. 2005).

The first disease studied from the viewpoint of the natural stable isotopes of iron was hereditary hemochromatosis (Krayenbuehl et al. 2005). This pathology is characterized by progressive iron overload of tissues due to a genetically disrupted function of the two critical proteins of hepcidin and ferroportin, which are involved in the control of intestinal iron absorption. This disruption leads to an ineffective control of intestinal iron absorption. Iron in the blood of patients with hemochromatosis is 0.2–0.4 per mil isotopically heavy compared to healthy individuals. This observation suggests that the blood of hemochromatosis patients uses the body's iron stores more heavily than is the case for people without the condition.

COPPER STABLE ISOTOPES IN THE BODY: A FLAG FOR POTENTIAL CANCER DIAGNOSIS

To understand how stable isotopes of copper can be used as a powerful medical tool for spotting cancer early, we first have to grapple with where copper resides in the body, what its function is, and what influence all this has on the distribution of its isotopes.

Copper plays both catalytic and structural roles in several essential enzymes: ceruloplasmin, which oxidizes Fe in human serum; cytochrome c oxidase in the mitochondrial membrane, which is the last courier in the respiratory

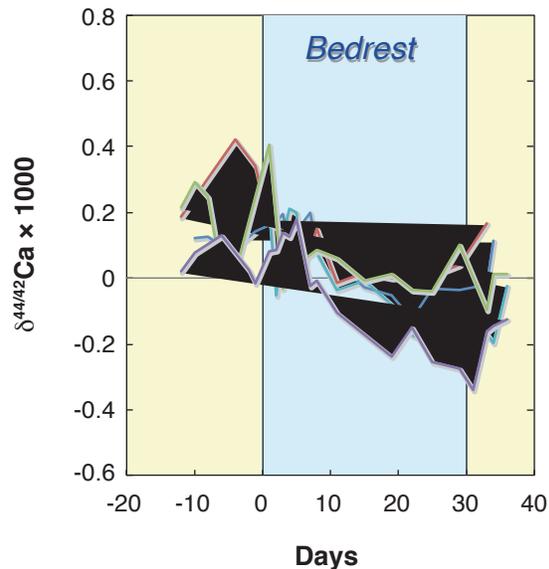


FIGURE 3 Calcium isotope evolution of the urine of volunteers (indicated by colored lines) confined to bed rest for a month (vertical blue band). Bone Ca is isotopically light relative to dietary Ca. Urine typically reflects dietary Ca. So, the observed changes in Ca isotopic composition of urine during bed rest indicates that bed rest enhances bone loss, which mimics what is observed in astronauts who have lived in space for a time (MORGAN ET AL. 2012).

electron chain; metallothionein, which is a major repository of intracellular Cu; and superoxide dismutase 1, which protects the cell and its DNA against reactive oxygen species, such as free oxygen ions. The Cu^{2+} in superoxide dismutase 1 binds with the nitrogen atoms of histidine, while some Cu^{2+} ions in ceruloplasmin bind to the sulfur atoms of cysteine and methionine. Due to its short bulk turnover time in the human body (~6 weeks; Goode 1991), Cu is a potentially valuable indicator of rapidly evolving diseases such as cancer. Anomalously high Cu levels are common in the serum of cancer patients; and, in experiments on mice, Ishida et al. (2013) demonstrated that increased levels of bioavailable copper actually promoted tumor growth. As a result, reducing body copper levels using the chelates tetrathiomolybdate and *D*-penicillamine (Brem et al. 2005; Brewer 2005) has now been approved for cancer treatment. Changes in copper concentrations in serum, however, do not remain amenable to quantitative predictions that are rooted in otherwise robust biochemical processes: isotope effects must also be examined.

The growth of centimeter-size cancer tumors is accompanied by pervasive neo-vascularization (the new growth of blood vessels), which secures the delivery of oxygen and nutrients to the tumor cells. Diffusion can only transport oxygen, carbon dioxide, and nutrients over a few hundred microns; therefore, tumors need to connect to the overall body's blood circulation system by growing blood vessels. Copper in cancer cells both facilitates vascularization (Carmeliet and Jain 2000) and plays a role in oxygen deficit (hypoxia), a hallmark of biological malignancies. Recent evidence suggests that hypoxia helps cancer stem cells survive in certain niches (Hill et al. 2009). Indeed, the overexpression of hypoxia-inducible factor 1 alpha, the protein that controls cellular oxygen levels, is associated with increased tumor growth, vascularization, and metastasis (Wilson and Hay 2011).

In order to explore the potential of Cu isotopes as a biomedical marker, a control dataset of healthy individuals first had to be established. Albarède et al. (2011) analyzed the copper isotope compositions of the serum and red blood cells of 50 young male and female blood donors

and found that ^{65}Cu is enriched in red blood cells with respect to serum. Copper is enriched in the light ^{63}Cu isotope in serum because of this isotope's soft bond with sulfur from cysteine in ceruloplasmin; copper is enriched in the heavy ^{65}Cu isotope in red blood cells, because this isotope strongly binds with nitrogen from the histidine-forming superoxide dismutase 1 (Albarède et al. 2011; Fujii et al. 2014).

Copper isotopes have the strong potential to be markers of cancer. Télouk et al. (2015) measured, using phenotype and molecular biomarker documentation (Fig. 4), the $^{65}\text{Cu}/^{63}\text{Cu}$ ratios in 140 serum samples from 8 patients with colorectal cancer and 20 patients with breast cancer. The $^{65}\text{Cu}/^{63}\text{Cu}$ ratio in the serum of the cancer group who had a negative prognosis (i.e. were likely to die from their condition) was lower than the control group. The $^{65}\text{Cu}/^{63}\text{Cu}$ ratio predicted, to a good degree, mortality in the colorectal cancer group and the ratio could discriminate, at a high confidence level, the group of breast-cancer patients from the group of control women. Furthermore, Balter et al. (2015) found that the $^{65}\text{Cu}/^{63}\text{Cu}$ ratio in the serum of liver-cancer patients was significantly lower relative to a control group of healthy blood donors; and, in a mirror image result, the $^{65}\text{Cu}/^{63}\text{Cu}$ ratio was higher in liver tumors relative to healthy tissue (Fig. 5).

The outstanding question is, therefore, “What is the mechanism responsible for lowering $^{65}\text{Cu}/^{63}\text{Cu}$ in the serum of cancer patients and for increasing it in tumor tissue when it is disabled in healthy individuals?” The mechanism is probably linked to copper chelation by lactate, a substance painfully familiar to athletes for accumulating in the muscles during prolonged strenuous anaerobic activity. This common substance is also observed in tumor cells.

As a biomedical marker, the longitudinal study of Télouk et al. (2015) showed that the variations of Cu isotope abundances precede by several months those of the more conventional molecular biomarkers, e.g. carcinoembryonic antigen (CEA) and carbohydrate antigen CA 19.9—both recommended markers for colorectal cancer—and CA 15.3, which is a recommended biomarker for breast cancer. As a process biomarker, the opposite shift of Cu isotope abundances between liver tissue and serum suggests that

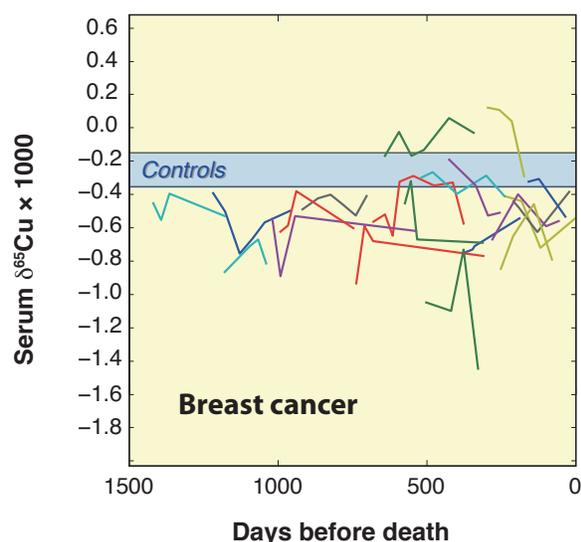


FIGURE 4 Evolution of serum ^{65}Cu in 140 samples taken from 20 breast cancer cases up to patient death. Each line represents a different patient, with color used for differentiation purposes. The blue band (controls) represents the range of ^{65}Cu in the serum of healthy donors. AFTER TÉLOUK ET AL. (2015).

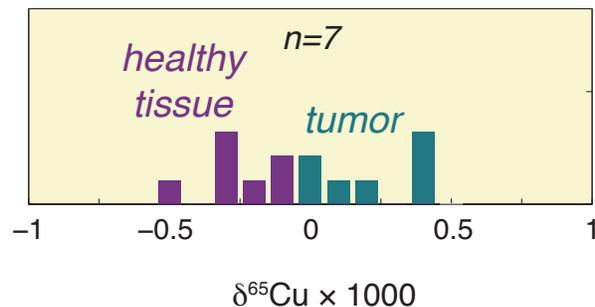


FIGURE 5 Graph of ^{65}Cu values in seven sample pairs of healthy tissue and of cancer tumor taken from the liver of the same patient. The higher ^{65}Cu values in the tumor relative to normal tissue is a mirror image of the lower ^{65}Cu of serum for patients with liver cancer relative to healthy individuals. Cu^{2+} is chelated by intracellular lactate in the tumor, which preferentially releases ^{65}Cu -depleted copper into serum. AFTER BALTER ET AL. (2015).

fractionation between chelated and non-chelated forms of Cu should play a role in the effectiveness of Cu isotopes as biomarkers.

Lactate generation in the body is linked to how a cell produces energy. The universal biological energy currency unit is adenosine triphosphate (ATP), which packs an enormous amount of energy in phosphate bonds. Glucose burning (glycolysis) is the primary fuel of ATP production, which is achieved by the attachment of an inorganic phosphate to adenosine diphosphate (ADP). In normal *aerobic glycolysis*, ATP is produced by a set of reactions also involving reduction of nicotinamide adenine dinucleotide (NAD^+), an electron acceptor, into NADH. The end product of *aerobic glycolysis* is a carboxylate ion known as pyruvate, which is transported into the mitochondrion to produce more ATP. NADH produced in the process is re-oxidized into NAD^+ , which allows the transport of electrons into the mitochondrion while consuming protons in the process. Excess H^+ therefore remains limited.

In contrast, under oxygen-deficient conditions, pyruvate is used as electron acceptor instead of NAD^+ , another carboxylate anion, lactate is now the end product, and aerobic glycolysis is replaced by *anaerobic glycolysis*. Excess protons are pumped out of the cell into the blood stream. Cancer cells mimic *anaerobic glycolysis*, and their tendency to produce lactate, despite the presence of adequate oxygen, is known as the Warburg effect. Lactate levels in the range of 10 mMol in the cytosol of tumor cells are observed after biopsy and correlate well with disease severity.

The strong signal of Cu isotopes appears to be related to Cu chelation by lactate, which binds Cu(II) in mono- and bi-dentate complexes, and is, therefore, associated with the Warburg effect. The Cu bond with the side hydroxyl of lactate is even stronger than the bond with histidine. Fujii et al. (2014) found that Cu mono- and bidentate lactate complexes are unusually stable and isotopically heavy. The extent of ^{65}Cu preference over ^{63}Cu for the lactate monodentate form with respect to analogous Cu isotopes that are bonded to cysteine is more than one per mil—which is very large compared to most common compounds—and for the lactate bidentate form it is about two per mil. Copper chelation begins to be significant at lactate concentrations of 0.1 mMol, but at 10 mMol, which is typical of tumor cells, 50–80% of the Cu is chelated by lactate. Such a process explains why tumor tissues rich in Cu^{2+} -lactate complexes are isotopically heavy, whereas Cu^+ excreted into the bloodstream is correlatively light.

How under these conditions would a biomarker based on Cu isotopes be useful? Serum lactate itself is tightly regulated by membrane transport and then metabolized

and is, consequentially, a poor marker of intracellular lactate. Copper isotopes in the bloodstream, by contrast, reflect the state of intracellular lactate metabolism and the extent to which this metabolism replaces normal glycolysis. The abundance of Cu isotopes in serum, therefore, appears to represent a potentially powerful biomarker of cancer growth and dissemination.

FUTURE DIRECTIONS FOR “MEDICAL ISOTOPE METALLOMICS”

Metal stable isotopes seem to have a bright future as biological markers, a field that I suggest be called “medical isotope metallomics” (metallomics being the study of metals as essential constituents in biological systems). The effect of specific ligands on isotope variability in body fluids can be predicted from first principles, which allows specific biological pathways to be identified. As epitomized by Ca isotopes as a determiner of the extent of bone loss, the observable extent of isotopic fractionation is a quantitative index of pathological evolution. Analyzing isotope compositions does not demand a stringent timetable, with

the important consequence that many legacy samples can be analyzed years after they have been collected. Finally, different metals have different turnover times in the body, and, thus, isotope metallomics offers a broad spectrum of potential markers that are sensitive to the different timescales that characterize different types of disease. Nevertheless, it will be essential to assess whether isotopic drifts represent primary signals or whether they reflect the associated inflammatory conditions that normally accompany the evolution of a disease.

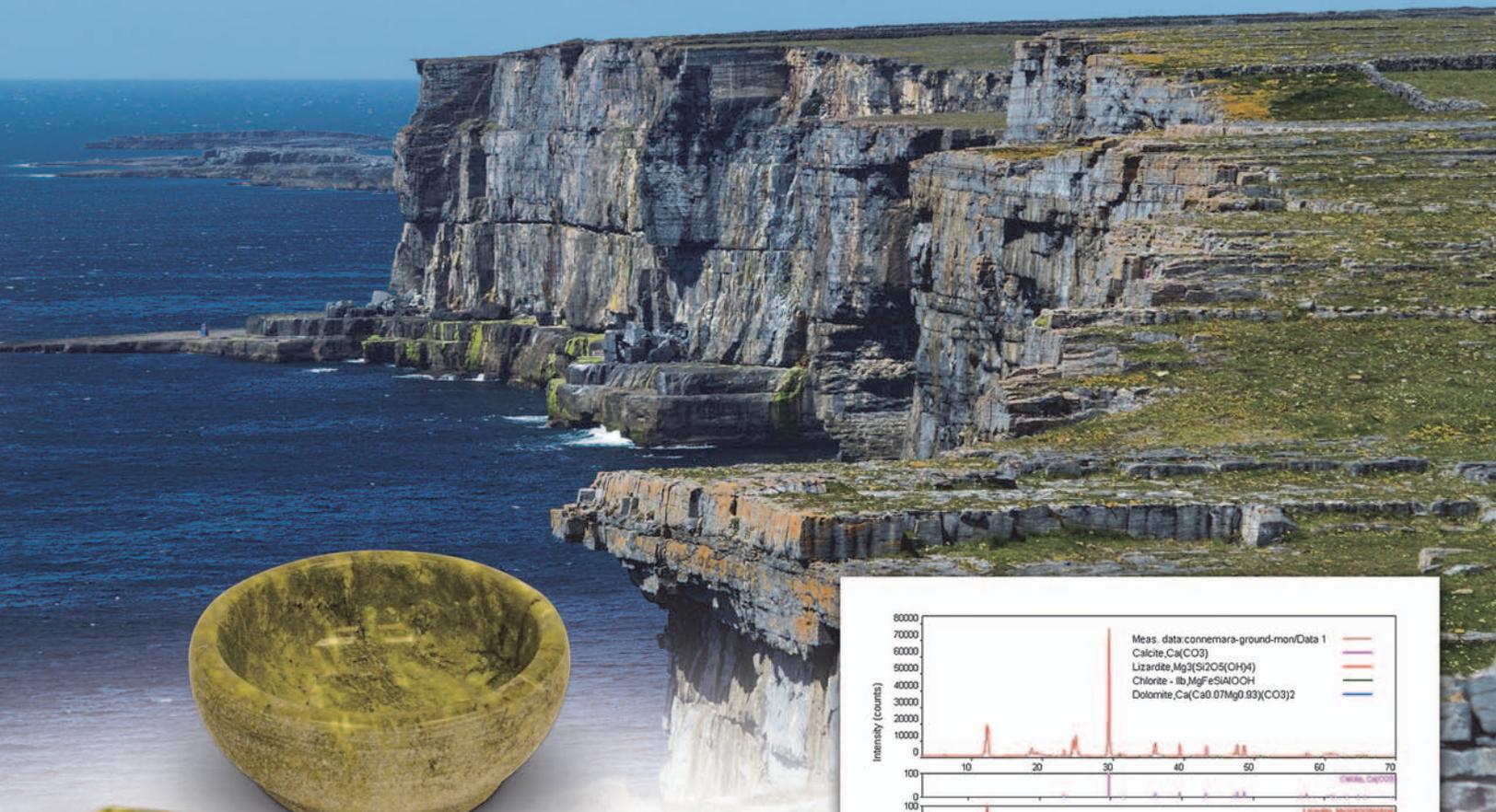
ACKNOWLEDGMENTS

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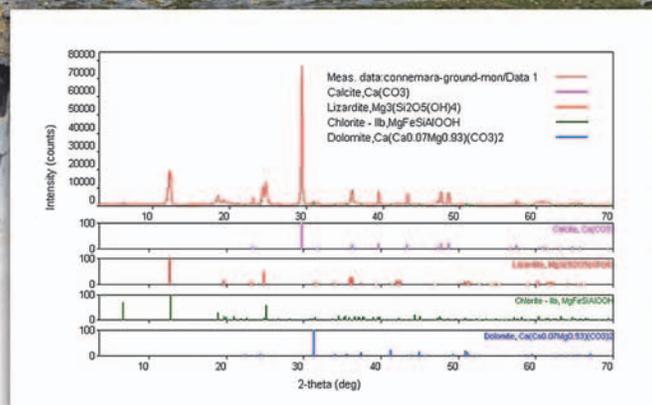
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Phase identification and Rietveld refinement of Connemara marble with a benchtop X-ray diffractometer



Connemara marble is unique in the sense that it is only found in one place on earth – in Galway County on the scenic west coast of Ireland.

In addition to containing a limestone mineral (calcite), three other phases belonging to the serpentine mineral family are found in Connemara Marble. The main polymorphic forms are chrysotile, antigorite, and lizardite. X-ray diffraction is a viable technique to identify and pinpoint the exact phase of the serpentine family.



Mineral	Chemical Formula	Wt %
Lizardite	Mg ₃ (Si ₂ O ₅ (OH) ₄)	38.2
Calcite	CaCO ₃	44.5
Chlorite IIb	MgFeSiAlOOH	15.1
Dolomite	CaMg(CO ₃) ₂	2.2

Specimens of Connemara marble were pulverized and analyzed with the Rigaku MiniFlex benchtop XRD. A Rietveld analysis was performed using the model obtained from these phases.



