Elements

An International Magazine of Mineralogy, Geochemistry, and Petrology

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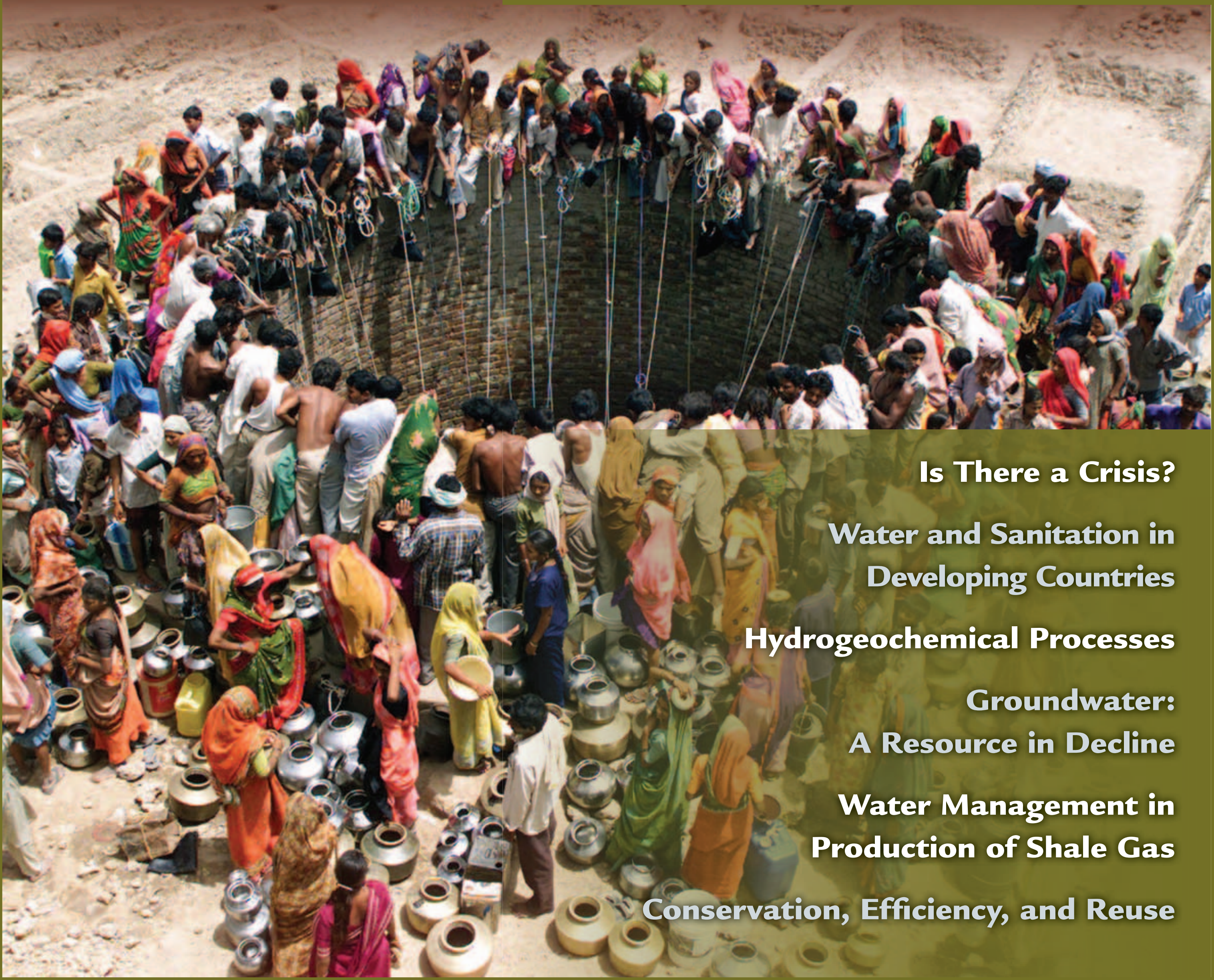
Global Water Sustainability

JANET G. HERING, CHEN ZHU, and ERIC H. OELKERS , Guest Editors



Is There a Crisis?

Water and Sanitation in Developing Countries

Hydrogeochemical Processes

Groundwater: A Resource in Decline

Water Management in Production of Shale Gas

Conservation, Efficiency, and Reuse

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Elements

An International Magazine of Mineralogy, Geochemistry, and Petrology

Elements is published jointly by the Mineralogical Society of America, the Mineralogical Society of Great Britain and Ireland, the Mineralogical Association of Canada, the Geochemical Society, The Clay Minerals Society, the European Association of Geochemistry, the International Association of GeoChemistry, the Société Française de Minéralogie et de Cristallographie, the Association of Applied Geochemists, the Deutsche Mineralogische Gesellschaft, the Società Italiana di Mineralogia e Petrologia, the International Association of Geoanalysts, the Polskie Towarzystwo Mineralogiczne (Mineralogical Society of Poland), the Sociedad Española de Mineralogía, the Swiss Society of Mineralogy and Petrology, and the Meteoritical Society. It is provided as a benefit to members of these societies.