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THE OLDEST MINERALOGICAL SOCIETY

“**Mineralogy in all the space of this word**”—this motto of the Russian Mineralogical Society (RMS) perfectly reflects its general purpose of uniting under its umbrella not only professional mineralogists but also those who are interested in minerals from the standpoint of their beauty, their relevance to other sciences (biochemistry, archeology, materials research, etc.), or their practical use. The RMS was founded in 1817 as the Mineralogical Society of Saint Petersburg and is the oldest of the existing national mineralogical societies. It traces its history back to Lorenz Pansner (1777–1851), a German expatriate who obtained his PhD in physics from the Friedrich Schiller University in Jena (Germany) but who, after 1803, worked in Russia as a cartographer and mineralogist. Pansner founded the RMS and served as its first director. Its other founding members were C.B. von Vietinghoff-Scheel (1767–1829), Ya.G. Zemnitsky (1784–1851), D.I. Sokolov (1788–1852), V.M. Severgin (1765–1826; who developed the concept of paragenesis), and several other prominent naturalists. Between 1817 and 1882, the RMS undertook the geological mapping of the Russian Empire, and, between 1869 and 1928, published the voluminous *Materials on the Geology of Russia*. The society received new momentum in the 1860s when it became Imperial and moved its headquarters to Saint Petersburg Mining Institute, Russia’s first geological and mining school. In the 1950s, the society, then known as the All-Soviet Mineralogical Society (Vsesoyuznoe Mineralogicheskoe Obshchestvo, VMO) was involved with the International Mineralogical Association and opened its first Republic branches in Ukraine, Uzbekistan and elsewhere. Some of these daughter organizations now continue to function as national societies.



St. Petersburg Mining Institute

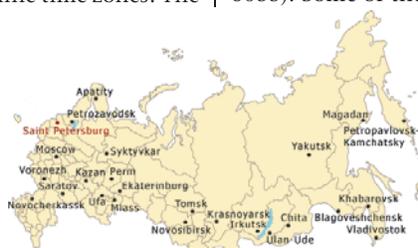
Some of the members of the RMS who achieved international fame include N.I. Koksharov, E.S. Fedorov (who derived the 230 space groups), V.V. Dokuchaev, D.I. Mendeleev (the father of the periodic table), A.P. Karpinsky, V.I. Vernadsky (the celebrated Russian geochemist), A.E. Fersman, A.N. Zavaritsky, A.G. Betekhtin, N.V. Belov, D.S. Korzhinsky (the only Russian Roebbling medalist), D.P. Grigoriev (member of the IMA Founding Committee and one of its first vice-presidents), V.S. Sobolev (IMA President in 1974–1978), I.I. Shafranovsky, V.I. Smirnov, G.B. Boki, and V.A. Frank-Kamenetsky. More recently, Nikolay V. Sobolev of Novosibirsk Geology and Mineralogy Institute was awarded the IMA Medal of Excellence for 2013 (*Elements*, 2013, v9, p 326), whereas Igor V. Pekov of Moscow State University set an unprecedented record in terms of the number of new mineral discoveries (161 species, including 99 where he is the lead author; see also *Elements*, 2015, v 11, pp 214–215).



RMS President D.V. Rundqvist

The RMS activities are coordinated by 17 special commissions focusing on a wide range of topics (mineral processing, mineral museums, organic

Today, the society is 900 members strong and has 25 regional branches spanning nine time zones! The current president is Dmitry V. Rundqvist, who is assisted by three vice-presidents: Yury B. Marin, Nikolay V. Sobolev, and Sergey V. Krivovichev (IMA President during 2014–2015). The RMS activities are coordinated by 17 special commissions focusing on a wide range of topics (mineral processing, mineral museums, organic



RMS regional branches

mineralogy, to name but a few). The society’s library is a unique collection of literature on mineralogy and related disciplines, including rare editions of classic works published between the 16th century and the 19th century.

SCIENTIFIC MEETINGS AND CONFERENCES

The RMS organizes 10–15 conferences annually on mineralogy, petrology, geochemistry, and crystallography. Its general meetings are held every five years and include elections of honorary fellows, award presentations, and council elections. The XII General Meeting (www.minsoc.ru/2015) will be held 13–16 October 2015 in Saint Petersburg. Registration will be open until 15 September 2015 for anyone interested in the excursion program (natural stone in the architecture of Saint Petersburg and in the State Hermitage Museum). Scientific sessions will cover a wide range of topics: fundamental mineralogical problems, strategic mineral deposits, alternative and unconventional deposit types of deposits (including technogenic mineral deposits, e.g. accumulations of waste metals, often rare metals, as a result of industrial processes), advancements in mineral analysis (including environmental and gemological applications), crystallography and crystal chemistry, and natural stone in the history of culture.

The RMS will celebrate its 200th anniversary with a special meeting in Saint Petersburg in January 2017 (www.minsoc.ru/2017). The session topics proposed so far are fundamental problems of modern mineralogy; mineralogy and geochemistry of mineral deposits; applied mineralogy; mineral crystallography, crystal chemistry and new minerals. Interested in attending? Mark your calendar with two important deadlines: March 2016 (call for sessions; new suggestions are welcome!) and November 2016 (nominations for RMS Honorary Fellows). Furthermore, persons nominated for RMS awards, or for any of the competitions that are announced on our website (www.minsoc.ru/award), need not be RMS members. A prominent scientist anywhere in the world can be nominated for an **Honorary Fellowship**. Since 1817, more than 140 foreign scientists have been elected as honorary fellows, including Charles Lyell, Alexander von Humboldt, Jöns J. Berzelius, René-Just Haüy, Roderick I. Murchison, Victor M. Goldschmidt, William H. Bragg, Max T. F. von Laue, Norman L. Bowen, James D. Dana, Reginald A. Daly, Paul A. Ramdohr, Alfred E. Ringwood, and seven past IMA presidents. Competitions for an outstanding contribution by a young researcher (published in *any* peer-reviewed journal) and photo contests are run by the RMS on a regular basis.

PROCEEDINGS OF THE RMS

Since 1830, the RMS has published its own journal, which was initially entitled *Transactions of the Mineralogical Society*, then became the *Proceedings of the Imperial Mineralogical Society of Saint Petersburg*, changing again during the Soviet era to *Zapiski VMO*. The journal is presently published six times per year as the *Proceedings of the RMS (Zapiski Rossiiskogo Mineralogicheskogo Obshchestva, ISSN 0869-6055)*. Some of the 60-plus papers contributed annually to *Zapiski* are translated as a supplement to *Geology of Ore Deposits* (MAIK/Springer). The journal welcomes manuscripts in all areas of mineral science and related fields, written in either Russian or English. A special section of the journal offers articles on new minerals and *Elements*’ readers should be aware that more than 460 new species descriptions have been published in *Zapiski* since 1958.

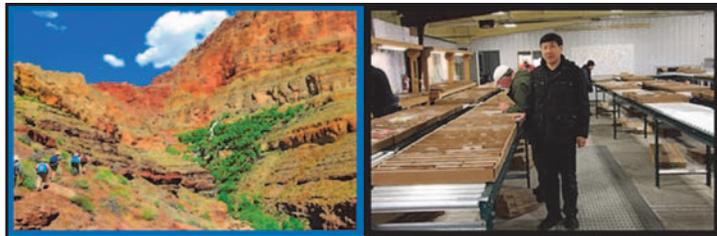




Association of Applied Geochemists

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A SUCCESSFUL IAGS CONFERENCE!



The 27th International Applied Geochemistry Symposium (IAGS) was held on 20–24 April 2015 in Tucson, (Arizona, USA) and was a great success, with excellent technical presentations, well attended short courses, and unique field trips. The cochair (Erick Weiland, Sarah Lincoln, and Rob Bowell) sincerely thank the sponsors and exhibitors who participated and made this event possible, despite the current tight financial environment. Attendees included 192 professionals, 32 students, and 25 guests, from 23 countries, with USA (119), Canada (75), and Australia (27) accounting for over 80%. Other countries represented were UK (8), China (7), Chile (5), Croatia (5), South Africa (5), Peru (3), Brazil (2), Costa Rica, Ecuador, Finland, France, Germany, Greece, Ireland, Israel, New Zealand, Pakistan, Portugal, Russia, and Sweden.

Two field trips were held, one in the Grand Canyon (led by Matt Leybourne, with Wayne Ranney highlighting the canyon's geology and history), and the other a visit to select Colorado mines and mills (led by David Bird and Rob Bowell). Five short courses and one student workshop, coordinated by Graham Closs and Owen Lavin, were also offered: Application of Indicator Mineral Methods to Exploration (McClenaghan and Layton-Matthews); Metal Mobility in Hydrothermal and Supergene Environments (Chavez and Peterson); Adding Value in Exploration and Remediation with Isotope Geochemistry (Kyser and Leybourne); Application of Field Portable X-Ray Fluorescence in Exploration and Mining (Hall); Interpretation of Geochemical Survey Data (Grunsky); and a Student Publishing Workshop (Leybourne).

The conference adhered to the IAGS format of four days of technical content broken up by a free Wednesday; there were 12 keynote presentations, 20 technical sessions covering 72 technical presentations, and 62 poster presentations. Keynote speakers were: Steve Reynolds (Arizona State University), Peter Bradshaw (First Point Minerals Corp.), Tony Christie (GNS Science), David Seneshen (Amplified Geochemical Imaging), Kathleen Smith (US Geological Survey), Bruno Lemièr (BRGM), Peter Winterburn (University of British Columbia), Lynda Williams (Arizona State University), Charlie Alpers (US Geological Survey), Cliff Stanley (Arcadia University), Pertti Sarala (Geological Society of Finland GTK), Wang Xueqiu (IUGS/IAGC), Eric Grunsky (Geological Survey of Canada), and Wolfrum Schuh (Freeport-McMoran). The technical sessions covered a wide geochemical breadth from exploration, isotopes, environmental, analysis, government

surveys, biogeochemistry, deeply buried deposits, to hydrogeochemistry. Two medical geology technical sessions and a keynote were presented and we thank Laura Ruhl for introducing these sessions to the IAGS.

Two student cash prizes were awarded: best oral presentation to Antonio Celis from Vancouver (British Columbia, Canada), and the best poster to Stacie Jones from Kingston (Ontario, Canada). Second place in each category went to Steven Kramar from Wolfville (Nova Scotia, Canada), and Yadi Wang from Tucson (Arizona, USA).

At the well-attended IAGS dinner, Colin Dunn and Ravi Anand were awarded the Association of Applied Geochemists (AAG) Gold Medal for outstanding achievement in exploration geochemistry, and Beth McClenaghan received the AAG Silver Medal for outstanding service to the AAG.

Erick Weiland (Erick_Weiland@fmi.com)
27th IAGS Chairman, Freeport-McMoran, Arizona, USA

RECENT ARTICLE PUBLISHED IN EXPLORE

R.G. Garrett (2015) A Comparison of Shewhart, Thompson and Howarth, and Youden Plots – Advantages and Disadvantages. Explore 167 (June 2015)

A review is presented of graphical and statistical tools available in the R Open Source package 'rgr' to support QA/QC tasks for applied geochemical survey data, with examples drawn from Geological Survey of Canada data. With data provided by the user, a variety QA/QC plots may be prepared for visual inspection and estimates made of analytical precision. Analytical duplicate analyses are presented as Shewhart plots to recognize if data have fallen out of the provided tolerance statistics. Alternately, these same data may be presented as Thompson and Howarth plots and tested to determine if they fall within a predefined population precision supplied as a relative standard deviation. Control reference data may be presented as Shewhart plots, with user-defined tolerance levels, to determine if there has been analytical drift. Youden plots are used to compare determinations on the same samples by different analytical procedures, analyses of material drawn from the same geographic site, e.g. field duplicates, or even analytical duplicates. As geochemical analytical data are of a closed compositional form, i.e. they sum to a constant, the Youden plots are prepared with logarithmic scaling. This is appropriate for trace and minor element data up to the 10 wt% level. The plots are presented with a 1:1 line to aid the recognition of bias between the analyses. Optionally, the orthogonal regression line (reduced major axis) may be added, this is the appropriate regression model as the two data sets are independent of one another. The intercept and slope coefficients of the orthogonal regression are estimated and tested against (0,1); if they are not significantly different the data can be accepted as equivalent. An alternate display is introduced where the ratio of the two analyses, being ideally one if the data are equivalent, is plotted against their mean. This is effectively a paired t-test of the logarithmically transformed data, the ratio is tested to determine if is significantly different from one, and classical and robust estimates of the precision made at the 95% confidence level. Optionally a cumulative probability plot of the ratios may be displayed to check that the variability about unity is normally distributed and identify any outliers.

Robert G. Garrett
(garrett@NRCan.gc.ca)

Emeritus Scientist, Geological Survey of
Canada, Ottawa, Canada

A call for laboratory support...

The Association of Applied Geochemists (AAG) invites analytical laboratories to participate in pairing their analytical facilities with student projects to develop emerging geochemists and their science. The AAG Education Committee is seeking analytical laboratories to offer in-kind support to students in terms of analysis, while receiving acknowledgement on AAG's website and in the Association's EXPLORE newsletter.

**"Today's students are
tomorrow's clients"**

If your laboratory is interested in learning more about this program, please contact the Chair of AAG's Education Committee at education@appliedgeochemists.org



International Association of GeoChemistry

www.iagc-society.org

TRIBUTE TO PROFESSOR WYNDHAM MICHAEL (MIKE) EDMUNDS: 31 JULY 1941 – 28 APRIL 2015



Mike Edmunds at WRI-13 conference in Guanajuato, Mexico, August 2010

We are deeply saddened to announce the passing of IAGC member Mike Edmunds on 28 April 2015 after a short battle with cancer. Mike had a distinguished career that spanned 50 years and will be remembered for his outstanding contributions to geochemistry, especially in hydrogeochemistry, palaeohydrology, and water resources. Our deepest sympathies and thoughts are with his wife, Kathy, their four children and six grandchildren.

Mike obtained his PhD in metamorphic petrology from the University of Liverpool (UK) in 1968. He joined the British Geological Survey in 1966, and, until mandatory retirement in 2001, conducted pioneering research in the field of groundwater. In 2003, Mike was appointed Senior Research Associate in the School of Geography and Environment, University of Oxford (UK), where he focused on water problems affecting modern society and on developing links between science and policy.

Mike also pioneered new methods by which to study water–rock interactions, including high-resolution interstitial water–depth profiles to characterize natural processes and pollution migration. Using an array of environmental tracers – including chloride mass balance, stable and cosmogenic isotopes, and noble gases applied to the unsaturated zone – he was among the first to show how tracer-based approaches may be used to resolve recharge rates and history. With co-workers from all over the world, he investigated many of the classical aquifers and sedimentary basins in Europe, and other continents, to define the controls on water-quality evolution, especially the origin and migration of palaeowaters. Mike conducted some of the earliest detailed investigations on hot dry rock reservoir geochemistry and on how acid rain affects shallow aquifers.

Mike contributed 230 professional publications and supervised 16 PhD theses in the UK and overseas. Because Mike was passionate about science and achieved the highest international stature in geochemistry, he was often invited to be a plenary speaker at international meetings. In the past decade alone, he was leader of over 10 major projects worldwide on aquifer management, groundwater pollution, mineral and hydrothermal waters, and palaeowaters. He also carried out international training, mentoring, and joint work in the water quality sector for the International Atomic Energy Agency and UNESCO.

Mike was made a fellow of the Geological Society of London (GSL) in 1972. For his scientific leadership and pioneering discoveries, Mike was awarded the GSL's Whitaker Medal in 1999; the Geological Society of America's O. E. Meinzer Award (being the first British recipient of that award), as well as being elected a GSA Fellow in 2009; and received the first Vernadsky Medal of the IAGC in 2010.

Mike was a strong supporter of the IAGC via the Water–Rock Interaction (WRI) Working Group. One of the founding fathers of WRI, Mike was the only person to have attended all 14 of the triennial WRI symposia. He was elected Chairman of the WRI Working Group (1989–2001) and Secretary General of the highly successful WRI-6 (1989) conference held in Malvern (England). And Mike was a founding Associate Editor of, and reviewer and author for, *Applied Geochemistry*.

Mike's death "in harness" is a great loss to geochemistry and to water science and policy. His passing has greatly saddened the large number of colleagues, scientists and students that he influenced worldwide.

ELSEVIER PHD STUDENT RESEARCH GRANT WINNERS

The IAGC is happy to announce the recipients of the 2015 Student Research Grants, sponsored by Elsevier and the IAGC. Every year, strong research proposals are submitted by students from around the world, and every year the awards become even more competitive, with a record 30 submissions in 2015. Congratulations to our grantees!



Jotautas Baronas
(University of Southern California)

"Si cycling dynamics in the Critical Zone: $\delta^{30}\text{Si}$ and Ge/Si multiproxy approach."

Jotautas earned his BSc in chemistry at Jacobs University in Bremen (Germany) in 2011 and his MSc in Earth Sciences at the University of Southern California (USA) in 2014. The goal of his PhD research is to develop new tools that can be used to reconstruct how weathering has changed in the geological past. He applies a multiproxy approach that utilizes a combination of element and isotope geochemical tracers (Ge/Si, $\delta^{30}\text{Si}$, and a novel proxy $\delta^{74}\text{Ge}$ currently in development, to name but a few). His work in tropical river catchments and anoxic ocean basins is aimed at finding a unique response of this multiproxy system to both continental weathering and marine sediment diagenesis processes.



Melissa Foster (University of Colorado)

"From the mountains to the plains: constraining the evolution of Front Range surfaces through Quaternary dating"

Melissa earned her BA in geology from Humboldt State University (USA) in 2003, and then worked in environmental consulting for several years in Arcata, California. Melissa returned to Humboldt State University for her MS in geology (2010), and she is currently a PhD student at the Institute of Arctic and Alpine Research (INSTAAR) and the Department of Geological Sciences at the University of Colorado (USA). Melissa's dissertation provides the timeline for Quaternary landscape evolution and surface processes in the Colorado Front Range and western High Plains. She is particularly interested in the rates of fluvial incision in the Front Range and in the exhumation history of the Denver Basin. To quantify rates and timing of sediment production, transport, and deposition in the Colorado Front Range, she measures the concentrations of cosmogenic radionuclides in fluvial sediments, colluvium, and mobile regolith.



Michael Short
(The Australian National University)

"Investigating salt and solute cycling in a small endorheic basin using stable halogen isotopes"

Michael graduated from Flinders University (South Australia) with a BSc in Environmental Science in 2012. He spent a year working as a hydrogeologist before beginning a PhD at the Research School of Earth Sciences at the Australian National University. His work is mostly focused on applying environmental tracer techniques to investigate water and salt/solute movement through arid and semi-arid landscapes. Michael is applying chloride, bromide and the stable halogen isotopes ($\delta^{37}\text{Cl}$ and $\delta^{81}\text{Br}$) as environmental tracers in catchment hydrology. This has involved investigating large international data sets, as well as field work in the Lake George Basin (New South Wales), to investigate catchment-scale variations in Cl⁻/Br⁻ ratios and solute transport through a 50 m thick clay aquitard. He also hopes that these techniques will provide further insight into the rich geologic and hydrologic history of the Lake George Basin.

Cont'd on page 274



European Association of Geochemistry



www.eag.eu.com

2016 EAG AWARDS: CALL FOR NOMINATIONS

To ensure the recognition of deserving scientists from all generations, your nomination can make the difference. Below is a short description of the EAG awards. The nomination process is simple.

	The Urey Award recognizes outstanding contributions advancing geochemistry over a career.
	The Houtermans Award is given to a scientist no more than 35 years old or within 6 years of their PhD for a single exceptional contribution to geochemistry, published either as a single paper or as a series of papers on a single topic.
	The Science Innovation Award subject area differs every year according to a five-year cycle; in 2016, the award will be named in honor of Werner Stumm for his work on low-temperature and surface geochemistry. This award is conferred to mid-career scientists for important and innovative breakthroughs in geochemistry.
	The GS/EAG Geochemical Fellows Award is bestowed upon outstanding scientists who have made major contributions to the field of geochemistry.

Please submit your nominations **before 31 October 2015 for the GS/EAG Geochemical Fellows and before 15 November 2015 for all other awards**. All details are available at www.eag.eu.com/awards/nomination/.

Cont'd from page 273



Yolanda Ameijeiras Mariño
(Université Catholique de Louvain)

"Tracing the impact of land use change on soil chemical weathering processes"

Yolanda received her bachelor's and master's degrees in chemical engineering at the Universidade de Santiago de Compostela (Spain) in 2011, specializing in environmental engineering. She is now pursuing a PhD at the Earth and Life Institute, Université Catholique de Louvain (Belgium), where she is researching the impact of changing land usage on sub-tropical southern Brazilian soil weathering processes and the effect this has had on chemical solute fluxes to rivers. To achieve this, Yolanda uses weathering indices and geochemical tracers, such as stable silicon isotopes and Ge/Si ratios, to identify weathering processes impacted by land conversion from forest to cropland, and to quantify the effect on solutes exported from soils. The research will improve our capacity to address the major environmental and socio-economic challenges posed by changing mineral weathering conditions in soils on decade-to-century timescales.

WOUTER PETERS RECEIVES THE 2015 EMINENT SPEAKERS AWARD AT EGU



Wouter Peters (left) receives the EAG Eminent Speakers Award from Bernard Marty, EAG Vice President

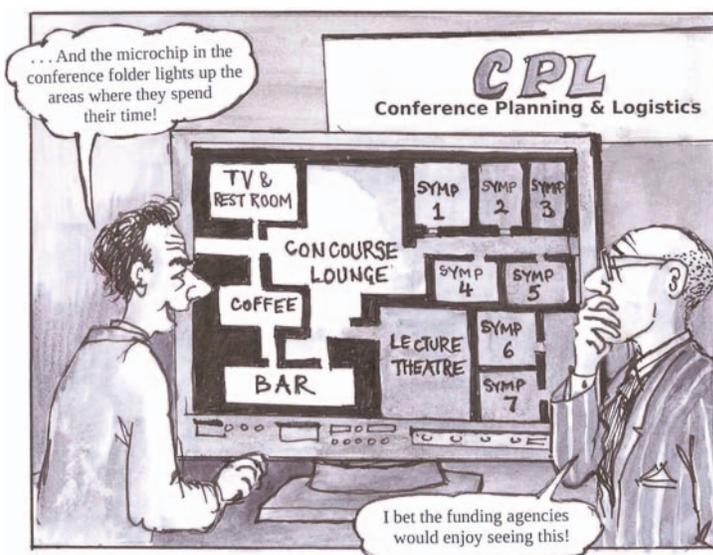
Wouter Peters (University of Wageningen and University of Groningen, The Netherlands) was recognized at the recent European Geoscience Union General Assembly for his contributions to geochemistry. Peters' work centres on deriving greenhouse gas budgets from observations of CO₂ and its isotopes, which he achieves by using data assimilation techniques on physical and biogeochemical models that are combined with real measurements. This has resulted in the widely used "CarbonTracker" products. In a new European Research Council-funded program, starting in 2015, Prof. Peters and his collaborators will collect and analyze air samples from the Amazon rain forest for their δ¹³C and Δ¹⁷O in CO₂ signatures to better understand the tropical carbon cycle.

2015 DISTINGUISHED LECTURE PROGRAM GOES TO 4 NEW INSTITUTIONS



Prof. Miryam Bar-Matthews (Geological Survey of Israel) is EAG's Distinguished Lecturer this year. She will deliver lectures this October in Ukraine, Hungary, Slovenia and Croatia on the topic of speleothems.

These are public lectures, so staff, students and visitors are welcome to attend. For more information, visit eag.eu.com/education/dlp.





THE LIVES OF GREAT GEOCHEMISTS*: AKIMASA MASUDA

Akimasa Masuda is without doubt one of the “Grandmasters” of modern geochemistry. Born in 1931, and growing up through the difficulties of WWII, he graduated from the University of Tokyo with a BSc in chemistry (1953) before moving into the field of Earth Sciences and finishing his MSc (1955) and PhD (1962) at Nagoya University. He held positions at universities in Tokyo and Kobe, at the Goddard Space Flight Center in the US, and at the Korean Institute of Geoscience and Mineral Resources.



Prof. Akimasa Masuda in 1973 (4th from the left)

During his career, Masuda published more than 200 papers, 25 of which were in the journal *Nature*. His first two publications were in fields he later pioneered and continuously advanced throughout his long, successful and very productive career: the first one was on rare earth element (REE) geochemistry (Masuda, 1957, Simple regularity in the variation of relative abundances of rare earth elements. *Journal of Earth Sciences, Nagoya University*, 5, 125–134); the second one was on isotope geochemistry (Masuda, 1958, Isotopic composition of primeval lead of the earth. *Geochimica et Cosmochimica Acta* 13, 143–152)

Undergraduate students are occasionally asked to plot REE concentrations against REE atomic numbers: this usually results in zig-zag patterns that are very inconvenient to discuss or interpret. Unbeknownst to many younger geochemists, it was Akimasa Masuda who was one of the inventors of the method we use today to illustrate REE data: normalizing REE concentrations for rocks, minerals or waters against REE concentrations in chondrites or shale (the latter as an equivalent of average post-Archean upper continental crust). This plotting technique



Prof. Akimasa Masuda a few days before his 79th birthday in October 2010

eliminates the effect of Oddo–Harkins' Rule (that elements with an even atomic number are more common than elements with an odd atomic number) and results in a smooth distribution pattern in which any anomalous behaviour by an individual REE is easily discernable. For many years, these normalized REE distribution patterns used to be referred to as Masuda–Coryell diagrams (Larry Coryell had almost contemporaneously developed a similar concept). Although only rarely called this anymore, the approach is

still the standard way of presenting REE data (with the slight difference that we no longer arrange the REEs on the *x*-axis according to their ionic radii). Another one of Masuda's REE geochemistry discoveries was much more controversial: he claimed that the lanthanide tetrad effect resulted in the subdivision of a REE pattern into four segments and that may be observed in natural materials. This observation was initially rejected by most geochemists, and it took many years until it was widely acknowledged that he had been right.

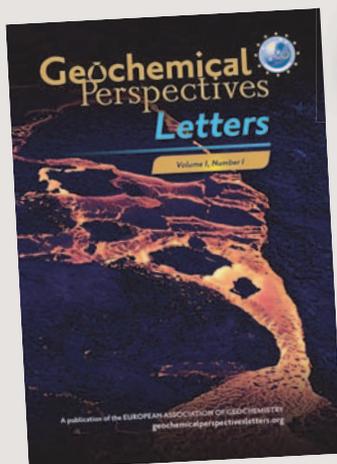
Not surprising, Masuda's last publication combined his two favourite topics of REE geochemistry and isotopes in his contribution to Lee et al. (2010, La–Ce and Sm–Nd isotopic systematics of early Proterozoic leucogranite with tetrad REE pattern. *Chemical Geology*, 276, 360–373). And I myself had the pleasure of a memorably stimulating conversation with him during a meeting in Tokyo in November, 1995.

In March of 2011, half a year before his 80th birthday, Akimasa Masuda, the Grandmaster of REE geochemistry, passed away.

Michael Bau (Jacobs University)

(Photos kindly provided by Profs. Tanaka and Shimizu, with the help of Y. Takahashi)

* Previous published articles on the lives of great geochemists include Alfred Ringwood (April 2011), Samuel Epstein (June 2014), Werner Stumm (June 2015).



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Mineralogical Society of Great Britain and Ireland

www.minersoc.org

NOMINATIONS SOUGHT FOR MINERALOGICAL SOCIETY AWARD FOR BEST PAPER



In honour of
R.A. Howie

An award will be made annually to “the lead author of the ‘best paper’ published (in English) in a mineralogical journal (*sensu lato*) within three years of award of his/her PhD thesis”. The award will take the form of a bursary (£1000) to attend an international conference (to be agreed with the society) and to present a paper as the “R.A. Howie Memorial Lecture”. The money will be paid on receipt of an official confirmation of conference registration.

The “R.A. Howie Memorial Lecture” award is named in honour of Prof. R.A. Howie (1923–2012) who was a distinguished professor of mineralogy at Kings College London and Royal Holloway University, London (UK). The nomination process is outlined below.

Nominations

Nominations can be made by any scientist (including a co-author) but not the nominee him/herself and must be supported by a fellow scientist familiar with the nominee’s work.

Nominations must be received, by the Executive Director, by the closing date of 1 September 2015. The Awards Committee will consider the nominations and rank them. This ranking will then be passed to the society’s council (by mid-October) for a formal decision at their November meeting. Council will make a decision and inform the winner.

Nominations should consist of a letter of nomination together with at least one letter of support along with a copy of the paper being nominated and a copy of the nominee’s CV. The letter(s) should address the criteria outlined below and how any or all of them are met by the paper in question. Each nomination package should be submitted in electronic form (a single pdf file) and sent to the society’s Executive Director, Kevin Murphy (kevin@minersoc.org).

Award criteria

The Awards Committee will take into consideration the following points:

1. Novelty
2. Interdisciplinary
3. Applicability
4. How the science is advanced by the new work

Timing

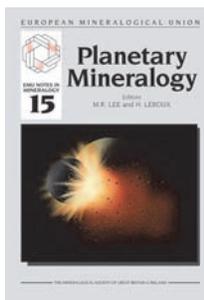
The nominated paper must have been published in the calendar year before the nomination and within three years of award of the candidate’s PhD, and it will remain on the slate for up to two years.

EMU NOTES IN MINERALOGY, VOL. 15

Planetary Mineralogy, edited by Martin Lee and Hugues Leroux, is now available from the Mineralogical Society’s online bookshop: price £30 for individuals, £45 for institutions.

The contents list is as follows:

- **Chondritic meteorites and early Solar System solids.** Ian S. Sanders
- **Organics in primitive meteorites.** Laurent Remusat



- **Aqueous alteration in chondritic asteroids and comets from the study of carbonaceous chondrites.** Josep M. Trigo-Rodríguez
- **Impact metamorphism in terrestrial and experimental cratering events.** Alex Deutsch, Michael H. Poelchau and Thomas Kenkmann
- **Lunar geology.** M. Anand, J.J. Barnes and L.J. Hallis
- **Noble gas chemistry of planetary materials.** Julia A. Cartwright
- **Isotopic analyses of primitive meteorites.** Jutta Zipfel
- **Shocked rocks: impacts from the laboratory to the Solar System.** Mark J. Burchell
- **Micrometeorites.** Luigi Folco and Carole Cordier

GEOMICROBIOLOGY NETWORK: A JOINT GROUP OF THE MINERALOGICAL SOCIETY AND THE SOCIETY FOR GENERAL MICROBIOLOGY

Focused Meeting 2015: Industrial Applications of Metal–Microbe Applications

9–10 November 2015, London, UK

The Industrial Applications of Metal–Microbe Applications is the third of the 2015 Focused Meeting series. It will take place at Charles Darwin House, central London, UK.



Metals are key components of life, and they play crucial roles in many areas of science of technology. Metal–microbe interactions, therefore, underpin many areas of industry, from the mining sector, which relies on “biomining” for extracting valuable metals from low grade ores and on biorecovery for metal processing, through to the water companies and contaminated-land stakeholders who rely on “bioremediation” for sustainable clean-up of contaminated land. Metal–microbe interactions also play key roles in many high-technology applications: they are involved in the correct processing of metal co-factors that are required for a large range of pharmaceuticals and fine chemicals; and they are required for novel nanotechnology biofabrication strategies, including the synthesis of quantum dots, catalysts, nanomagnets and other high-value products (often from wastes).

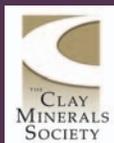
The UK is well placed to lead this field, but targeted meetings that bring together the complementary microbiological and applied expertise are scant. The complementary interests of the Biotechnology and Biological Sciences Research Council–Networks in Industrial Biotechnology and Bioenergy (BBSRC–NIBB) network program “Metals in Biology: The Elements of Biotechnology and Bioenergy” and the Geomicrobiology Network (a Mineralogical Society Special Interest Group, co-supported by Society of General Microbiology (SGM)), will combine to run a two-day meeting supporting this area.

There are four main themes, supported by a cross-cutting theme on enabling microbiological and analytical infrastructure:

1. Biomining
2. Biorecovery and Bioprocessing
3. Bioremediation
4. Biofabrication of higher-value products

The meeting will have ~100 participants, with representatives from industry and academia. The Geomicrobiology Network/Mineralogical Society will support a session on bioprocessing of e-tech elements (Co, Ga, In, Te, Li and the rare earths) and subsidizing an evening social event; the BBSRC–NIBB will support the attendance of key industrialists. Participants will be drawn from a broad range of sources, including the SGM membership, Geomicrobiology Network membership and those signed up to the Metals in Biology NIBB. Key European Union groups will also be targeted to enhance UK participation in future Horizon 2020 programmes (the biggest ever EU Framework Programme for Research and Innovation). The organizers aim to have a 50:50 blend of industry and academic invited speakers, with supplementary oral and poster presentations for younger researchers.

For more information contact Jon Lloyd (jon.lloyd@manchester.ac.uk).



The Clay Minerals Society

www.clays.org

THE PRESIDENT'S CORNER



Prakash Malla

Dear Clay Minerals Society Community,

Greetings from Sandersville, Georgia (USA), the "kaolin capital of the world"! As the new president of the Clay Minerals Society (CMS) for 2015–2016, I would like to take this opportunity to thank and congratulate our outgoing president, Dr. W. Crawford Elliott. Crawford conducted his presidency with great enthusiasm and determination and has made much-needed progress on multiple fronts. I hope to build on his success and continue to sustain and increase the vitality of our society.

The primary mission of the CMS is to encourage and stimulate research in the field of clay science and technology, as well as to disseminate research findings, exchange innovative ideas, and facilitate network-building activities. The society has established a multitude of vehicles to accomplish the above goals: (1) our journal, *Clays & Clay Minerals*, (2) workshop volumes, (3) E-newsletters, (4) the CMS website, (5) annual meetings and field trips, (6) source clays, (7) student research scholarships and travel grants, (8) professional awards, and (9) the Reynolds Cup. The journal is the heart and soul of our society, and the editorial board, executive committee, and council are working to improve its impact factor and circulation. This is my top priority. The CMS website is the face and the first impression of our society, but it needs a facelift to be more communicative and representative of who we are and what we do.

Members are the pillars of any organization and the CMS is no exception! The CMS is truly an international organization, with over 40 countries represented by our members. The diversity of our membership is one of our greatest strengths. Our members come from many different backgrounds, including clay mineralogy, geology, soil science, chemistry, physics, materials science, ceramics, chemical engineering, civil engineering, biology, archeology, and anthropology. Members represent academia, industry, government research labs, and independent consultants. These clay scientists and technologists are tirelessly working to understand the structure and properties of clays and clay minerals in relation to their interactions with and influence on the environment in which they exist. These efforts have led to significant advances in a range of areas including the management of environmental issues such as oil spills, hazardous waste, radionuclides, and greenhouse gases; the design of heat and fire resistant plastics/rubber (organic polymers); the design of better paper, paint, and ceramics products; the design of better metakaolin for high strength and durable concretes; a better understanding of clay swelling and shrinking properties and their mitigation to prevent foundation damage and other geotechnical/civil engineering issues; improved use of healing clays; the extraction of oils and natural gas; improved soil management practices to feed the growing world population; and the understanding of the origin and history of the Earth and the existence of water and habitability on Mars. Was it clays that facilitated the synthesis of and helped to cradle, protect, and nurture the first DNA and protein molecules that, a few billion years later, make us who we are today? Whatever the answer to that deep puzzle, it is collaborations that are the key to successfully tackling the many challenging clay-related problems. I am proud to say that CMS has been providing many platforms for such collaborations.

I am a true believer in the expression, "There's no such thing as a free lunch." I appeal to you and challenge you to get involved in the activities of the Clay Minerals Society. As a member, there are many different ways you can contribute: serve on a committee (there are 12 of them),

the council, the executive or editorial boards, a panel of reviewers, or on the annual meeting organizing committee. You could also identify and nominate a deserving colleague for awards, judge student presentations, organize special sessions, lead a field trip, invite a colleague to join the society, and so forth. It is mind boggling to imagine the impact you could have if every member invited a colleague to become a new CMS member in 2016. I consider this a peer-to-peer concept, and, if you agree, the process should begin now. Your contribution to the CMS is a way to give back to your profession, which is, trust me, very gratifying.

By the time you read this note, the 52nd Annual Meeting of the CMS will have been completed. The meeting was held 5–10 July 2015 in conjunction with Euroclay2015 in Edinburgh (Scotland) and was led by Steve Hillier and Kevin Murphy. The full report on the 2015 conference will appear later, but for now I would like to take this opportunity to let you all know that the 53rd Annual Meeting will be held at the Georgia Tech Hotel and Conference Center in Atlanta (Georgia), 5–8 June 2016. In addition to its interesting geology and soils, Georgia is a home to many industrial minerals, such as kaolin, mica, calcium carbonate (limestone), bauxite clays, attapulgite, palygorskite, and iron oxides. The 2016 annual meeting will include a workshop, a field trip to Georgia's kaolin mines, a full spectrum of technical sessions, and excellent opportunities for networking. I invite and welcome everyone to Atlanta in 2016. Please make every effort to attend and make this conference a great success.