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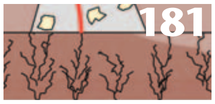
Global Water Sustainability

Guest Editors: **Janet G. Hering, Chen Zhu,** and **Eric H. Oelkers**



ABOUT THE COVER:

People gathering water from a huge well in the village of Natwargadh in the western Indian state of Gujarat on June 1, 2003. Groundwater levels in this area are currently dropping 3 m per year, on average, and salt water is infiltrating local aquifers, primarily due to overwithdrawal to support local agricultural activities. ORIGINAL PHOTO: AMIT DAVE, REUTERS

DEPARTMENTS

PARTICIPATING SOCIETIES

The Mineralogical Society of America is composed of individuals interested in mineralogy, crystallography, petrology, and geochemistry. Founded in 1919, the Society promotes, through education and research, the understanding and application of mineralogy by industry, universities, government, and the public. Membership benefits include special subscription rates for *American Mineralogist* as well as other journals, a 25% discount on Reviews in Mineralogy & Geochemistry series and Monographs, *Elements*, reduced registration fees for MSA meetings and short courses, and participation in a society that supports the many facets of mineralogy.

Society News Editor: Andrea Koziol (Andrea.Koziol@notes.udayton.edu)

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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*.

Society News Editor: Kevin Murphy (kevin@minersoc.org)

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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.

Society News Editor: Pierrette Tremblay (ptremblay@mineralogicalassociation.ca)

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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 an annual meeting, workshop, 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 co-hosting 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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The European Association of Geochemistry was founded in 1985 to promote geochemical research and study in Europe. It is now recognized as the premiere geochemical organization in Europe encouraging interaction between geochemists and researchers in associated fields, and promoting research and teaching in the public and private sectors.

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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 "bulletin de liaison" (in French), 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. Tschermak, 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*, the DMG Forum, *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*.

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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 by 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 and 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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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.

Elements

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WATER RESOURCES—SCIENCE AND VALUES


James I. (Tim) Drever

The theme of this issue raises many questions beyond the technical problem of providing more fresh water where it is needed, whether for agriculture or domestic use. The problem is clear: water supplies, particularly groundwater supplies, are diminishing as a result of pollution and depletion of aquifers by extracting more water than the natural recharge. In many instances, the current rate of recharge is essentially zero and we are extracting "fossil" water that was recharged under previous more humid climatic regimes. At the same time, the human population is expanding, its diet is changing in a way that demands more water for agriculture, and climate change adds a level of uncertainty: current predictions include increased aridity in the subtropics.

> … We must recognize that many issues are a matter of values rather than matters of science.

How can we address the problem? The nature of the problem, and thus its solution, varies greatly from region to region. Overall, the United States has a surplus of water and the economic resources to build systems, notably in California, to transport water long distances. Although this may "solve" the problem of water shortage in the drier areas, the environmental impacts in the contributing areas can be severe. Modern sensitivities to environmental issues, particularly endangered species, are placing limits on such diversions. These constraints and high costs make it unlikely that we will see more grand-scale projects like those in southern California. Also, each U.S. state jealously guards "its" water and fights transfers to any other state. The situation is very different in subtropical Africa, where there are few nearby sources of surplus water and limited economic resources. In Western Europe, by contrast, the problem is not so much water shortage as pollution, particularly by nitrate from agriculture. The solution here is likely to be the modification of agricultural practices and water treatment where necessary. Some progress is being made in both areas.

Vaux (in this issue) stresses the importance of establishing markets for water so that it is allocated towards the most beneficial (highest-value) use. It is hard to argue with this in principle, but it does raise some philosophical questions: how does one assign a value (ultimately a monetary value) to a commodity that is essential for human survival? We could draw an analogy to food: food is also essential for human survival, and few would disagree that an agricultural system based on private producers and a free market (well, reasonably free) is more efficient and productive than one based on central planning. But food and water are not the same. Food can be transported long distances with existing infrastructure at relatively modest cost, whereas water, generally speaking, cannot. The authors of this issue argue that the cost of desalination is going down and that desalination may be an economically viable source of fresh water. This may be true for places like California and the oil-rich countries of the Middle East, but I have my doubts about the poorer countries of the world. And desalination requires energy, which has implications for greenhouse gases and potential costs in the future.

The question of assigning a monetary value to water is complex. In the United States it does not matter much if water is diverted from agriculture to golf courses because golfers are willing and able to pay more. But how does one assign a monetary value to maintaining in-stream flow? Or to sport fishing and recreation? I have listened to economists giving talks on these subjects but I come away with the feeling that ultimately these are issues of personal values. They are best decided by elected governments, who are, realistically, the only people in a position to make such judgments. We may see their judgments as unwise or shortsighted: in such cases we, as professionals, have an obligation to try to educate the public and the politicians, but we must recognize that many problems are a matter of values rather than a matter of science.

The situation is very different in subtropical regions, where subsistence agriculture represents a major use of water and where, as discussed in this issue, supplies are decreasing even as the population is increasing. A poor person in a developing country is not in a position to pay much for water, and the product of his subsistence agriculture may, according to standard economic analysis, have little commercial value. From a narrowly economic perspective (which tends to discount the future in favor of the present), the best use of the water is likely to be commercial farming for the export market, but this would have the effect of eliminating some traditional ways of life and driving people to the cities and to emigration. We need to take a broader view of economic value: the disruption of traditional agriculture may have all sorts of societal costs.