Lastly, as an incoming society president, I appreciate the opportunity to continue to be a part of the *Elements* family and to regularly inform the wider mineral community of CMS news. Finally, I would also like to encourage our CMS members to take a greater role in contributing to *Elements*.

With best regards,

Prakash B. Malla, CMS President
Thiele Kaolin Company, Sandersville, Georgia, USA

STUDENT RESEARCH SPOTLIGHT

Congratulations to **Tara Selly** (University of Missouri, USA) for winning a CMS Student Research Grant!



Tara Selly is researching the **potential preservational role of clay minerals in the Burgess Shale-type (BST) mode of fossilization**.

Through comparative elemental analyses across fossil and host-rock matrices, her goal is to better constrain the timing (and, therefore, the taphonomic influence) of aluminosilicification, whether detrital, authigenic, or metamorphic in origin. The timing and preservational influence of clay minerals

in BST fossilization are not well established despite multiple studies across numerous fossil taxa and BST deposits. Tara's work on Cambrian anomalocaridids found distinct elemental signatures of the host rock and fossil-associated clays, along with extensive pyrite associations, perhaps indicating concurrent authigenic mineralization in the earliest diagenetic environment around the still decaying carcass. To further assess the timing of clays in BST fossil preservation, Tara will conduct actualistic decay experiments in a restricted, anoxic marine setting. These experiments might allow her to witness the earliest stages of decay on a seafloor and of associated authigenic/early diagenetic aluminosilicification.



<http://jams.la.coocan.jp>

NEW INTERNATIONAL RESEARCH PROJECT

Eliminating Radionuclides in Seawater at Fukushima Daiichi Nuclear Power Plant — The Use of Halophilic Microorganisms

The fuel debris from Units 1–3 of the Tokyo Electric Power Company (TEPCO) Fukushima Daiichi nuclear power plant (FDNPP) was stabilized by circulative cooling using seawater and by using water within a primary containment vessel (PCV). However, the incursion of more than 300 tons per day of groundwater through the FDNPP, in addition to some groundwater entering the PCV, has resulted in the generation of large quantities of contaminated water. This contaminated water is currently being treated by TEPCO, who are taking three countermeasures:

1. *Eliminate the contamination sources* The level of 62 nuclides in the contaminated water is reduced using multi-nuclide removal equipment, called ALPS (advanced liquid processing system). This removes the contaminants by sorption into adsorbent materials and by coprecipitating the contaminants with iron and/or carbonates. The treated wastewater is then stored in tanks because it still contains tritium (Fig. 1).



FIGURE 1 Large storage tanks used to house treated contaminated water.

2. *Isolate non-contaminated water from contamination* Uncontaminated groundwater is continuously being pumped to bypass the FDNPP, reducing groundwater flow from 400 m³ to 300 m³ per day. On the landward side, an impermeable wall of frozen soil will be used to reduce groundwater inflow into the buildings. Waterproof pavements have been installed to reduce rainwater infiltration into the ground and to protect radiation workers from mobile contaminants.
3. *Prevent leakage of contaminated water* Impermeable walls on the seaward side are now being constructed and will extend around the harbour. These walls will prevent the transport of contaminated waters.

Even with these countermeasures, radionuclides of ¹³⁷Cs and ⁹⁰Sr are being detected in the seawater intake channel and in the port at the TEPCO site (Fig. 2). In 2014, the highest concentrations of ¹³⁷Cs and ⁹⁰Sr inside the water intake channel of Units 1–4 was 73 Bq/L and 220 Bq/L, respectively; inside the port these values were 7.3 Bq/L and 49 Bq/L, respectively. The challenge, therefore, is to decontaminate

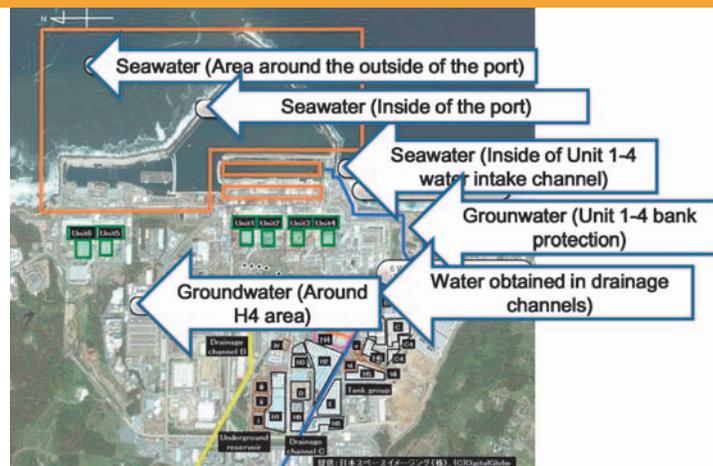


FIGURE 2 Plan view and sampling locations of the TEPCO Fukushima Daiichi Nuclear Power Plant site.

this water before it is transported further into the environment. Currently, TEPCO is using zeolite to remove ⁹⁰Sr from seawater; this produces more than 200 kg/m³ of waste sorbent.

New research on novel restoration materials is being conducted by an international team led by Dr Toshihiko Ohnuki (Japan Atomic Energy Research Agency), with collaborators from the Shibaura Institute of Technology of Japan (abbreviation Shibaura TU), the Kyushu University of Japan, and Dr Joseph Hriljec and investigators from the University of Birmingham (abbreviation UB; UK). This joint research is being funded by Japan Science and Technology Agency (JST) for the Japanese team and by the Engineering and Physical Sciences Research Council (EPSRC) (grant EP/M012719/1) for the UK team.

There are three objectives of this international team. First, to use halophilic (“salt-loving”) microorganisms to eliminate radionuclides from local seawater (Fig. 3). Second, to prevent the dispersion of the halophilic microorganisms out from the harbour area by using magnetized materials attached to the microorganisms. The novelty of using magnetized materials attached to the halophilic microorganisms is that the movement of the organisms, along with their radionuclide cargo, is designed to be controlled. Magnetized halophilic microorganisms could, therefore, be used to decontaminate the port seawater of the FDNPP. Third, to develop novel fluidized adsorbent materials to inject directly into the contaminated subsurface area. These adsorbent

Remediation by biogenic apatite

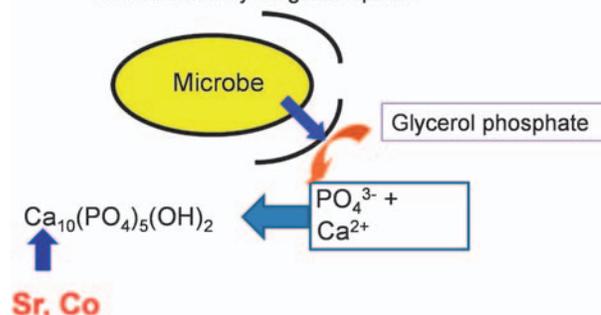


FIGURE 3 Radionuclides of ⁹⁰Sr and ⁶⁰Co can be eliminated by biogenic minerals from contaminated seawater and groundwater. This example shows biogenic hydroxylapatite as an entrapment mineral for Sr²⁺ and Co²⁺.

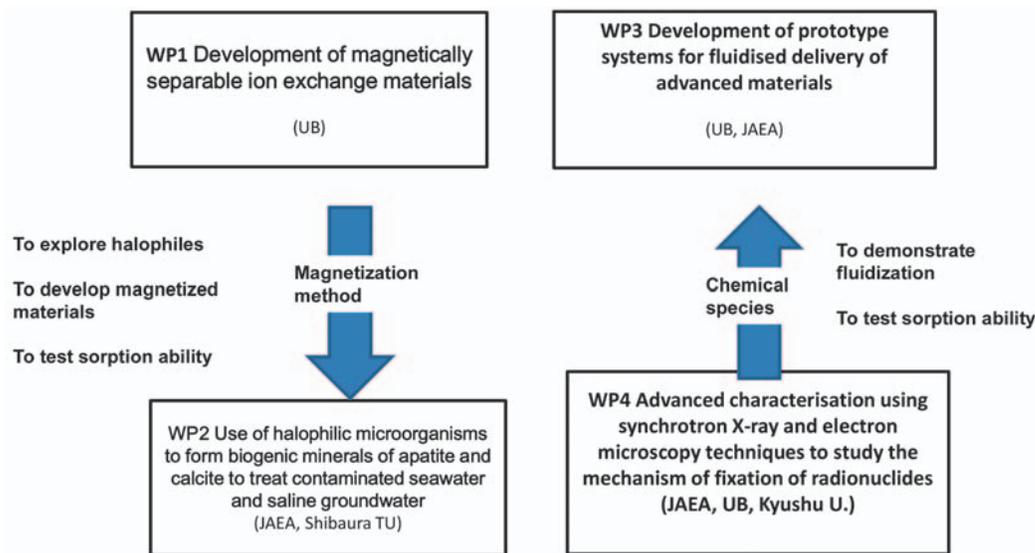


FIGURE 4 Collaboration flow chart of Japanese and international participants for four remediation/analytical work packages (see text).

materials would be designed to be poured or injected into the ground to form porous barriers that could then trap the targeted radionuclides and prevent further migration.

To achieve the above objectives, four work packages have been proposed:

- 1) Develop magnetically separable ion exchange materials
- 2) Use halophilic microorganisms to form biogenic minerals to treat contaminated seawater and saline groundwater
- 3) Develop prototype systems for the fluidized delivery of advanced materials
- 4) Develop advanced characterization using synchrotron X-ray and electron microscopy techniques to elucidate the mechanism of radionuclide fixation

The collaboration flow chart of participants in each work package is shown in FIGURE 4. The joint research will build on the work of an established internationally lead team for the development of novel systems for immobilizing Cs^+ , Sr^{2+} and Co^{2+} . This research project, the culmination of the previous “projects” started in 2014, will extend for 3 years.

Dr. Toshihiko Ohnuki

Japan Atomic Energy Research Agency

JAMS AT THE JpGU2015 MEETING

The Japan Geoscience Union Meeting 2015 (JpGU 2015) was held on 24–28 May 2015 in the Makuhari Messe Convention Centre at Chiba (outside Tokyo). The meeting had 189 scientific sessions, including 55 international sessions, and was attended by approximately 7000 participants. During the meeting, the Japan Association of Mineralogical Sciences (JAMS) had an exhibition booth to advertise our journals—*Journal of Mineralogical and Petrological Sciences (JMPS)* and *Ganseki Koubutsu Kagaku (GKK)*—as well as books authored by our members and back issues of *Elements*. The number of international sessions at the JpGU meeting is increasing year by year, and next year’s JpGU will be held 22–26 May 2016, once again, in the Makuhari Messe. There are planned approximately 70 international sessions, including 10–15 Japan Geoscience Union–American Geophysical Union joint sessions. We look forward to your participation.

JOURNAL OF MINERALOGICAL AND PETROLOGICAL SCIENCES

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Original Articles

Sr–Nd–Pb–Hf isotopic constraints on the diversity of magma sources beneath the Aden Ridge (central Gulf of Aden) and plume–ridge interaction Ryuichi SHINJO, Daniel MESHESHA, Yuji ORIHASHI, Satoru HARAGUCHI and Kensaku TAMAKI

Crustal assembly of the Antananarivo and Masora domains, central–eastern Madagascar: constraints from U–Pb zircon geochronology and whole-rock geochemistry of meta-granitoids Takashi ICHIKI, Masahiro ISHIKAWA, Jun–Ichi KIMURA, Ryoko SENDA and Raymond RAKOTONDRAZAFY

Cs–sorption in weathered biotite from Fukushima granitic soil Ryosuke KIKUCHI, Hiroki MUKAI, Chisaki KURAMATA and Toshihiro KOGURE

Mieite–(Y), $\text{Y}_4\text{Ti}(\text{SiO}_4)_2\text{O}[\text{F},(\text{OH})]_6$, a new mineral in a pegmatite at Souri Valley, Komono, Mie Prefecture, central Japan Ritsuro MIYAWAKI, Satoshi MATSUBARA, Kazumi YOKOYAMA, Masako SHIGEOKA, Koichi MOMMA and Sadaoki YAMAMOTO

Letters

Spatial U–Pb age distribution of plutonic rocks in the central Abukuma Plateau, northeastern Japan Arc Yoshiaki KON, Terumi EJIMA, Sayaka MORITA and Tetsuichi TAKAGI

Yukonite and walkkildellite–(Fe) from the Kiura mine, Oita Prefecture, Japan Satomi ENJU and Seiichiro UEHARA



Mineralogical Association of Canada

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2015 MAC AWARDS

Peacock Medal to Donald Bruce Dingwell



The Peacock Medal, the highest award bestowed by the Mineralogical Association of Canada (MAC), was awarded to Donald Bruce Dingwell of the Ludwig-Maximilians-Universität München (Germany) for his outstanding contributions to the new and expanding field of experimental volcanology. Dingwell's principal research interest is the physicochemical properties of molten rocks and their impact on volcanic systems. He has published

about 350 papers whose impact is reflected in more than 10,000 citations.

Born in Corner Brook, Newfoundland (Canada), Don Dingwell received his BSc (1980) in geology/geophysics from the Memorial University of Newfoundland and his PhD in geology from the University of Alberta (1984). After two years at the Geophysical Laboratory of the Carnegie Institution of Science and one year on the faculty of the University of Toronto (Ontario), he was recruited as assistant to the director of a newly founded research institute in Bayreuth (Germany). In 2000, he became chair in mineralogy and petrology at the Ludwig-Maximilians-Universität München where he founded the Department of Earth and Environmental Sciences, of which he is currently director.

His research has been recognized by numerous scientific awards, including the Norman L. Bowen Award of the American Geophysical Union, the Otto Schott Research Award of the Ernst Abbe Foundation, the Robert Wilhelm Bunsen Medal of the European Geosciences Union, the Viktor-Moritz-Goldschmidt Award of the German Mineralogical Society, the MSA Award of the Mineralogical Society of America, and the Gerhard-Hess Research Prize of the German Research Council (DFG). The president of Germany has also bestowed upon him the Order of Merit of the Federal Republic of Germany.

Don Dingwell has held office in national and international societies, recently serving as president of the European Geosciences Union. He currently chairs the Earth and Cosmic Sciences section of the Academia Europaea and serves on its board, he is a member of the European Academies Sciences Advisory Council, and he is the president-elect of the International Association of Volcanology and Chemistry of the Earth's Interior. Don recently completed his term as 3rd Secretary General of the European Research Council, Europe's flagship research funding organization.

Young Scientist Award to Gordon R. Osinski



Gordon "Oz" Osinski is an associate professor and the NSERC/MDA/CSA Industrial Research Chair in Planetary Geology at the University of Western Ontario. He holds a BSc (Hons) from the University of St. Andrews (Scotland) (1999) and a PhD from the University of New Brunswick (2004). His research focuses on understanding impact cratering as a planetary geological process on Earth, the Moon, and Mars. His interests also include the

development of exploration technologies and techniques for application in remote and extreme environments both on Earth and in space. He was awarded a Canadian Space Agency Fellowship in Space Science (2007), an Ontario Ministry of Research and Innovation Early Researcher Award (2009), the 2009 Nier Prize of the Meteoritical Society, and an NSERC Discovery Accelerator Supplement in 2013. Dr. Osinski is also director of the Centre for Planetary Science and Exploration at the

University of Western Ontario, the principal investigator of the Canadian Lunar Research Network, and the founder and first chair of the Planetary Sciences Division of the Geological Association of Canada.

Berry Medal to Martine M. Savard



The MAC recognizes the long-term dedication of individuals to our association through awarding of the Berry Medal (named after Len Berry, a professor of mineralogy at Queen's University (Ontario) and editor of *The Canadian Mineralogist* from 1955 until 1975). This year's winner is Dr. Martine M. Savard who, over a ten-year period, served the Mineralogical Association of Canada as a councilor (2004–2006), treasurer (2006–2008), and signing officer (2008–

2014). Importantly, Martine was instrumental in coordinating major changes in the financial institutions used by MAC and in facilitating the move of MAC's business office from Ottawa to Quebec City in 2005. She was also our champion for space in the Institut National de la Recherche Scientifique–Commission Géologique du Canada (INRS-CGC) building, a location that the MAC continues to operate from today.

Martine Savard has been a researcher at the Geological Survey of Canada (GSC) since 1990. She is also an adjunct professor at Institut National de la Recherche Scientifique–Eau, Terre, Environnement (INRS-ETE) where she has been coteaching a stable isotope graduate course for 14 years. She is the head of the GSC's Delta-Lab, a stable isotope laboratory. Recently, she and her team have been addressing such environmental questions as the sustainable development of groundwater resources in eastern Canada, and distinguishing between natural and anthropogenic metal accumulations in the vicinity of Canadian smelters and mining operations.

Hawley Medal to Fernando G. Sardi and Adriana Heimann

The Hawley Medal is awarded to the authors of the best paper published in *The Canadian Mineralogist*. For 2014, it is awarded to Fernando G. Sardi and Adriana Heimann for their paper, "Pegmatitic beryl as indicator of melt evolution: example from the Velasco District, Pampeana Pegmatite Province, Argentina, and review of worldwide occurrences" (*Canadian Mineralogist* 52: 809-836).



Fernando Guillermo Sardi has been professor (since 2009) and assistant/associate professor (1992–2009) of geochemistry at the Faculty of Natural Sciences and Miguel Lillo Institute of the National University of Tucumán (Argentina). He has also been a researcher of the National Research Council (CONICET, Argentina) since 2007. Currently, his research deals with the mineralogy and geochemistry of pegmatites and hydrothermal

mineral deposits localized mainly in the Precambrian–Paleozoic Sierras Pampeanas.



Adriana Heimann Ríos holds a faculty position in mineralogy and petrology at the East Carolina University in Greenville, North Carolina (USA) since 2009. Her current research focuses on the chemistry of minerals from granitic pegmatites as indicators of melt evolution, the geochemistry and genesis of banded iron formations, and Fe isotope geochemistry in igneous systems.