There is no easy solution to this problem. The most obvious conclusion is that we need to manage existing supplies efficiently to minimize aquifer drawdown and to minimize the salination that often accompanies diversions for irrigation. Decisions in the political arena need to be based on a sound understanding of the consequences, particularly the long-term consequences, of alternative strategies for the utilization of ground and surface waters. As Earth scientists we have much to contribute.

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THIS ISSUE

The very first issue of *Elements* had as its theme "Fluids in Planetary Systems." In it, Guest Editor R. E. Bodnar and invited authors explored the role of fluids in ore deposits, magmas, the mantle, extraterrestrial bodies, faulting, and flow. More than 6 years later, we revisit the theme of fluids, but the focus this time is on water at the Earth's surface and the ways to ensure its sustainability for future generations—one of the many societal issues we face today.

Many publishers have several books dealing with water. What could an issue of *Elements* contribute in its 36 pages of thematic content? Guest Editors Hering, Zhu, and Oelkers have chosen to cover some key issues in which mineralogists and geochemists can contribute meaningfully.

The topic is global, but it is also close to all of us at the local level. Here are some of the "water issues" that are close to me.

At the INRS research center where I have my office, the debate over bottled water is ongoing. Many are adamant that bottled water should be banned. We willingly pay up to the equivalent of the price of a liter of gas for a resource that we can get out of our tap for next to nothing and that scientists insist is of high quality in this part of the world.

I was heartened to learn about Project Eau Nicaragua: 11 INRS graduate students in "sciences de l'eau" are preparing to do field work in a rural area of Nicaragua. The project has many pedagogical objectives but will deal with the real water problems. The students will work with the local population to implement solutions. Follow their work at www.eaunicaragua.net.

A close relative is dealing with an artesian well contaminated with *E. coli* bacteria. In Canada, the deterioration of groundwater made the headlines in 2000 when 7 people died and 5000 fell sick in the small Ontario town of Walkerton; the well providing their water became contaminated with a virulent strain of *E. coli*. This crisis highlighted the need to adequately train employees who deal with water-quality controls.

The exploration for shale gas has been a very controversial issue in the province of Quebec and in many other parts of the world. In Quebec, public opposition is strong, with many citizens clamoring for a moratorium on exploration for shale gas. Citizens' concerns range from fear of their water well being contaminated to their property losing value, and there is also the underlying question, "Should we keep this resource available for future generations?"

Jordan Bay, Nova Scotia, where my family's summer home is located, is the proposed site of a fish farm. How will this affect our neighbors who fish the bay for lobster every fall and spring?

NEW FEATURES

Two new features make their debut in this issue: CosmoElements will keep us in touch with exciting discoveries in cosmochemistry. As pointed out by Principal Editor Hap McSween in his editorial (7: 3), "Geology would do well to take advantage of the widespread interest that planetary exploration engenders." We hope to provide short articles that can be used in the classroom or keep you up to date on the latest space missions carrying geochemical or mineralogical instruments.

The idea for A Life in Science column originated in a brainstorming session with Penny King during the last GSA meeting. We hope to provide tools and food for thought to Earth science graduates at all stages of their careers, but perhaps with emphasis on the 30% or so of our readers entering, or about to enter, a career in the geosciences.

SEE YOU AT GOLDSCHMIDT!

Elements will have a booth at the Goldschmidt Conference in Prague. Make sure to drop by and say hello and let us know how we are doing.

WE ARE ON FACEBOOK

Elements now has its Facebook page: www.facebook.com/elementsmagazine. It will offer an easy way to obtain timely information. Thanks to Seth Davis of the Geochemical Society who helped me set it up.

Pierrette Tremblay, Managing Editor

Back issues of *Elements* for the classroom

Order online at www.elementsmagazine.net

EAWAG

We thank EAWAG for its support of this issue and congratulate the organization on its 75th anniversary.

WHOSE PAPER IS IT ANYWAY?


Bruce Yardley

A while back I returned a manuscript to a journal after making the relatively minor revisions requested by the reviewers. The editor responded promptly but explained that he could not make a final decision without sending it back to the reviewers for further comment. Given that there is so much literature out there, should we be grateful that there are mechanisms in place to spare us from more than is really necessary, or does micromanagement of publication stifle independent thought and make unnecessary work for reviewers and editors?

Attitudes to reviewing evolved throughout the twentieth century and sometimes varied significantly between countries. But then, new technology and the dominance of just a few publishers have made everything a lot more homogeneous over the past decade. When I edited a volume of Russian science about 20 years ago, I found that many of the authors were not used to having reviewers read their papers in sufficient detail to actually point out when figures did not show what was claimed in the text or when data tables were incomplete. Without exception they really appreciated the rigorous scientific reviewing. In the early 20th century, reviewing seems to have been universally a lot more lax than today, although the classic techniques for using the review process to delay or prevent the appearance of your rival's work were of course perfected at a very early stage. At one time it seemed that North American journals took reviewing more seriously than many of their European counterparts, who were happier to let authors publish rubbish under their own names if they insisted on doing so. Even with modern technology and lengthy check lists for appraisal, some papers still appear with glaring errors of content or communication because reviewers have ticked the boxes without really checking things out.

At the other extreme, some reviewers and editors insist on detailed changes before they will accept a manuscript, even against the author's better judgment. It may be insistence on a particular grammatical usage, but it can also be more contentious: citation of a particular source for an idea for example. I can recall one particularly pernickety editor who was so exact in his demands that after the fifth revision I seriously thought of making him an author. He seemed to have rewritten most of the text and at least the journal would have had to pass the manuscript on to another editor at that point!

It might seem a good thing that reviewers and editors take such care over manuscripts, but it is possible that they may be cutting out independence and originality, and making us concentrate on presenting things in a way that will accord with mainstream views, even when it is not really relevant or necessary to do so. If the reviewers have checked that the data are gathered appropriately and are well documented and that calculations have been done correctly, shouldn't that be enough for publication? What if the interpretation seems crazy? Should journals spare the scientific community the sight of your hard-won data because you chose to interpret them in a way that is unconventional, or should they encourage publication, if only so that right-thinking scientists can reinterpret your data and show how they actually fit better with their own ideas? As far as possible, I think it is best to let the author put his name on the paper and take the flak if it turns out to be wrong, although I would certainly insist on removing lengthy flights of fancy that are not supported by the data, irrespective of whether they are mainstream views or novel ones. I have heard journals rightly criticised for publishing papers with data and observations that are clearly flawed, but if it really mattered whether all the ideas in a paper also turn out to be correct in the long run, then *Nature* would hardly be treated with such reverence by the scientific community!

Peer review is rightly regarded as a cornerstone of how we advance our science, but it is review, not veto…

Classically, the job of an editor is to suppress flawed papers and encourage those that are right, and much of the time it comes down to rejecting papers that are probably not wrong but say nothing new and looking for papers with new data or new ideas that will be of value to other scientists. Reviewers point out problems that are apparent through their specialist knowledge, but the editor has final responsibility to decide whether the flaws are fatal or simply an irritation to the cognoscenti. Increasingly, however, the major publishing houses seem to want to publish only those papers of which the reviewers actually approve, which is not at all the same thing as publishing those papers in which reviewers have not found an obvious flaw. Reviewers are now routinely asked if they are prepared to take a second look at a manuscript after it is returned in the light of the initial review. Why? There are times when this is appropriate, but not many. At this stage the editor should be able to make an informed call, based on personal experience and judgment. Are the authors at least as well informed about the subject as the reviewers? Have the authors taken valid comments and suggestions seriously, or did they have no intention of making any substantive changes and just wanted to see the paper in print with minimal effort on their part? Peer review is rightly regarded as a cornerstone of how we advance our science, but it is review, not veto, and journals should ensure that good observations and data can still get published even if the interpretations and conclusions that go with them are not considered to be of the same standard. It is the authors who will be judged by a paper, very rarely the reviewers or editors.

Go back just 50 years and you will find that some of the most intense debates in the Earth sciences were on topics that look to us now as about as sensible as counting the number of angels that can stand on the head of a pin. Geosyncline theory springs to mind for example. My guess is that this observation will be just as true in 50 years time, despite the best endeavours of authors, reviewers, editors and publishers to ensure that now we only publish the truth. Fortunately, it matters not a jot: what matters is that we will have moved on.

Bruce Yardley, University of Leeds
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Jillian F. Banfield was named the 2011 North American Laureate by the L'Oréal-UNESCO Women in Science Foundation. Banfield is a geomicrobiologist and biogeochemist whose work focuses on the fundamental relationship between microorganisms and their natural environment. She was selected for her work on bacterial and material behavior under extreme conditions relevant to the environment and the Earth.

Originally from Australia, Jillian Banfield received her bachelor's and master's degrees in geology from the Australian National University. She subsequently completed a PhD in Earth and planetary science at Johns Hopkins University, USA. From 1990 to 2001 she was a professor at the University of Wisconsin–Madison. Since then she has been a professor at the University of California, Berkeley, and an affiliate scientist at the Lawrence Berkeley National Laboratory. She has been honored with numerous prestigious awards, including a MacArthur Fellowship, the Dana Medal of the Mineralogical Society of America, and a John Simon Guggenheim Foundation Fellowship. She was elected to the U.S. National Academy of Sciences in 2006. She was also one of seven recipients of the 2011 Franklin Medal, presented every year by the Franklin Institute in Philadelphia to "preeminent trailblazers in science, business and technology."