WELCOMING NEW COUNCIL MEMBERS

Finance Committee Chair



Michelle A. E. Huminicki (Brandon University, Manitoba) received a BSc (honors) in geology from the University of Manitoba in 2000, an MSc from Laurentian University (Ontario) in 2003, and a PhD from the Memorial University of Newfoundland in 2008. She has worked for Falconbridge Ltd (2000), the Ontario Geological Survey (2002), Anglo American (2007), and Rockcliff Resources Inc. (2008). Michelle is registered as a professional

geoscientist with the Association of Professional Engineers and Geoscientists of Manitoba. Since 2009, she has been employed at Brandon University as a faculty member and manager of the Micro Analytical Facility. In addition to carrying out analytical work and research, Dr. Huminicki supervises thesis students and research assistants.

Councilors 2015–2018



Ekaterina Reguir is a research associate and sessional lecturer at the Department of Geological Sciences, University of Manitoba. She received an undergraduate degree in mineralogy from St. Petersburg State University (Russia), an MSc in geology from Lakehead University (Ontario), and a PhD from the University of Manitoba. Her main areas of research are the petrogenesis of carbonatites and kimberlites, trace element characteristics of minerals from alkaline rocks, and geochronology.



Anežka Borčinová Radková is currently a PhD candidate in environmental mineralogy at Queen's University (Ontario). She received a BSc in geology and an MSc in mineralogy and petrology at Comenius University in Bratislava (Slovakia). Currently, under the supervision of Dr. Heather Jamieson, she investigates the oxidation products of tetrahedrite-group minerals and studies the influence of the crystallization of secondary minerals

on antimony mobility in mine drainage. Her field sites include some abandoned copper deposits in Slovakia and the Beaver Brook antimony mine in Newfoundland. Her research interests include environmental mineralogy and geochemistry and the application of synchrotron radiation-based techniques on the study of mine-waste mineralogy.

We extend our thanks to outgoing Finance Committee Chair, Neil Banerjee, and outgoing councilors Roberta Flemming and Mostafa Fayek, who have served MAC for the last 3 years.

AN INVITATION TO ATTEND WHITEHORSE 2016

From the Margin of Laurentia, to the Margin of Beringia, to the Margin of Society

The Whitehorse 2016 Organizing Committee invites you to attend the first-ever GAC–MAC meeting in the Yukon Territory, which will be held 1–3 June 2016 at the Yukon College Campus in Whitehorse, the wilderness city. The conference will highlight Northern Cordilleran geology and feature field trips to some unique geologic settings. A diverse program will cover a range of geoscience disciplines, including tectonics, metallogeny, geological hazards, and glaciated (and unglaciated!) northern landscapes, all against a backdrop of spectacular scenery and warm hospitality. Here is a sampling of the special sessions and field trips that will be on offer.

Special Sessions

- Proterozoic basins of Northern Laurentia
- Northwest Laurentia's neighbors in Proterozoic supercontinents: Cratonic identifications and their geodynamic implications
- Geology and tectonics of accretionary settings
- Structure, magmatism and metallogeny of the evolving North American Cordilleran margin
- Environmental stewardship in mining
- Indicator minerals in till and stream sediments
- Geohazards in a changing climate
- Investigating crustal neotectonics on the western margin of North America
- Tectonic controls on northern Canada's mineral and petroleum resources
- Cratons, kimberlites and diamonds
- Characteristics and causes of low-pressure metamorphism
- Ore petrology – application of past, present and future methods to ore systems
- Stable isotopes and the Earth system

Field Trips

- SED-EXhumed: Catch a rare glimpse into the belly of the Faro Mine Complex, one of Canada's most prolific past-producers of lead and zinc
- From veins to valleys: The history of Klondike gold
- Overview of geology of accreted terranes and Whitehorse Trough
- Tour of the Keno Hill Mining District
- History of the Whitehorse Copper Belt
- Geology of the Whitehorse Copper Belt
- VMS and orogenic gold deposits of the Chatham Strait, southeast Alaska



Whitehorse 2016

GAC®–MAC Joint Annual Meeting

L'AGC®–AMC Congrès Annuel

June 1–3, 2016




Special Sessions
Rodinia to Laurentia in NW North America

Geology and tectonics of orogenic belts

Remediation and mine closure in cold climates

Join us for the first GAC®–MAC annual meeting to be held in Yukon! The conference theme, *“From Laurentia to Beringia: Margins through time”*, reflects a wide array of technical sessions and field trips sure to cover topics of interest to geologists of all kinds.

www.whitehorse2016.ca

Séances Spéciales
De la Rodinie à la Laurentie dans le Nord-Ouest de l'Amérique du Nord

Géologie et tectonique des chaînes orogéniques

Remédiation des sites miniers sous climats froids

Join us for the first GAC®–MAC annual meeting to be held in Yukon! The conference theme, *“From Laurentia to Beringia: Margins through time”*, reflects a wide array of technical sessions and field trips sure to cover topics of interest to geologists of all kinds.

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Joignez-vous à nous pour le congrès annuel de l'AGC®–AMC 2016 qui se tiendra pour la première fois au Yukon. Le thème de la conférence: *“De la Laurentie à la Béringie : les marges au fil du temps”*, comprend une large variété de séances techniques et d'excursions qui couvriront sûrement les sujets d'intérêt des géologues de tout genre.



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PRESIDENT'S LETTER



Steven B. Shirey

Speak Up for Basic Research in Mineralogy and at NSF

Mineralogy, petrology, crystallography, and geochemistry make up an integral part of the Directorate for Geosciences basic research programs, which are run by the National Science Foundation (NSF). Science proposals arising from our community—from individual investigators, voluntary collaborations of investigators, or community-driven initiatives—make up the heart of the

Directorate for Geosciences core programs, i.e. programs that focus on fundamental, academic, curiosity driven research. For the health of our science, we need to support and publicize the research accomplishments of the core programs and mineralogy's role in them. Please become a more active advocate for our science, especially with the public and (if in the USA) your congressional representatives.

The aim of the NSF core programs is to support research on key scientific questions. This focus makes the core programs instrumental in preparing for the future. Through basic research, for example, the core programs reveal in much better detail the role of plate tectonics in creating natural hazards, such as earthquakes, explosive volcanism, and tsunamis, or by revealing the processes that form beneficial mineral and hydrocarbon deposits. Geoscience research funded by NSF programs also reveals the role of deep and surficial crustal processes in creating landforms, habitats, and, the conditions for life itself. This type of research and training is not provided by industry, whose chief interest usually lies in applied geoscience, as opposed to basic research, and whose results are rarely shared outside of the company itself. The concern here is for the future of basic, intellectually accessible, geoscience research, which NSF's programs fund more substantially and more fairly than anyone else.

Funding levels for core program research at NSF have been either stagnant or eroding for more than 20 years and sometimes even cut in favor of big programs of the moment. This situation has led to such severe competition for research dollars that the health of our science is threatened by a seemingly unending and unproductive proposal-submittal churn, which is made worse by high rates of proposal rejection. This situation inevitably results in the failure to fund some excellent research, especially that of our brightest young academic researchers. Some young academic researchers, even at endowed institutions with "hard-money" support, now spend more time writing proposals than doing research! Our current science is at risk and so is our future science.

Core geoscience programs are further suffering because some politicians think that geoscience is not "hard" science and that it has taken away resources from sciences like biology and mathematics. The recent America COMPETES Act (HR 1806) was intended to strengthen US science research. For the geosciences, however, the bill became a way for the US Congress to direct money away from the geosciences and to inject itself into NSF decision-making in order to politicize and cherry-pick which science should and should not be supported. Efforts like this, if successful in the future, will lead to dangerous, politically driven micromanagement of science for political or philosophical reasons. The battle over the America COMPETES Act may be over, but we can expect more, similarly motivated efforts. Thus, given US leadership in a wide range of geosciences, given the increasing need to understand the natural hazards and bounty of our planet, and given the need for strong academic geoscience departments to prepare future geoscientists, it is dangerously short-sighted to politicize geosciences. As a community, we should come together to oppose such attacks.

The frontiers in geoscience are defined by the research projects of the individual investigators in the core programs. Furthermore, US leadership in industrial geosciences relies on talented students who are attracted to and trained by strong geoscience departments. Geoscientific frontiers for both academia and industry will be defined by the geosciences graduate students trained by the professors supported by NSF core-funded research projects. Ideas generated by core funding are essential for specialized initiatives that cannot be developed without core program research. NSF core-funded science is the incubator for academic and industrial US leadership in the geosciences. And as such, NSF core-funded science deserves to be treated as a national treasure to be given more funding, not less.

Steven B. Shirey, MSA President
sshirey@carnegiescience.edu

NOTES FROM CHANTILLY

- At its meeting in May, the Mineralogical Society of America (MSA) Council voted for no increase in membership dues for 2016 for regular and student members (i.e. remaining at \$80 and \$20, respectively) and that all members will have electronic access to the *American Mineralogist* and receive print+electronic versions of *Elements*. Sustaining memberships will remain at \$150 + regular dues.
- Member subscription rates to the print version of the 2016 *American Mineralogist* will increase. US member print subscription price will be \$115 (currently \$110), and foreign member print subscription price be set at \$125 (currently \$120). US institutional subscription price (paper and electronic) will increase to \$1050 (from \$1025), and foreign institutional subscription will be raised to \$1075 (from \$1050). Institutional electronic-only subscription will increase to \$975 (from \$950). These prices represent increases of 3–5%. Included in the institutional subscription are all the current-year print issues of *American Mineralogist*, *Reviews in Mineralogy and Geochemistry (RiMG)*, *Elements*, as well as access to the electronic versions of these publications on the MSA website starting with volume 1, number 1. GeoScienceWorld institutional subscriber prices for archival print copies of *American Mineralogist* and *RiMG* are \$180 and \$135 respectively.
- MSA 2016 membership renewals will start by October with membership renewal notices sent electronically, followed by several electronic reminders before a paper copy is sent to those who do not renew online by the end of October.
- Members and Fellows who are in the senior, honorary, and life categories are sent renewal notices. They need not pay dues, but are sent notices as the best way to prompt an update of membership information, particularly postal mail and e-mail addresses.
- If you subscribe to other journals through MSA—*Gems & Gemology*, *Journal of Petrology*, *Mineral News*, *Physics and Chemistry of Minerals*, *Mineralogy and Petrology*, or *Rocks & Minerals*—please renew early. MSA needs to forward your renewal to those publishers before your subscription runs out.

J. Alex Speer
jaspeer@minsocam.org

IN MEMORIAM

RICHARD W. BERRY – Senior Member, 1958
ARTHUR A. SOCOLOW – Senior Fellow, 1949
MASARU YAMAGUCHI – Senior Member, 1952

CONTRIBUTORS AND BENEFACTORS

Many members contribute to MSA by including a contribution with their annual dues and/or by responding to special appeals. Depending on the wishes of the member, the money is deposited with the principal of the MSA Endowment, MSA Outreach, MSA Mineralogy/Petrology, J.B. Thompson, Edward H. Kraus Crystallographic Research, Bloss, or General Operating funds. The income of these funds is used to support MSA's research grants in crystallography, mineralogy, and petrology; to publish the *American Mineralogist*; to pay for the MSA Undergraduate Prizes, the Mineralogical Society of America Award, the Distinguished Public Service Award, the Dana Medal, and the Roebling Medal; to maintain the website; and to deliver the lectureship program. If you have not done so previously, you may wish to consider contributing at the next opportunity. Here, we want to extend our gratitude to the individuals and organizations that have made contributions to MSA between 1 July 2014 and 30 June 2015. These contributors are listed on the MSA website and can be found by selecting "Contributions to MSA" on the MSA home page (www.minsocam.org), under "About MSA".

2015 MSA AWARDS AT THE ANNUAL MEETING, BALTIMORE



At this year's MSA annual meeting in Baltimore, Maryland (USA), **Dr. Rodney C. Ewing** will receive the 2015 Roebling Medal, given for a lifetime of outstanding original research in mineralogy. Dr. Ewing is the Frank Stanton Professor in Nuclear Security in the Center for International Security and Cooperation in the Freeman Spogli Institute for International Studies and a professor at the Department of Geological and Environmental

Sciences in the School of Earth Sciences, both within Stanford University (USA). He is a significant advocate for integrating mineralogy and materials science, and is the most influential force behind the use and application of natural mineral analogues, mineralogical science, and mineralogical methods to developing new nuclear waste containment forms and advancing the understanding of the behavior of nuclear waste forms in geologic repositories over geologic time. As a result, he plays a very prominent and active national role in the direction of science and technology on the challenging issues associated with the disposal of nuclear waste.



The Mineralogical Society of America Award is given for outstanding contributions by a scientist beginning his or her career. **Dr. Nicholas J. Tosca**, Associate Professor of Sedimentary Geology in the Department of Earth Sciences at the University of Oxford (UK), is the 2015 MSA awardee. Dr. Tosca is cited for his contributions to low-temperature mineralogy for which he has used both experimental and theoretical modeling approaches to

understand terrestrial and Martian clays and to investigate other sedimentary rocks, with implications on understanding the surface of Mars, petroleum reservoir porosity, and changes in the composition of clay mineral assemblages going back to the Proterozoic.

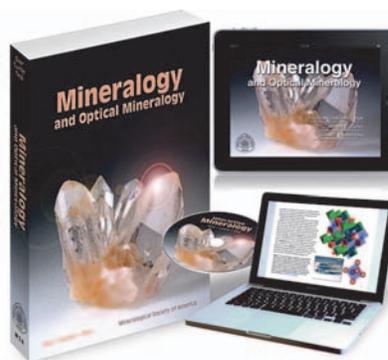
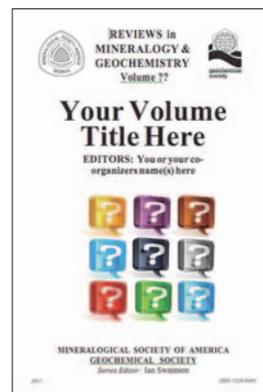


The Mineralogical Society of America's Distinguished Public Service Medal is awarded to an individual for distinguished contributions to public policy, to furthering the vitality of the geological sciences—especially the fields of mineralogy, petrology and crystallography—or for service to, or on behalf of, the mineralogical community. **Dr. J. Alex Speer**, who is the Executive Director of the Mineralogical Society of America (based at Chantilly, Virginia, USA), is the 2015 medalist. Dr. Speer is cited for his excellence beyond expectation as MSA Executive Director and for skillfully shepherding the society and its programs through the rapidly changing environment that associations and societies must adapt to today.

Call for MSA/GS Short Course and RiMG proposals

Have you ever benefitted from an MSA/GS short course, where diverse researchers and students broaden their skills and knowledge in a key area of interest? Have you ever read or used an article from a RiMG volume? Would you like to see more? If so, consider developing a proposal for a MSA/GS short course and/or a RiMG volume in 2016 and submit it to the Chair of the MSA/GS Short Course Committee soon! For courses/volumes in spring 2017, submit proposals by September 1, 2015; for fall 2017, submit proposals by December 1, 2015. To learn more about MSA/GS Short Courses and RiMG volumes, visit our web sites:

www.minsocam.org/msa/SC/
and
www.minsocam.org/msa/RiMG/About_RiMG.html



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FROM THE PRESIDENT



François Holtz

The preparations for the GeoBerlin meeting, to be held 4–7 October 2015, are heating up. More than 600 abstracts have been submitted and will be arranged into 9 parallel sessions (www.geoberlin2015.de/programme.html). The meeting is jointly organized by the German Geological Society (DGGV) and the German Mineralogical Society (DMG). Most of the submitted abstracts are from members of the two societies, but there are also a high number of international contributions. Four plenary lecturers will introduce the main focus of the meeting, which is “Dynamic Earth.”

I invite all DMG members to participate in the annual business meeting on 5 October. There will be at least four important topics, including a necessary revision of our bylaws. The DMG board will also propose some honorary members, which has to be approved by at least 4/5 of the members present. I will report on the objectives of the new amalgamated geological society DV-Geo (an association of geologists, geophysicists, mineralogists and palaeontologists). Finally, we will prepare the nominations for the 2016 elections. The board has prepared a list of persons who are willing to take responsibilities, but we are still open for nomination of other candidates. The full list of candidates was published in the GMIT (www.gmit-online.de) of June 2015.

The GeoBerlin meeting will offer an opportunity to attend the talk given by Oliver Nebel (Australian National University, Canberra; now at Monash University), who received the Victor Moritz Goldschmidt award in 2014, and to congratulate the new 2015 suite of DMG medalists: Albrecht Hoffman (former director of the Max Planck Institute for Chemistry, Mainz), who receives the Abraham Gottlob Werner medal; and Eva Stüeken (University of Washington), who receives the Victor Moritz Goldschmidt award. Eleanor Berryman (Technische Universität Berlin) received the Paul Ramdohr prize in 2014 and will also be on the podium of the DMG medalists.

Most of the members of the board will be at GeoBerlin for the entire meeting. Don't hesitate to contact me or another member of the board for any question relevant to DMG. Our role is to serve the interests of DMG members, and we are keen to hear your suggestions or concerns. As usual, the society will be continuously present at the DMG booth, which will be under the kind and efficient supervision of Heidi Höfer and Klaus-Dieter Grevel. And, new student members can benefit from reductions for the meeting fees. See you in Berlin!

François Holtz (DMG President)

HIGH-PRESSURE EXPERIMENTAL TECHNIQUES AND APPLICATIONS TO THE EARTH'S INTERIOR (Short Course Report)

The short course “High-Pressure Experimental Techniques and Applications to the Earth's Interior” took place 23–27 February 2015, in Bayreuth (Germany). The course was organized by the Bayerisches Geoinstitut/University of Bayreuth and sponsored by the Deutsche Mineralogische Gesellschaft (DMG), the German Research Foundation Priority Program “First 10 Million years of the Solar System” (DFG SPP 1385) and the Bayerisches Geoinstitut (BGI).

Each morning, 29 Masters and PhD students from all over the world attended interesting, and even humorous, lectures on what we currently know about the Earth's internal structure and composition. This included information on cutting-edge high-pressure–high-temperature experimental techniques. Afternoon classes comprised hands-on



FIGURE CAPTION: Participants at the 2015 high-pressure short course in Bayreuth.

practical demonstrations on how to use the various experimental and analytical (in situ or ex situ) techniques of the BGI. Among the practical demonstrations was the piston cylinder and multi-anvil press, where the participants were delighted that samples sizes of up to 1 mm can now be studied, as well as the possibility of reaching up to 25 GPa (equal to the Transition Zone between the upper and lower mantle). Pressures up to 100 GPa (equal to the lower mantle) can be achieved by the diamond anvil cell, but only for samples of ~250 μm . However, this is no problem: today's spectrometers, mass-spectrometers and electron microscopes allow scientists to analyze small sample sizes and concentrations barely dreamt of several decades ago. Analytical techniques that were demonstrated in the short course included infrared, optical and Mössbauer spectroscopies, plus X-ray diffraction, laser ablation inductively coupled plasma mass spectrometry and scanning and transmission electron microscopy.