For the past 13 years, the L'Oréal Corporate Foundation and UNESCO have recognized women researchers who have contributed to overcoming the global challenges of tomorrow. Each year, the For Women in Science Program highlights scientific excellence and encourages talent. Faced with global challenges such as the acceleration of new technologies, aging populations, and the threat to biodiversity, L'Oréal and UNESCO remain convinced that these women researchers will have a major impact on society and lay the foundations for the future. As such, L'Oréal and UNESCO want to contribute to their recognition and provide them with the means to continue their commitment to science with energy and passion. In 13 years, the L'Oréal-UNESCO Awards have recognized 67 laureates, and 864 fellowships have been granted to young women scientists from 93 countries so that they can continue their research projects. The program has become a benchmark of scientific excellence on an international scale. The awards ceremony took place on March 3, 2011, at UNESCO headquarters in Paris. Each of the five women laureates (one per continent) received US$100,000 in recognition of her contribution to science.

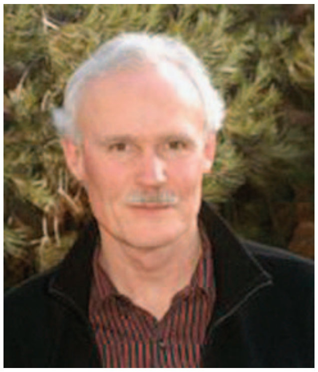
Alexandra Navrotsky, Interdisciplinary Professor of Ceramic, Earth, and Environmental Materials Chemistry, Edward Roessler Chair in Mathematical and Physical Sciences, director of the Nanomaterials in the Environment, Agriculture and Technology (NEAT) Organized Research Unit, and Distinguished Professor, University of California at Davis, was one of the 37 new members elected to the American Philosophical Society (APS). Alex's research addresses the fundamental question of why a chemical compound forms a particular structure at a given temperature and pressure. That question has taken her into studies of the deep Earth, other planets, and the behavior and fate of nanomaterials in the environment.

The APS was founded in 1743 by Benjamin Franklin and others to promote knowledge in science and the humanities. Today, the society runs an academic library and museum, publishes books and journals, organizes meetings, and gives grants and prizes for scholarly work.

T. MARK HARRISON – NEW MEMBER OF THE NATIONAL ACADEMY OF SCIENCES

Mark Harrison, director of the Institute of Geophysics and Planetary Physics and professor of geochemistry in the Department of Earth and Space Sciences, University of California, Los Angeles, has been elected Member of the National Academy of Sciences. He is one of the 72 new members elected this year. Harrison studies the very early years of the Earth's history. In 2008, he and UCLA colleagues Craig Manning and Michelle Hopkins presented a new picture of what the early Earth was like in the journal *Nature*, including the surprising finding that plate tectonics may have started more than 4 billion years ago, much earlier than scientists had believed.

2011 JAEGER MEDAL TO IAN JACKSON



Ian Jackson, professor in the Research School of Earth Sciences, Australian National University, was awarded the 2011 Jaeger Medal for Research in Earth Sciences of the Australian Academy of Science. His research has centered on laboratory study of the physical properties of geological and analogue materials under conditions simulating those of the Earth's deep interior. His work has involved the development of novel methods for the measurement and analysis of elastic and near-elastic behavior related to the speeds and attenuation of earthquake waves. Such laboratory-based insights find application in the interpretation of seismological models for the Earth's internal structure in terms of temperature and chemical composition.

EXTRATERRESTRIAL WATER

The origin of water in the terrestrial planets remains one of the primary mysteries of planetary science. While it is believed that the terrestrial planets formed inside the water evaporation line (snow line) in the solar nebula, there is abundant evidence that material in the early Solar System traveled widely both into and out of the inner region near the Sun. It is necessary to use isotopic compositions as a tracer in order to understand the actual origin and evolution of materials. However, despite the fact that telescopic observations of Solar System bodies (e.g. the moons of the giant planets) indicate that water ice and attendant cryovolcanism are abundant and that clay-bearing astromaterials fall to Earth every day, until recently we had no direct samples of early Solar System water to analyze in the lab.

This situation changed dramatically in 1999, with the fall of two ordinary chondrite meteorites, Monahans (Fig. 1) and Zag. Both of these meteorites were found to contain halite crystals hosting water-filled fluid inclusions. The host halite grains are clearly extraterrestrial, as shown by their color, caused by irradiation by cosmic rays in space. These fluid inclusions were the first authenticated, direct samples of early Solar System water ever discovered, and they have since been followed by discoveries of similar water-bearing fluid inclusions in several carbonaceous chondrite meteorites (Fig. 2). Unfortunately, these water samples are very tiny, the mass of each being on the order of femtograms. Despite having these samples firmly in hand, we have had to wait for laboratory analytical capabilities to progress to the point where analysis of this water became possible. At the 2010 Meteoritical Society meeting in New York City, Shoichi Itoh and Hisayoshi Yurimoto (University of Hokkaido) reported the results of the first analyses of hydrogen and oxygen isotope compositions of individual fluid inclusions in Monahans and Zag halite crystals. These water samples have widely varying compositions, but all appear to have compositions roughly intermediate between those for comet coma and hydrous phases in carbonaceous chondrites. We are awaiting further data from this research group as they refine their analytical techniques, but the mere fact that they have teased out results from these excruciatingly tiny water samples is a considerable feat.

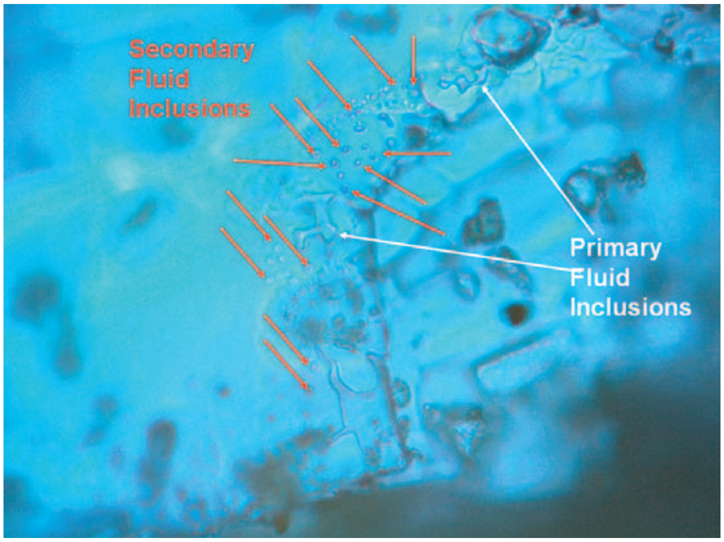


Figure 1 Monahans halite with fluid inclusions indicated

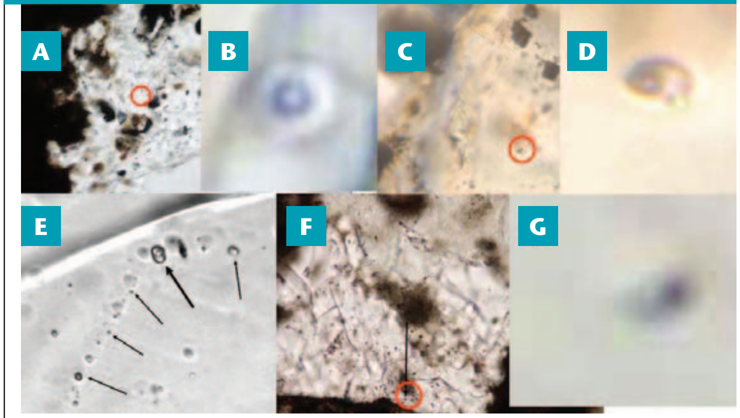


Figure 2 Transmitted-light views of aqueous fluid inclusions observed in meteorites. (**A**) Low-magnification image of a Murray carbonate grain. (**B**) Close-up of the two-phase fluid inclusion circled in (A), which measures 5 µm across. The outer circle in this image is the trace of the fluid inclusion's outer boundary, and the "bull's-eye" is a vacuum bubble. (**C**) Low-magnification image of a Tagish Lake carbonate grain. (**D**) Close-up of the two-phase fluid inclusion circled in (C), which measures 4 µm across. (**E**) Close-up of several two-phase fluid inclusions from Ivuna, the largest of which measures 6 µm across. (**F**) Low-magnification image of an ALH 84029 olivine grain. (**G**) Close-up of the two-phase fluid inclusion circled in (F), which measures 5 µm across.

Water is also known to have been a critical participant in the creation and evolution of early Solar System organic compounds. All the organic building blocks for life are found in clay-bearing astromaterials, indicating that hydration reactions on early Solar System bodies dramatically altered organic structures and compositions. Amino acids are found in some carbonaceous chondrites, and these were always thought to be equally right- and left (L)-handed in structure. However, in 1997, John Cronin and Sandra Pizzarello (Arizona State University) began to find L-excesses in isovaline and several other nonbiologic amino acids in the Murchison carbonaceous chondrite. In 2009, Daniel Glavin, Jason Dworkin, and coworkers at Goddard Space Flight Center reported the first independent confirmation of L-isovaline excesses in Murchison using a different analytical technique than employed by Cronin and Pizzarello. The Goddard group has since done an extensive study of the abundance and symmetry of amino acids in carbonaceous chondrites that experienced a range of alteration by water in their parent asteroids. The amino acids are more abundant in the less-altered meteorites, implying that aqueous processing changes the ratios of the various amino acids. These organic cosmochemists proposed that aqueously altered planetesimals might have seeded the early Earth with nonracemic amino acids, perhaps explaining why life, from microorganisms to people, uses only L-forms to make proteins. The initial imbalance in amino acid handedness caused by nonbiologic processes in wet asteroids might have been amplified by biological processes on Earth. Alternatively, the same processes that originally produced the L-amino acid excesses in carbonaceous asteroids may also have operated on the early Earth.

Now, Marc Fries (Planetary Science Institute) and Andrew Steele (Carnegie Institution Geophysical Lab) are locating and examining organics trapped in the meteoritic halite crystals by confocal Raman spectroscopy. These organics cannot ever have been heated beyond room temperature (else the halites would have dissolved), providing perhaps our best window into the dawn of organic reactions in the Solar System.