Attendees also saw the rock deformation laboratory, with its 6-ram multi-anvil press that can reproduce strain rates from 10^{-4} to 10^{-6} s^{-1} (in nature this value is from 10^{-11} to 10^{-15} s^{-1}). Laboratory experiments approximate the rheology and appropriate flow laws under pre-determined P/T conditions, phase stability and grain growth. Over all, the new technologies invented at the BGI (the newest design of sample holder for the diamond anvil cell) and the rare instruments such as the 5000 ton multi-anvil press also amazed the participants and made some of us feel like we had just jumped into the latest sci-fi movie.

An appropriate social event for scientists trying to understand the Earth's interior was a “field trip” to the deep underworld of Bayreuth's catacombs. This visit was followed by a typical Frankonian buffet dinner, with Haxe (hock; meat from an animal's lower leg), Rinderroulade (roll of beef), and the local beer with its 150 years of brewing tradition.

On behalf of the participants, I would like to thank the BGI, the DMG, the DFG, and all the lecturers and demonstrators for sharing their knowledge with our generation of young scientists. The five days were a very nice opportunity not only to establish contacts between the participants but also between students and lecturers. What remains for us now is to go back to our own labs, apply the new experiences, and...

- start to pressure up!
- den Druck zu erhöhen!
- aumentar a pressão!
- faisons monter la pression!
- iniziamo ad aumentare la pressione!
- πάμε να ανεβάσουμε την πίεση!
- давайте начнем компрессию!
- Bo nale et hlachats!
- 让我们开始增加压力(Ràng wǒmen kāishǐ zēngjiā yālì)!
- 加压を始めよう!
- πάμε να ανεβάσουμε την πίεση!

This 5-day course is offered annually, and the next will take place in February 2016. More information is available at www.dmg-home.de/kursprogramm.html and <http://www.bgi.uni-bayreuth.de/>.

Lena Boeck (Münster), **Felipe P. Leitzke** (Bonn)
Larissa C. Carniel (Münster and Rio Grande do Sul, Brazil)



Meteoritical Society

<http://meteoriticalsociety.org>

2015 METEORITICAL SOCIETY TREASURER'S REPORT



Candace Kohl

The society's finances continue to be on a sound footing, and both the Operating Fund and our Investment Fund are currently very healthy. A large portion of the operating budget relates to the publication of *Meteoritics and Planetary Science (MAPS)*, our international monthly journal of planetary science, which covers topics including the origin and history of the Solar System, planets and natural satellites, interplanetary dust and the interstellar medium, lunar samples, meteors, meteorites, asteroids, comets, craters, and tektites. The *MAPS* journal has been published by Wiley since 2010, and our income from Wiley closely matches the expenses of the Editorial Office at the University of Arizona, which is managed by Editor Tim Jull.

Society memberships include subscriptions to *MAPS* and *Elements*. Membership with subscription to only the electronic version of *MAPS* has become a popular option, although more than half of our membership still purchases the printed version. Collection of membership dues for 2016 will begin in October 2015. Please pay your dues on time as this greatly helps with financial planning. Healthy finances depend on a stable number of memberships.

Our Investment Fund, which includes four separate endowed funds, continues to do as well as we can expect with the current market situation. Many society members contribute generously to support all of these funds, and your donations are always greatly appreciated. The Nier Fund supports the annual Nier Prize, which recognizes outstanding research by young scientists in meteoritics and closely allied fields. The 2015 recipient is Prof. Pierre Beck (Institut de Planétologie et d'Astrophysique de Grenoble, France). The Gordon A. McKay Fund supports an award to the student who gives the best oral presentation at the annual meeting of the society: the 2014 fund was given to R. D. Hanna (University of Texas at Austin, USA). During the past year we have established the Travel for International Members (TIM) Fund to support travel to Meteoritical Society meetings for professional members of the society from low-income countries. The TIM Fund was initiated through the generosity of Prof. Tim Swindle who has made a commitment to fund it over a total of 10 years. Council has agreed to support the program during this time. This year it will be used to fund travel to our 2015 meeting in Berkeley, California.

The General Endowment Fund supports a variety of outreach projects. Over the last year, this fund has been used to provide travel support for students to attend the 2015 Gordon Conference on Origins of Solar Systems. Funds have also been allocated to support a meteoritics outreach and lecture tour program in Brazil under the direction of Dr. Klaus Keil. Endowment funds were also used to support travel for scientists from low-income countries and for students from North Africa and the Middle East to attend the Meteoritical Society meeting in Casablanca (Morocco). This year, endowment funds will be used to fund students and postdoctoral scholars to attend the meeting in Berkeley. Some of the money used has been contributed directly as part of the annual membership renewal. Thirty-seven members responded to this request this year. Your contributions directly help strengthen our international community. We always welcome suggestions and ideas for ways in which the General Endowment Fund can be utilized to promote the goals of the society and enrich its activities.

Candace Kohl, Treasurer

2015 MEMBERSHIP REPORT

As of May 2015, the Meteoritical Society is made up of 677 regular members, 94 student members, 154 retired members, 26 life members,

Country	Regular Member	Student Member	Life Member	Retired Member
Australia	14	10		4
Austria	6			3
Belgium	8	1		1
Brazil	4	1		1
Canada	21	3	1	10
Chile	2			
China	3			
Czech Republic	2			1
Denmark	2	2	1	1
Finland	2	1		1
France	29	2	2	5
Germany	79	9	4	13
Hungary	3			
India	3			2
Italy	9	1		
Japan	75	7		12
Korea, Republic of	5			
Netherlands	2	1		2
Norway	3			
Poland	6	1		1
Russian Federation	6	3		1
South Africa	3			
Spain	4			1
Sweden	4			
Switzerland	18	4	1	8
United Kingdom	37	14		4
United States	317	33	16	82
Subtotals	677	94	26	154

The following 17 countries have one member at this time: Algeria, Argentina, Egypt, Estonia, Greece, Vatican City State, Islamic Republic of Iran, Ireland, Latvia, Luxembourg, Malaysia, Mexico, Morocco, New Zealand, Oman, Romania, Slovak Republic

and 8 members from developing countries, making a total of 968 members. Many thanks to Erin Walton for providing these statistics. We can be proud that we have members in 46 countries, but statistics show that we still have a lot to do to gain members in many other countries. The society does, however, have a mechanism to subsidize annual dues for members in low-income countries, though prior approval is required from the Membership Committee to obtain this rate. Please see our website for more information.

For those wishing to avoid the hassle of paying dues every year, consider becoming a life member! For more information and details on how to become a member of the Meteoritical Society, please see our society web page at www.meteoriticalsociety.org.

PAUL PELLAS / GRAHAM RYDER AWARD WINNER

The Pellas–Ryder Award for the best student paper in planetary sciences is jointly sponsored by the Meteoritical Society and the Planetary Geology Division of the Geological Society of America. It is awarded to an undergraduate or graduate student who is first author of the best planetary science paper published in a peer-reviewed scientific journal during the year prior to the award. The award has been given since 2001 and honors the memories of meteoriticist Paul Pellas and lunar scientist Graham Ryder.



The winner of the 2015 Pellas–Ryder Award is **Steven Battaglia** of the University of Illinois at Urbana-Champaign (USA; advisor Dr. Susan Kieffer). Mr. Battaglia's paper, "Io's theothermal (sulfur) – Lithosphere cycle inferred from sulfur solubility modeling of Pele's magma supply," was published in *Icarus* in 2014. Mike, and his coauthors M. A. Stewart and S. W. Kieffer, modeled the role of sulfur in Ionian magmas and suggested that the excess sulfur on Io's surface comes from two sources: (1) an insoluble sulfide liquid phase in the magma and (2) from theothermal (sulfur-dominated thermal system) near-surface recycling.



Geochemical Society

www.geochemsoc.org

60th ANNIVERSARY OPENS A NEW CHAPTER



Kevin Johnson

This is a year of milestones for the Geochemical Society (GS): the society celebrates its 60th anniversary in 2015, and the 25th Goldschmidt Conference will be held in Prague (Czech Republic) in August. It is also a time of transition. In May, the business office officially relocated from Washington University in St. Louis (Missouri, USA) to the Carnegie Institution for Science (Washington, DC). I would like to express my gratitude to outgoing Chief Operating Officer Seth Davis for his guidance and patience during my

first two months on the job. During Seth's 15-year tenure, the society experienced tremendous growth, and I'm excited to expand on the strong foundation that Seth helped to build.

The initial focus of the newly opened Washington office will be on improving operations and providing excellent service to GS's 4,000+ members. The society's strength is the diversity and dedication of its membership, and I welcome your thoughts—big or small—on ways that we can better serve the needs of the geochemical community.

Kevin Johnson
Chief Operating Officer

GEOCHEMICAL SOCIETY AT GSA-BALTIMORE

Thanks to strong volunteer support, there are 44 sponsored or cosponsored events by the Geochemical Society at the 2015 Geological Society of America (GSA) Annual Meeting in Baltimore (Maryland, USA) this November. GS will again be organizing the F. Earl Ingerson Lecture, sponsoring a reception with the Mineralogical Society of America and the GSA's Mineralogy, Geochemistry, Petrology and Volcanology division, and welcoming attendees to our exhibit (Booth 1018). For more information on GS's activities at GSA-Baltimore visit: www.geochemsoc.org/programs/annual-gsa/.



MEETING ASSISTANCE PROGRAM: THREE GRANTS AWARDED

The Geochemical Society Program Committee approved three Meeting Assistance Program (MAP) grants of US\$2000 each to the following: the Gordon Research Seminar and Conference on the Interior of the Earth: Surface Connections, held 7–12 June 2015, in South Hadley (Massachusetts, USA); the Gordon Research Seminar and Conference on Chemical Oceanography, held 26–31 July 2015, in Holderness (New Hampshire, USA); and the Reviews in Mineralogy and Geochemistry Short Course: Pore Scale Geochemical Processes, held 15–16 August 2015, in Prague (Czech Republic). Applications for the next round of funding are due by 30 September 2015. To learn more about the program or submit an application, visit www.geochemsoc.org/programs/meetingassistanceprogram/.

2016 AWARD NOMINATIONS

Geochemists want and need recognition for their work. Awards help to inspire individuals to do their best. Awards set the bar for others to match or exceed. Your participation in the awards program by being a nominator or by writing a supporting letter of recommendation not only benefits the nominee, it benefits the whole geochemical community. Please take the time to highlight the accomplishments of your valued colleagues by nominating them. With your help, we can ensure that the award committees have a diverse and deserving pool of candidates. For more information and to download the nomination form visit www.geochemsoc.org/awards/makeanomination. The nomination deadline is **31 October 2015**.

	The V.M. Goldschmidt Medal is awarded for major achievements in geochemistry or cosmochemistry, consisting either of a single outstanding contribution or a series of publications that have had great influence in these fields.
	The F.W. Clarke Medal is awarded to an early career scientist for a single outstanding contribution in geochemistry or cosmochemistry, published either as a single paper or as a series of papers on a single topic.
	The C.C. Patterson Medal is awarded for a recent innovative breakthrough of fundamental significance in environmental geochemistry, published in a peer-reviewed journal.
	The Alfred Treibs Medal is awarded by the Organic Geochemistry Division for major achievements in organic geochemistry over a period of years.
	The GS/EAG Geochemical Fellows Award is bestowed upon outstanding scientists who have, over some years, made a major contribution in the field of geochemistry.

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The first seven volumes, more than 160 articles, of the Geochemical Society's Special Publication Series are available as free PDF downloads.

Programs > Introductory Student Memberships

This program grants a two-year Geochemical Society membership to qualifying students in underrepresented countries. These have all the benefits of membership, including a print subscription to *Elements* magazine and online access to the entire *Elements* magazine archive.

Check out these and other resources at www.geochemsoc.org.

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Mineralogical Society of Poland

www.ptmin.agh.edu.pl

TRIBUTE TO PROF. DR HAB. ENG. LESZEK STOCH (1931–2015)

Honorary Professor of the AGH University of Science and Technology in Kraków



Professor Leszek Stoch

On 20 January 2015 in Wieliczka, near Kraków (Poland), Professor Leszek Stoch passed away. He was an outstanding scientist, whose innovative achievements in Earth sciences, materials engineering, and ceramics are the pillars on which much of the Polish research in these fields currently stand.

Professor Stoch's early career focused on clay minerals and their host rocks and, despite his later diversification, it was clays that were to become his major scientific passion. His first large-scale scientific challenge was to characterize the mineralogical and technological properties of Polish kaolinite-bearing ceramic clays. His work had a substantial impact on the

opening of the kaolin mines in Kalno (Lower Silesia, Poland) and on ensuring that the kaolins in the lignite quarry in Turów (Lower Silesia) were processed as a useful associated mineral.

Professor Stoch also performed a detailed investigation into the Miocene clays from the overburden of the sulphur deposit in Machów, near Tarnobrzeg. His results laid the foundation for the technology of manufacturing specific clay-based sorbents, the so-called *bleaching earths*, which act to remove pigments from materials and take away unpleasant odors, all of which aid in the manufacture of pure minerals and of edible oils.

Other types of industrial minerals studied by Professor Stoch were the Polish glass sands and vein quartzes. He determined their mineral and chemical characteristics, which prepared the way to produce raw silica-rich materials with the required purity that were needed in the manufacture of whiteware ceramics and of special types of glass.

Professor Stoch also introduced new research methods to the Earth sciences. In the 1960s, he was the first person in Poland to design and construct a differential thermal analysis machine. These hand-crafted devices were used in many scientific laboratories across Poland.

Professor Stoch was highly regarded outside Poland for his work in mineralogy and mineral raw materials. For his many distinguished contributions, he was awarded the Emanuel Boricky Medal from Charles University in Prague (Czech Republic).

Professor Stoch's scientific accomplishments are contained in some 260 papers, 14 patents, his two books *Clay Minerals* (1974, Wydawnictwa Geologiczne) and *Biomaterials* (2003, Akademyka Oficyna Wydawnicza), and many review-style book chapters such as "Structural thermochemistry of thermal processes" in *Flash Reaction Processes* (Kluwer Academic Press, 1995) and "Internal thermal reactions of minerals" in *Thermal Analysis in the Geosciences* (Springer-Verlag, 1991).

His very productive and diverse scientific activity led him to be elected a member of the Polish Academy of Arts and Sciences, to be a member of many other foreign and domestic scientific bodies, and to have received many state and regional awards. However, one of his most treasured awards was a relatively recent one, and it was from his home university in Kraków: in 2011, Professor Leszek Stoch received the title of Honorary Professor of the Akademia Górniczo-Hutnicza (AGH) University of Science and Technology (see *Elements* October 2011, p 354, for a photo of this event).

With the death of Professor Leszek Stoch, we have lost a wonderful professor, an unquestioned authority on ceramics and biomaterials who was admired by his peers and colleagues, a man with an inexhaustible supply of innovative ideas, somebody who was always ready to offer help and advice, and, last but by no means least, a person who was joyful and brimming with humour.

We are filled with deep sorrow that the man, at whose side we had the chance to develop ourselves as well as our research, has passed away. We will forever cherish the memories of dear Professor Leszek Stoch and of the times we spent together.

On behalf of Professor Leszek Stoch's alumni and colleagues:

Irena Waclawska and Krzysztof Bahranowski

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11th INTERNATIONAL ECLOGITE CONFERENCE, RIO SAN JUAN, DOMINICAN REPUBLIC

The 11th International Eclogite Conference (IEC-11) was held January 31–February 7 2015 in a self-contained hotel complex near the town of Rio San Juan on the northern coast of the Dominican Republic. The conference was attended by 91 participants from 19 countries. Forty-eight talks and 41 posters were presented over three days of conference sessions; the remaining four days were spent on field trips to some of the local exposures of high-pressure and ultra-high-pressure rocks. An 86-page field guide edited by A. Hertwig and W. Maresch (Ruhr-University Bochum, Germany) made it easy for participants to understand the local geology within the framework of the geodynamics of the entire Caribbean.



International Eclogite Conferences were established in 1982 and are organized in different countries every two years to promote worldwide communication and cooperation among scientists who study high-pressure and ultrahigh-pressure rocks. Such rocks are the key to our modern understanding of plate tectonics: bear in mind that it was only 25 years ago that metamorphic diamonds were first discovered in deeply subducted crustal rocks, revolutionizing our concepts of subduction and exhumation processes. Continuing that tradition, scientists from Austria, China, the Czech Republic, England, the Dominican Republic, Germany, France, Japan, Mexico, the Netherlands, Poland, Turkey, Italy, Russia, Sweden, Slovenia, Southern Korea, Spain, and the USA presented their petrological, geochemical, and geochronological research on subduction-related rocks and processes and discussed how these bear on large-scale tectonic evolution. The poster sessions provoked intense discussions that continued well into the night. A final highlight was the award ceremony, where the best student talk and poster awards went to Anastasia Mikhno (Novosibirsk, Russia) and Wan-Cai Li (Hefei, Anhui Province, eastern China).

Field trips are, without doubt, a specialty of the International Eclogite Conferences. Although the IEC-11 was focused on the central four-day conference block, the meeting also included three field trips: a one-day “syn-conference” field trip and two 2-day pre- and post-conference field trips. These field trips illustrated the variety of (ultra)high-pressure rocks that are representative of the fossil subduction-zone complex that is exposed on this Caribbean island.

The two-day pre-conference field trip was led by Walter Maresch, Andreas Hertwig, and Hans-Peter Schertl (Ruhr-University Bochum, Germany) and focused on the serpentinite mélanges of the Rio San Juan Complex (Fig. 1). These rocks are interpreted to represent the



FIGURE 1 The pre-conference field trip to Magante (Dominican Republic) showing concordant jadeite layers in blueschist facies blocks of the Rio San Juan serpentinite mélange.

former subduction channel of an intra-oceanic island arc that has been moving eastward relative to the Americas for more than 100 million years and which is today represented by the Lesser Antilles. Highlights in the field were all the different kinds of jadeitites and jadeite-lawsonite rocks, blueschists, eclogites and serpentinites, as well as the memorable and remarkable tropical weather we experienced. The first day in the field was characterized by an uncommonly steady but warm rain, resulting in a second day of very muddy and slippery footpaths. “Fortunately” the rivers had swollen to the extent that fording them helped to clean our shoes and trousers.