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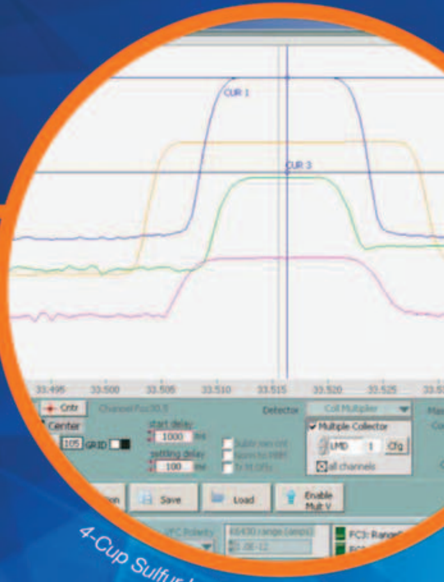
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Meet the Authors

Michael Berg leads the Contaminant Hydrology group at the Swiss Federal Institute of Aquatic Science and Technology (Eawag). His research focuses on the occurrence, fate, and behavior of organic and inorganic contaminants in groundwater and surface water. Since 1998 he has been involved in environmental issues in Vietnam, Cambodia, and China, where arsenic and manganese contamination of groundwater is a major concern. A recent interest is the geospatial modeling of geogenic contaminants at local to global scales. As a result of his research, he received two *Environmental Science & Technology* top-paper awards and was given the Medal of Honour by the Government of Vietnam. He received a PhD from the University of Karlsruhe, Germany.

David A. Dzombak is the Walter J. Blenko, Sr. Professor of Environmental Engineering in the Department of Civil and Environmental Engineering at Carnegie Mellon University, Pittsburg. The emphasis of his research and teaching is on water-quality engineering, environmental remediation, and energy–environment issues. He earned a PhD in civil and environmental engineering from the Massachusetts Institute of Technology, an MS in civil and environmental engineering and a BS in civil engineering from Carnegie Mellon University, and a BA in mathematics from Saint Vincent College. He is a fellow of the American Society of Civil Engineers, a diplomate of the American Academy of Environmental Engineers, and a member of the National Academy of Engineering.

Kelvin B. Gregory is an assistant professor of civil and environmental engineering at Carnegie Mellon University in Pittsburgh, Pennsylvania. His research explores the microbiology, ecology, and fundamental interactions of bacteria with their physical and geochemical environment. He studied biological systems engineering as an undergraduate at the University of Nebraska and later received a doctorate in civil and environmental engineering from the University of Iowa; he then completed postdoctoral studies at the University of Massachusetts' Environmental Biotechnology Center. His current research interests lie in applied environmental biotechnology and biogeochemistry for the management of produced water from oil and natural gas production and the control of radionuclide contamination.

Janet G. Hering is the director of the Swiss Federal Institute of Aquatic Science and Technology (Eawag), a professor of environmental biogeochemistry at the Swiss Federal Institute of Technology, Zürich (ETHZ), and a professor of environmental chemistry at the Swiss Federal Institute of Technology, Lausanne (EPFL). She has degrees in chemistry from Cornell and Harvard Universities and a PhD in oceanography from the Massachusetts Institute of Technology–Woods Hole Oceanographic Institution Joint Program. She currently serves as a member of the Board of Reviewing Editors for *Science*. Her research interests include the biogeochemical cycling of trace elements in natural waters and water treatment technologies for the removal of inorganic contaminants from potable water.

Motomu Ibaraki is an associate professor in the School of Earth Sciences, Ohio State University. He conducts research on the human health and environmental/ecological problems that result from water contamination and insufficient water supplies caused by human activities. He also carries out research on scientific communication. His recent projects include the hydrological impact on parasitic disease transmission, wetland hydrology with the application of radar altimeter measurements, and water and energy sustainability.

C. Annette Johnson is a senior staff member of Eawag (Swiss Federal Institute for Aquatic Science and Technology). Her research focuses on the geochemical properties of inorganic geogenic and anthropogenic substances in soils and water. Her current interest is on the identification of fluoride-contaminated groundwaters and the development of fluoride-removal technologies for drinking water treatment. She received her BSc in chemistry and her PhD in applied geochemistry from the Royal School of Mines, Imperial College, London. She is a fellow of the American Chemical Society, the International Society for the Environmental and Technical Implications of Construction with Alternative Materials (ISCOWA), and the European Association of Geochemistry. She is a member of the Swiss Nuclear Waste Commission and is on the advisory board of *Environmental Science & Technology*.

Richard B. Johnston has degrees in environmental engineering from Johns Hopkins University (MSE) and the University of North Carolina at Chapel Hill (PhD). From 1996 through 1999 and again from 2004 through 2009, he worked with UNICEF on arsenic-mitigation projects in Bangladesh. Since 2009 he has led the Water Supply and Treatment group in the Department of Water and Sanitation in Developing Countries at Eawag, the Swiss Federal Institute of Aquatic Science and Technology. His current research deals with ongoing arsenic mitigation in Bangladesh, fluorosis mitigation in East Africa, and the field application of low-cost technologies for measuring and improving microbial water quality.