The syn-conference field trip covered geological as well as archaeological aspects. After an introduction by Adolfo López Belando (Museo del Hombre Dominicano) to the excavation site of a pre-Columbian Taino village at Playa Grande, where a multitude of jadeite artefacts have been found, the participants visited the famous Amber Museum at Puerto Plata. Walter Maresch, Hans-Peter Schertl, Andreas Hertwig, and Grenville Draper (Florida International University) then showed us further outcrops of the Rio San Juan Complex.

The two-day post-conference field trip was led by Richard Abbott (Appalachian State University), Grenville Draper and Walter Maresch. Highlights of the first day were eclogites and garnet peridotites from Las Cuevas of the southern Rio San Juan Complex, a locality characterized by scenic cocoa plantations and a multitude of non-geological photos. The exhumation mechanisms necessary to produce such a rock inventory within an intra-oceanic environment led to intense discussions. The second day brought us to the picturesque Samaná Peninsula (Fig. 2) and a coastal exposure of a mélange-like outcrop of blueschists and eclogites within a metasedimentary matrix dominated by marble



FIGURE 2 The post-conference field trip to the Samaná Peninsula at Punta Balandra (Dominican Republic), participants viewing some blueschist and eclogite blocks in a metasedimentary marble matrix.

– considered by many participants to represent a “textbook” locality. The final stop at the palm-rimmed coral beaches of Las Galeras was a fitting farewell to the Caribbean.

The organization of IEC-11, in this somewhat unusual but certainly beautiful location, rested in the hands of an organization committee headed by Walter Maresch and Hans-Peter Schertl. Many thanks to them and the whole organization committee for perfect organization and the highly interesting field trips. The conference building was surrounded by lovely palm trees, and the “all inclusive” hotel was the “bedrock” of excellent spirits and a contagiously good atmosphere.

Further information on the IECs is available at www.rub.de/eclogite. The upcoming IEC-12 will be organized 2017 in Sweden.

Reiner Klemd (Erlangen)

REACHING OUR GOALS EFFECTIVELY – A WORK IN PROGRESS

Penny L. King¹

Wouldn't it be nice to magically create time? Many of us have an e-mail "In Box" that is constantly full. Deadlines disappear only to reveal new ones. During the day, we might rush from one fire to another. "I just don't have enough time," pervades our lives as an unwelcome guest. Unfortunately, even the best magicians have not created time and the best that we can do is to manage how we use it. How we invest our time is critical. Good time investment pays immense dividends. We can discover new things, create new theories, achieve our goals, and interact profitably with colleagues, family, and friends. In contrast, poor time investment tends to foster an attitude of, "Poor me, how do I deal with this insane world?" It negatively affects our relationships, health and work environments. Ineffective use of time also limits our full potential, which is, after all, what we get paid for.

ACHIEVING OUR GOALS

Successfully reaching our goals starts with having "the end in mind" (Covey 2013). If you are working towards an important goal that is satisfying and interesting then you are more likely to be engaged in the process. Experts recommend planning where you can use your strengths to reach long-term goals. This topic fills the shelves of career and personal psychology books (e.g. Rath 2007; Bolles 2014).

As researchers, we commonly take a circuitous path to reach a goal because we deal with complex problems that can be hard to define, have many input parameters, and might not have a definitive or unique solution. In turn, this makes many scientists avoid time management just in case it gets in the way of an elusive "eureka" moment. In fact, the eureka moment is much more likely if we can focus on our research, having ensured that we have the time to do it. A scientist's work trajectory is generally quite different from the sequential pathway taken by project managers and business leaders who advise us on "time management". Standard workflow methods are not necessarily applicable for researchers, where our goals are defined and change as we go along. Therefore, we need to modify mainstream "time management" methods to suit our own work situation.

TECHNIQUES FOR DECIDING WHAT TO DO

A simple place to start is to decide what you need to do on a given day. Covey (2013) breaks daily tasks into categories of important, not important, urgent, and not urgent (see TABLE). The "not important" row includes time-sapping tasks that do not add to an overall goal. The "important" row includes urgent tasks that need to be done now ("fires"); non-urgent tasks are those that move us forward towards our goals. Covey (2013) argues that maximizing the time spent on important, non-urgent (quality) tasks allows us to better reach our goals and be more creative.

SO, HOW ABOUT STARTING HERE?

Once your goals are clearer, it is easier to use time more effectively by following some simple tips.

Balance your goals across all areas of your life: career, family, personal, physical and mental. Create a daily plan with small tasks to help keep track of commitments and expect Murphy's Law to rule (i.e. if something can go wrong, it will).

When you have urgent tasks due, use a "do not disturb" sign or work in a secluded location.

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TABLE A TIME MANAGEMENT APPROACH THAT MAY BE USED TO PRIORITIZE TASKS (Following Covey 2013).

	URGENT	NON-URGENT
IMPORTANT	<ul style="list-style-type: none"> • Crises • Pressing problems • Deadline-driven projects 	<ul style="list-style-type: none"> • Prevention • Production capability exercises • Relationship building • Recognizing new opportunities • Planning • Recreation
NOT IMPORTANT	<ul style="list-style-type: none"> • Interruptions, some calls • Some mail, some reports • Some meetings • Proximate, pressing matters • Popular activities 	<ul style="list-style-type: none"> • Trivia, busy work • Some mail • Some phone calls • Time wasters • Pleasant activities

Try using bursts of time (e.g. pomodorotechnique.com or 3030.binaryhammer.com), mini-deadlines throughout the day, and electronic task tracking (e.g. culturedcode.com/things), or apply peer pressure by working with a group (e.g. a writing group). Batch similar tasks together to work more efficiently (e.g. attempt to complete e-mail in one or two sittings).

"It is fundamentally the confusion between effectiveness and efficiency that stands between doing the right things and doing things right. There is surely nothing quite so useless as doing with great efficiency what should not be done at all. (DRUCKER 1963)"

Make sure you factor in time for "important" interruptions, and try scheduling "interruptions" by providing office hours when you are available. Also, schedule time to write, complete specific tasks (e.g. lab work), answer e-mails, and return phone calls. Turn off social media sites and e-mail when you don't need them.

Tame that e-mail box! Prioritize messages that align with your responsibilities and goals. Recognize more complicated e-mail issues may warrant a phone call or may be listed as a task on its own. Establish a system for filing and storing e-mails so you can find them easily; consider using folders organized by topic or date or using one folder and the search function. Decide on how you will flag e-mails that need to be followed up.

With regard to meetings, decide what you hope to achieve and set an agenda, finish on time, and, after meetings, summarize the results. If you have no valuable contribution to make, then why are you there?

When you complete a task, make a point of noticing. There can be a lot of satisfaction in ticking things off a list and throwing it away, or rewarding yourself when you reach a goal.

Don't underestimate the usefulness of taking a break before revisiting a problem. Many creative moments happen at the beach, the supermarket, during exercise, or after a good sleep.

IN THE END

Everyone has a busy life. Make it less busy by avoiding worry! It is inevitable that life's complications may wreck your best laid plans and make you late. One strategy is to confess and try to figure out a reasonable deadline. Also, recognize that it is not possible to always have days with highly creative and intelligent thought, but that it is still important to be moving forward; use those days for other types of useful, if mindless, progress. Above all, enjoy what you are doing and it will all work out!

ACKNOWLEDGMENTS

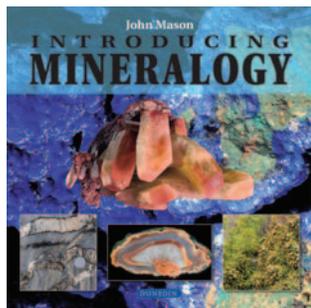
R. W. Henley provided extensive comments on this article.

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INTRODUCING MINERALOGY¹

Introducing Mineralogy is aimed at the amateur collector and anyone interested in minerals. It would also be appropriate for an introductory mineralogy class for nonscience majors. The author, John Mason, has done an outstanding job of presenting complex notions in simple terms,



providing many examples to which the reader can relate. The book is divided into seven chapters, and throughout, terms defined in the exhaustive glossary are highlighted. The book is also well illustrated, with over 100 color photographs mostly illustrating examples from the UK.

The first chapter presents the basics of mineralogy and crystallography. It can serve as a quick refresher if your notions of mineralogy are dusty. Chapter 2, Typical Mineral Occurrences, introduces

the main rock-forming minerals in the context of the three great rock classes. In chapter 3, Atypical Concentrations of Minerals, the processes leading to the formation of ore deposits are explained. Chapter 4, for the would-be collector, introduces this wonderful hobby and gives many tips on how to start. I found it interesting to read about the UK situation as regards mineral collecting. In chapter 5, Studying Mineral Assemblage and Parageneses, the minerals are discussed under different scales of magnification, starting with hand sample observations and passing to thin section characteristics and scanning electron microscope images. The uses of minerals are outlined in chapter 6. The book closes with a discussion of minerals and the environment. In this chapter, the author illustrates how minerals can both cause and cure pollution.

This book would have benefited from rigorous copyediting to reduce many long-winded sentences. The peculiar usage of hyphens (ore-deposits, magma-chambers, heat-engine, fracture-plane, fracture-systems, etc. versus platinum group metals, hand-in hand, fracture walls) and capitals was also distracting to this reader. But all in all, the book is a good introduction to the science of mineralogy.

The publisher, Dunedin Academic Press (www.dunedinacademicpress.co.uk), offers many Earth science titles, including a series on classic European localities and an introductory series on aspects of Earth sciences (volcanology, sedimentology, tectonics, etc.).

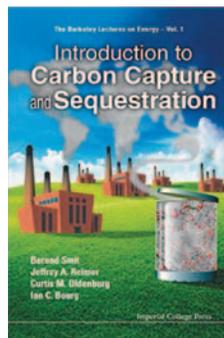
Pierrette Tremblay, Lévis, Canada

1 Mason J (2015) *Introducing Mineralogy*. Dunedin Academic Press Ltd, Edinburgh, ISBN 9781780460284, 118 pages



INTRODUCTION TO CARBON CAPTURE AND SEQUESTRATION²

Introduction to Carbon Capture and Sequestration is the first volume of the Berkeley Lectures on Energy series and is published by Imperial College Press. The book has a very appealing visual format, one that captures the attention of the reader without creating unnecessary distraction.



The US-based authors, Berend Smit, Jeffrey A. Reimer, Curtis M. Oldenburg and Ian C. Bourg, are well-known researchers of carbon capture and sequestration (CCS).

The book is organised such that the reader, whether familiar or new in the field, can build up their knowledge of the main questions regarding energy production and usage and what the consequences of each are in terms of carbon emissions. Following the introductory chapter on energy and electricity, there follows a very good description of current atmospheric and climatic models and a discussion of their associated uncertainties (chapter 2). In this

chapter, the authors venture into the realm of philosophy to discuss the “Truth” behind climate models and how scientists approach these very complex systems that are fraught with uncertainties.

Chapter 4 provides an excellent mix of describing the current technological solutions to carbon capture and explaining the thermodynamic laws that control gas separation. A graph showing the dependence of separation work on molar content of CO₂ is most informative and the discussion on parasitic energy of the carbon capture process makes very good teaching material. In the following chapters (5–7), the authors get inside the main carbon capture process and discuss absorption, adsorption and membrane techniques. Again, the mix of technological descriptions with thermodynamic basis and insights into molecular design is very pedagogic and nicely illustrates the different research areas involved in these carbon separation processes. There are also some simplistic cost analyses relating to the absorption and adsorption CCS technologies that might give the reader an idea of the complexity of investment decisions regarding this expensive technology. The chapter on membranes (chapter 7) is more front-edge and research-oriented and provides insights into the potential routes for carbon-capture efficiency.

In chapter 8, the authors provide a basic introduction to geological sequestration. Here, they illustrate the main CO₂ trapping mechanisms involved and the various geological settings that are favourable to carbon-dioxide storage. The mechanisms and their associated scientific challenges are discussed in chapter 9, called “Fluids and Rocks”: a deceptively generic title that hides a thorough description of the various trapping processes. Chapter 10 is a discussion of the consequences and challenges of large-scale CO₂ geological sequestration (storage); the final chapter (chapter 11) discusses the difficult issue of geo-engineering as a mitigation route for CO₂ emissions.

Overall, I highly recommend this book for any scientist wishing to understand CCS from different perspectives: the culprits, the global consequences, the potential solutions for mitigation of carbon emissions, the technologies involved in carbon capture, and the science behind the processes controlling carbon capture and storage. Everything is written in a clear and rigorous fashion with plenty of illustrations and associated web support. My only negative comment is that the authors do not use the international metric system in their work. This is somewhat surprising for a book that touches on a global issue. Nevertheless, I wish that this excellent book had been available when I started working on CCS some 15 years ago.

Jordi Bruno, Barcelona, Spain

2 Smit B, Reimer JA, Oldenburg CM, Bourg IC (2015) *Introduction to Carbon Capture and Sequestration*. Imperial College Press, London, ISBN 978-1783263288, 596 pages

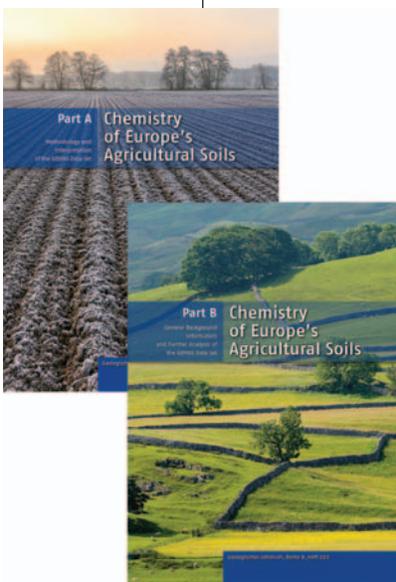
CHEMISTRY OF EUROPE'S AGRICULTURAL SOILS³

This two volume set (Parts A and B) arose from a project called the Geochemical Mapping of Agricultural and Grazing Land Soil in Europe (GEMAS). In this project, 2108 soil samples from ploughed land (0–20 cm depth) and 2023 samples of grazing land (0–10 cm depth) were collected in 2008/9 over an area of 5.6 million km², at a density of about 1 per 2,500 km². This was accomplished by a tremendous consortium of European national geological surveys, geologic institutions, academics, and industry. These groups used the same sampling protocols, with chemical analyses of all samples being carried out at specific labs. This ensured maximum comparability of the results from 33 countries across Europe. Oh, except Albania, Belarus, Malta, Moldova and Romania, which appear as blank spaces on the maps. Others outside Europe were also involved, from Australia, Canada and New Zealand. It was a truly international effort.

I hear you ask, “What chemical analyses did they make on these samples?” Well, quite a lot: too many to list here, in fact. In summary: total elemental analysis for 41 elements, aqua regia extractions for 53 elements, pH, effective cation exchange capacity (eCEC), total carbon, total organic carbon, lead isotopes, magnetic susceptibility, partial extractions for 56 elements, percent clay, and solid–liquid partitioning of elements. A real data-fest! Apparently, the project is not finished: for example, Sr isotope data are now being collected.

You may have noticed that industry was involved, and wonder why. The GEMAS project, and much of the funding, came from the European and international metals industries and industry associations. The chief reason behind this is the European Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation that came into force in 2007. In that same decade, many of us were involved in the collection of biological data on the risks of metals in soils. These studies developed algorithms that relate biological effects to key soil properties, which ultimately control the bioavailability in soils of metals on a continental scale. Hence, the GEMAS project was borne to provide the soil chemical data in order to perform the risk assessments for each substance.

Part A covers the sampling protocols, preparation methods, analyses and quality control of the results in a clear way, followed by the more mathematical aspects, such as the methods used for data analysis and mapping. Multivariate analyses include cluster and principle component analysis of the elemental data. The remaining four fifths of this volume gives detailed information on the distribution of each analyses, followed by a synthetic discussion chapter that looks at the influence of geography, geology, mineralisation, natural processes, anthropogenic influences, soil management (ploughed versus grazed land) and deficiency, and toxicity.



Part B is quite different. The first half provides background information on the soils, geology and mineral deposits in Europe, as well as several chapters on specific materials of interest (e.g. radionuclides, aeolian deposits, the elements As, B, C, Cd, Cl, F, and Se). The second half is divided into two parts: the first on mobility and risk assessment of metals; the second on regional interpretations, which concentrate

on Norway, Sweden, Finland, and the Ukraine. Remembering that REACH was a big motivation for the GEMAS project, it is the mobility and risk assessment portion of this volume that really stands out. Furthermore, the methodology for using the data under REACH is excellently described by two industry authors. They use Cu and Mo as examples to illustrate the amazing range of “predicted no (biological) effect concentrations” (PNECs) in European soils. Their specific examples illustrate how the combination of biology (toxicity assays in different soils) and soils data can be used for risk assessment and control of chemicals. In great contrast, the chapter on the use of mobile metal ion analysis (MMI®) sticks out, because the details of this partial extraction are not given and, as a result, we do not know what the extractants are. Furthermore, all of the REACH studies showed that these kinds of partial extractants did not improve the relationships between toxicity bioassays and soils data.

Perhaps the most disappointing finding for the project members was that there were very few differences in any of the measured chemical properties (apart from organic carbon) between ploughed and grazed soils. As these were *agricultural* soils, it may be that grazed soils are not permanent in the sense that they are often tilled and re-seeded. Indeed, the sampling instructions for this survey state that soil should not have been disturbed by ploughing in the last 10 years. How would the surveyors know, and is 10 years long enough time to be considered “undisturbed”? Nevertheless, interactions between climate, geology and substrate on the distribution of many elements shone through, as did the effects of glaciation and aeolian deposits. Both books have a list of abbreviations, and there are particularly useful statistical Appendices in Part B. One omission I feel is that there is no index in either book.

A focus on REACH (i.e. potential toxicity) is not the only use of these volumes. They will be useful for teaching and research in many areas, including environmental, climate (soil carbon), agriculture and food, geological and geochemical processes, amongst others. In this context, Part A includes a DVD with all of the data sets (I am already using them in a research project), graphics and maps, along with additional maps, graphics and tables that are not in the book. These are invaluable resources. At 3.6 kg together, these books are not light reading on the plane. But what they do represent is an unrivalled reference source on the geochemistry of Europe's agricultural soils.

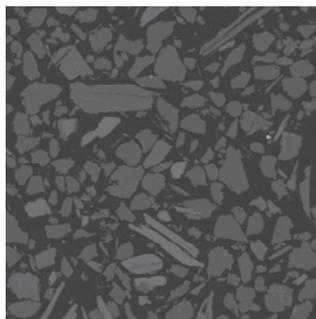
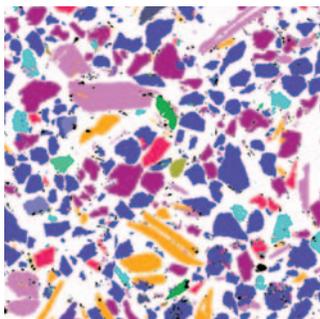
Steve P. McGrath, Rothamsted Research
Harpenden, United Kingdom

³ Reimann C, Birke M, Demetriades A, Filzmozer P, O'Connor P (eds) (2014) *Chemistry of Europe's Agricultural Soils*. Part A: Methodology and Interpretation of the GEMAS Data Set. 538 pages, ISBN 978-3-510-96846-6, €118 and Part B: General background Information and Further Analysis of the GEMAS data set. 352 pages, ISBN 978-3-510-96847-3, €78. Published by Schweizerbart Science Publishers

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August 23–28 29th Meeting of European Crystallographic Association (ECM29), Rovinj, Croatia. Web page: ecm29.ecanews.org

August 24–27 SGA 13th Biennial Meeting, Nancy, France. E-mail: sga-2015@univ-lorraine.fr; Web page: sga2015.univ-lorraine.fr

August 24–28 Joint DMG / MSA Workshop: Application of diffusion studies to the determination of time-scales in geochemistry and petrology, Bochum, Germany. Web page: www.minsocam.org/msa/SC/#open_sc

August 26–28 2nd European Mantle Workshop, Wrocław, Poland. Web page: www.emaw2015.ing.uni.wroc.pl

August 31–September 5 Deep Carbon Observatory second Early Career Scientist Workshop, University of the Azores, Sao Miguel, Portugal. Web page: deepcarbon.net/feature/second-dco-early-career-scientist-workshop#.VTpE15FVikp

September 9–11 8th European Conference on Mineralogy and Spectroscopy (ECMS 2015), Rome, Italy. Web page: www.ecms2015.eu

September 20–25 8th Hutton Symposium on Granites and Related Rocks, Florianópolis, Brazil. Web page: www.hutton8.com.br

September 21–25 11th meeting on Applied Isotope Geochemistry (AIG 11), Orléans, France. Web page: aig11.brgm.fr

September 27–30 Society of Economic Geologists (SEG) 2015 Conference: World-Class Ore Deposits: Discovery to Recovery, Hobart, Tasmania. Web page: www.seg2015.org

September 28–October 2 22nd International Symposium for Environmental Biogeochemistry, Portoroz, Slovenia. Web page: www.iseb22.ijs.si

October 4–7 GeoBerlin2015 (Annual Meeting DGG–DMG–GV), Berlin, Germany. Web page: www.geoberlin2015.de

October 4–8 MS&T15: Materials Science & Technology Conference and Exhibition, combined with ACerS 117th Annual Meeting, Columbus, OH, USA. Web page: ceramics.org/meetings/acers-meetings

October 8–11 Conference of the Mineralogical Society of Poland, Sandomierz, Poland. Web page: www.konferencja-ptmin.us.edu.pl/?lang=en

October 16–18 Gemmology Conference 2015, Vancouver, BC Canada. E-mail: dhawrelko@vcc.ca; Web page: www.gemconference2015.com

October 24–31 Short course - Geochemistry of Hydrothermal Ore Deposits, Ottawa, ON Canada. Web page: science.uottawa.ca/earth/short_course

November 1–5 Geological Society of America Annual Meeting, Baltimore, MD, USA. E-mail: meetings@geosociety.org; Web page: www.geosociety.org/meetings

November 9–13 Short Course "Introduction to Secondary Ion Mass Spectrometry in the Earth Sciences," Potsdam, Germany. Web page: www.gfz-potsdam.de/SIMS/short-course

November 29–December 4 MRS Fall Meeting & Exhibit, Boston, MA, USA. Web page: www.mrs.org/fall-meetings

December 14–18 American Geophysical Union Fall Meeting, San Francisco, CA USA. Web page: fall-meeting.agu.org/2015/

2016

January 18–22 10th International Symposium on Environmental Geochemistry (ISEG10), Perth, Western Australia. Web page: www.iseg10.com

January 24–29 40th International Conference and Expo on Advanced Ceramics and Composites (ICACC'16), Daytona Beach, Florida, USA. Details forthcoming

February 14–18 TMS Annual Meeting & Exhibition, Nashville, TN, USA. Web Page: www.tms.org/meetings/annual-16/AM16home.aspx

March 13–17 251st ACS National Meeting & Exposition, San Diego, CA, USA. Web page: www.acs.org

May 17–19 8th International Conference on Mineralogy and Museums. Changsha, China. Web page: www.agiweb.org/smmp/M&M8%20First%20Circular.pdf

May 22–25 10th South American Symposium on Isotope Geology

(SSAGI), Puerto Vallarta, Mexico. Web page: www.ssagi10.geofisica.unam.mx/

June 1–3 Geological Association of Canada–Mineralogical Association of Canada (GAC–MAC) Meeting, Whitehorse, Canada. Webpage: whitehorse2016.ca/

June 6–10 Inter/Micro 68th Annual Applied Microscopy Conference, Chicago, IL, USA. E-mail: intermicro@mcrl.org; Web page: www.mcrl.org

June 19–22 AAPG 2016 Annual Convention & Exhibition, Alberta, Canada. Web page: www.aapg.org/events/conferences/ace

June 26–July 1 Goldschmidt2016, Yokohama, Japan. Web page: goldschmidt.info/2016/

July 22–26 American Crystallographic Association Annual Meeting, Denver, CO, USA. Web page: www.americalassn.org/content/pages/main-annual-meetings

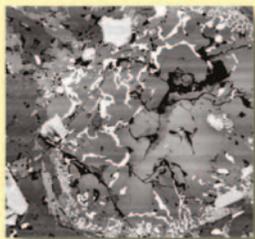
July 24–28 Microscopy & Micro-analysis 2016, Columbus, OH, USA. Web page: www.microprobe.org

The meetings convened by the societies participating in *Elements* are highlighted in yellow. This meetings calendar was compiled by Andrea Koziol (more meetings are listed on the calendar she maintains at homepages.udayton.edu/~akoziol1/meetings.html). To get meeting information listed, please contact her at akoziol1@udayton.edu

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Dodecahedral grossular crystal from Sierra de Cruces, Coahuila, Mexico. Photograph by Jeff Scovil from Excilibur's exclusive Photographic Guide to Mineral Species CD.

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ONE LONG GIGANTIC BLUNDER

We tend to remember Charles Darwin as he is depicted near the end of his life in 1882, captured by the new technique of photography. A solemn old man, with a great white beard, a black cape and a black hat, his haunted eyes suggesting he is brooding over the enormity of the big idea that had led, in 1859, to his great work *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. Less well known is the Darwin who returned from the five-year voyage of HMS *Beagle* in 1836, when still only 27, a handsome, ambitious young man who saw himself as a geologist (Fig. 1).



FIGURE 1 Charles Darwin in 1840, aged 31. FROM A PAINTING BY GEORGE RICHMOND.

He almost immediately became secretary of the Geological Society of London.

His first two proper scientific publications were both geological, very different but inter-related in an intriguing way. The first, read before the Geological Society in 1838 and published in 1840 in their *Transactions of the Geological Society of London*, was entitled 'On the Connexion of certain Volcanic Phenomena in South America; and on the Formation of Mountain Chains and Volcanos, as the Effect of the same Power by which Continents are elevated'. Its foundations were a global tectonic theory proposed by his mentor, Charles Lyell. It begins with a fine opening paragraph:

'The object of the present memoir is to describe the principal phenomena generally accompanying the earthquakes on the west coast of South America; and more especially those which attended the shock that overthrew the city of Concepcion on the morning of the 20th of February, 1835. These phenomena evince, in a remarkable manner, the intimate connexion between the volcanic and elevatory forces; and it will be attempted to deduce from this connexion, certain inferences regarding the slow formation of mountain chains.'

His second paper, published in *Philosophical Transactions of the Royal Society of London* in 1839, was more parochial: 'Observations on the parallel roads of Glen Roy, and other parts of Lochaber in Scotland, with an attempt to prove they are of marine origin'. Shortly after its publication he was made a Fellow of the Royal Society. These mysterious 'Parallel Roads' (Fig. 2) are three perfectly horizontal terraces, a few metres wide, on the sides of a valley about 30 km east of my home in the West Highlands of Scotland. In a world that is all curves, they have a distinctly engineered look, and the local people can be forgiven for calling them 'roads', produced by some ancient civilization.

In 1815–1817, geologist John MacCulloch, a Scot who lived in London, and Thomas Dick Lauder, a Scottish landowner and amateur geologist, working independently, surveyed the 'roads' and came to similar conclusions. They suggested that they were beaches, the shorelines of ancient freshwater lakes. But, this left a serious problem; there is no sign of a barrier that could have held back the water. MacCulloch considered the possibility that they were marine beaches but rejected the idea because the horizontal 'roads' were restricted to a few valleys, and he could not find any sea shells. Lauder's careful surveying showed that the height of the 'roads' was governed by that of cols in the surrounding ridges, which would have provided spillways for the lakes. While most geologists in subsequent years accepted the lake theory, the location and fate of the final barrier remained an enigma.

In 1838, Darwin, fired up by his discovery of elevated marine terraces at Coquimbo in Chile, visited Glen Roy, looking specifically for evidence that the 'roads' were of marine origin, thereby proving that global 'elevatory forces' were at work. His field evidence and conclusions



FIGURE 2 The three mysterious 'Parallel Roads' of Glen Roy. They are at 260 m, 325 m and 350 m, respectively, above present-day sea level.

appear in his long 1839 paper (45 pp). It goes into mind-numbing local detail, but in it, Darwin presented no new large-scale work and simply transposed Lauder's map of the 'roads' onto a new base-map (Fig. 3). He failed to find evidence of marine shells and brushed aside Lauder's discovery that the 'roads' equated with local col heights as a mere coincidence. Their restricted regional extent was put down to lack of preservation elsewhere. Despite these considerable difficulties, Darwin stuck to his model.

His nemesis arrived the following year in the form of the Swiss palaeontologist and glaciologist, Louis Agassiz. The Agassiz family have figured in Parting Shots before (*Elements*, 2010, v6n5, p 351). Louis never accepted Darwin's view of evolution; but that was a disagreement for the future. In 1840, Louis visited Britain to work primarily on fossil fish, but also to promote his 'Ice Age' theory in which he proposed that much of northern Europe had been covered by an ice-sheet. He lectured in Edinburgh and Glasgow and briefly visited Glen Roy, where he declared that the 'roads' were the shorelines of a lake held back by glaciers. He suggested where the snouts of glaciers could have been located, but their position did not adequately explain the distribution of the roads.

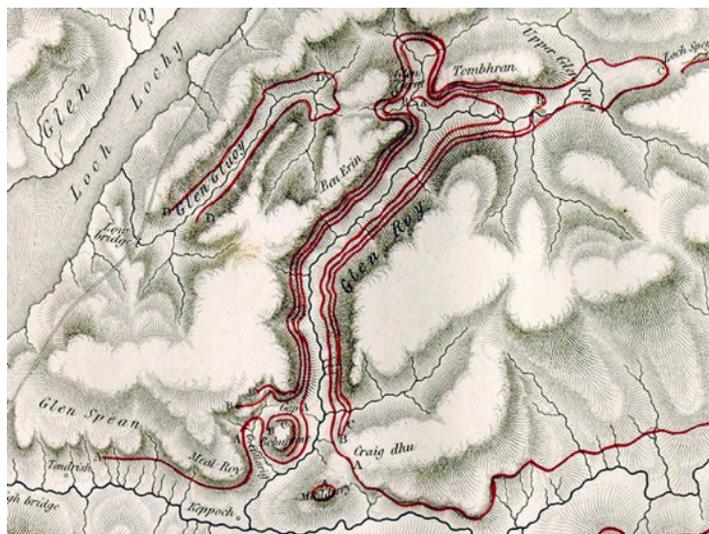


FIGURE 3 Part of Darwin's 1839 map of the 'Parallel Roads' (in red), based on Thomas Dick Lauder's mapping (1820) transposed onto a new base map. In Glen Roy there are three 'roads', but in the lower valleys there is just one. 'Glen' is the Scottish word for a steep-sided valley, and a 'loch' can be either a lake or an arm of the sea.

Cont'd on page 296

Cont'd from page 295

The geological community gradually came to accept Agassiz's hypothesis, but Darwin was slow to do so. It was more than twenty years before new evidence finally made him change his mind. He was, of course, pre-occupied by *Origin of Species* (1859). Nevertheless, it was Lyell and Darwin who suggested that Thomas Jamieson, a Scottish agricultural scientist and amateur geologist, should revisit Glen Roy and its surroundings. In 1861–1862, Jamieson came to Glen Roy, applied up-to-date understanding of the behaviour of glaciers, and made use of features such as glacial striae, moraines and erratics. His model of advancing and retreating glacier snouts, published in 1863 in the *Quarterly Journal of the Geological Society*, is the one we accept today. Darwin's reaction to Jamieson's work was one of despair. He wrote to Lyell, 'I am smashed to atoms about Glen Roy, my paper was one long gigantic blunder from beginning to end'.

My unexpected interest in geomorphology came about because I also work for a voluntary organization, Lochaber Geopark (www.lochaber-geopark.org.uk). We have recently opened a visitor centre and café at the foot of Glen Roy. My colleagues know much more about Glen Roy (and Quaternary geology!) than I do, but a small contribution I could make was to visit the Centre for Research Collections in Edinburgh University to get some engravings from these early works that have now been digitized. Among the box of volumes the librarians provided was a separate reprint of Darwin's 1839 paper, signed in ink by Darwin himself on the first page, 'C. Lyell Esq^u – From the Author'. Now, that was a thrill!

Ian Parsons (ian.parsons@ed.ac.uk)
University of Edinburgh

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For additional information, please see <http://pages.geo.wvu.edu/earthmaterials> or contact the search chair: Jaime Toro at earthmaterials@mail.wvu.edu or (304) 293 9817.

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Research Assistant Professor in Isotope Geochemistry

The Department of Geological Sciences and Center for Earth and Environmental Isotope Research (CEEIR) at the University of Texas at El Paso seek applicants for a Research Assistant Professor to support research activities at its isotope facility. The position provides 75% salary support with the expectation that the selected candidate will participate in research projects related to isotope geochemistry, direct graduate student research, and support the normal operation and maintenance of the isotope facility. Successful candidates will have the opportunity to raise an additional 25% salary through external support. For more information on the center and the department, see: <http://science.utep.edu/ceeir/> and <http://science.utep.edu/geology/>.

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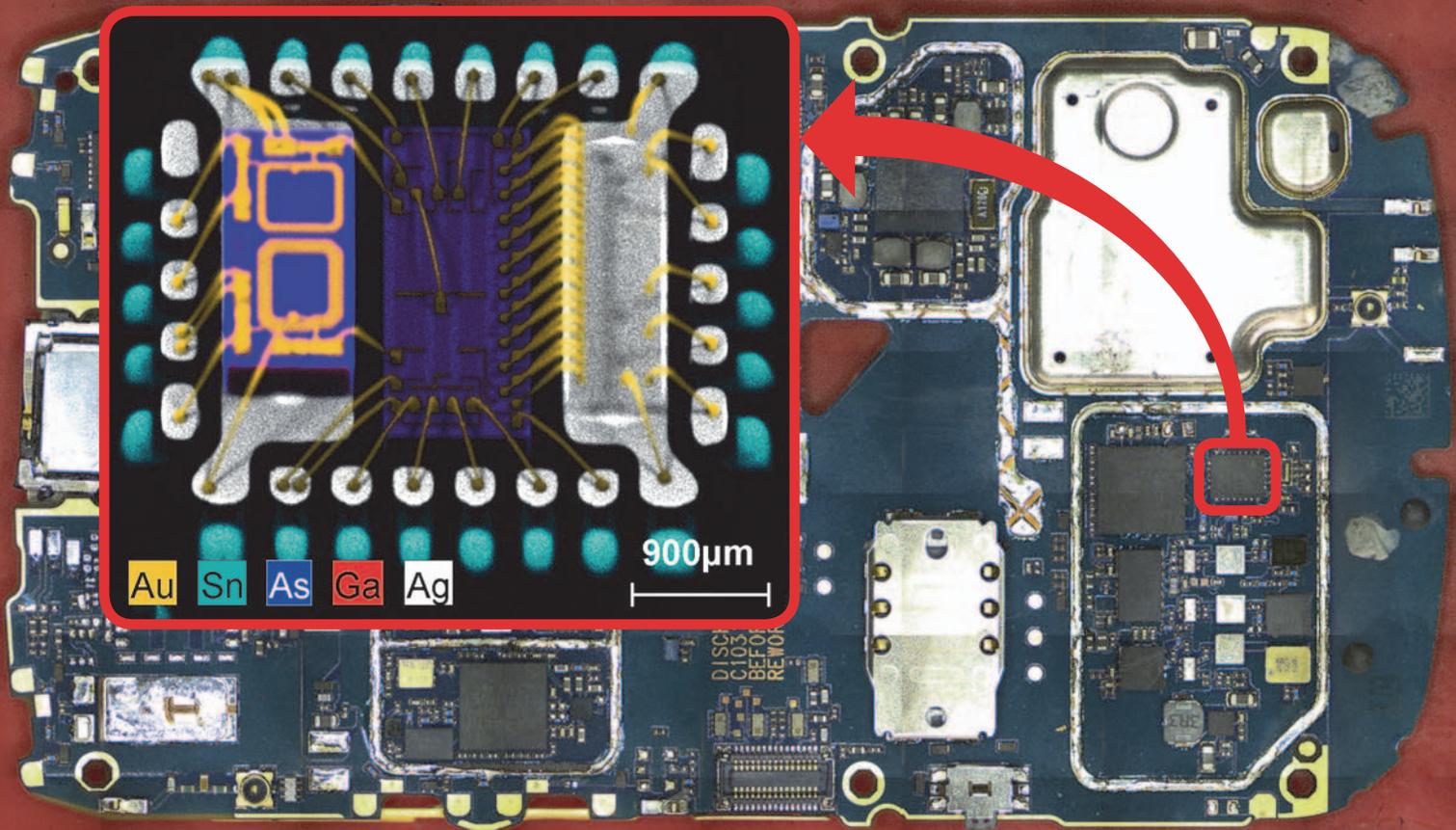
Application Procedure: Applications should be submitted via email to Dr. Lin Ma, Search Committee Chair, Geological Sciences, lma@utep.edu. The subject line should read "Research Assistant Professor Position Application: YOUR NAME".

Complete applications will consist of a single PDF file with 1) letter of interest, 2) detailed CV, and 3) names and contact information of at least three references.

Review of applications will begin in mid-September 2015 and will continue until the position is filled.

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