Eric H. Oelkers is a CNRS Research Director at the GET laboratory (CNRS UMR 5563) in Toulouse, France. His primary research area is the experimental determination of the thermodynamics/kinetics of mineral–fluid reactions and the application of this knowledge to the quantification of environmental processes and global cycles. Eric has served as president of the European Association of Geochemistry, director of the Geochemical Society, coeditor in chief of *Chemical Geology*, associate editor of *Geochimica et Cosmochimica Acta*, and member of the Executive Committee of *Elements*. One of Eric's main goals is to energize the Earth science community towards finding solutions for long-term sustainable development. Towards this goal, Eric has coedited the *Elements* issues "Phosphates and Global Sustainability" and "Carbon Dioxide Sequestration."

Frank W. Schwartz is a professor and Ohio Eminent Scholar in hydrogeology at The Ohio State University. His current research interests are in new technologies for the remediation of groundwater contaminated by chlorinated solvents; engineering-based, passive approaches for treating urban runoff; and climate influences on lakes and wetlands in the Prairie Pothole region of the United States and Canada. He is the recipient of several important awards for research and was elected as a fellow of the American Geophysical Union in 1992. He has served on several expert panels of the U.S. National Research Council and has chaired the committee responsible for reviewing the applicability of contaminant-transport models to contemporary problems in hydrogeology.

Cont'd on page 156


Do You Think Ions
Like Queuing Up?

Meet the Authors

Cont'd from page 154

Elizabeth Tilley is a PhD student at the Centre for Development and Cooperation at the Swiss Federal Institute of Technology, Zürich. Her previous work was on developing and improving appropriate sanitation technologies in developing countries, with a special focus on nutrient recovery from human waste. Currently, she is investigating economic drivers and tools for sanitation uptake, which could act as incentives and increase global coverage.

Henry Vaux Jr. is Professor Emeritus of Resource Economics at the University of California, Riverside. He is also Associate Vice President Emeritus of the University of California System. Currently, he is the chair of the Rosenberg International Forum on Water Policy, which promotes global dialogue on reduction of water-related conflicts and improvements in water policy. His research deals with the economics of water resources and water policy. He is a national associate of the U.S. National Academy of Sciences. He received his education at the University of California (BA) and the University of Michigan (MS, MA, PhD).

Radisav D. Vidic is a William Kepler Whiteford Professor and chairman of the Department of Civil and Environmental Engineering at the Swanson School of Engineering, University of Pittsburgh. He holds a BS in civil engineering from the University of Belgrade and received his graduate education in civil and environmental engineering from the University of Illinois (MS, 1989) and the University of Cincinnati (PhD, 1992). His research efforts focus on advancing the applications of surface science by providing fundamental understanding of molecular-level interactions at interfaces, developing novel physical/chemical water treatment technologies, managing water for Marcellus Shale development, and the reuse of impaired waters for cooling systems. He has published over 150 journal papers and conference proceedings on these topics.

Chen Zhu is a professor of geological sciences and public and environmental affairs at Indiana University and an adjunct professor at the University of Oslo, Norway. He received his PhD from Johns Hopkins University and completed a postdoctoral fellowship at Woods Hole Oceanographic Institution. His research interests are groundwater geochemistry and geochemical modeling of water–rock interactions. His recent work involves the kinetics of feldspar dissolution, geological carbon sequestration, and arsenic and antimony in the environment. He was the 2006 recipient of the John Hem Award from the National Ground Water Association and a Fulbright Scholar at the University of Oslo in 2009. He coauthored with Greg Anderson the textbook *Environmental Applications of Geochemical Modeling*.

Water: Is There a Global Crisis?

Eric H. Oelkers[1], Janet G. Hering[2] and Chen Zhu[3]

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Providing safe drinking water to the world's 6.9 billion and growing population is one of the greatest challenges of the century. Consideration of the global water cycle, however, shows that the available renewable freshwater resources exceed the current human demand by roughly a factor of 10. Scarcity results from the uneven spatial and temporal distribution of water. Over-withdrawal of surface water and groundwater has led to depletion of water resources and environmental damage in some regions. In many developing countries, inadequate sanitation is a major cause of disease. These problems can be solved through the improved management of water infrastructure and water resources, advances in technology, and a valuation of water that reflects its importance to society. The role of Earth scientists in addressing the global water crisis is crucial. Indeed, resource monitoring, development of novel waste-water treatment technologies, and determination of the quantities of water that can be withdrawn without causing adverse effects on the environment will be essential for the efficient management of global water resources in the future.

Keywords: water resources, waste management, desalination, environmental protection

INTRODUCTION

Water is an enigmatic substance. The popular press is full of stories about the present and upcoming water crisis, yet *71% of Earth's surface is covered by water.* In total, 1.4×10^9 km^3 of water are present at the Earth's surface (Gleick 1996). However, 97% of this water is saline. Two percent of the water on Earth is glacier ice at the North and South Poles. Less than 1% is fresh liquid water, which is potentially available for drinking, irrigation and industrial use. Most of this liquid fresh water occurs as groundwater in aquifers. This groundwater is one of the three major sources of water used by society. The other two are surface water (rivers and lakes) and atmospheric water (via rainfall). Rivers and the atmosphere store no more than 0.0012% of global water reserves, but these resources are rapidly replenished by natural processes; the mean residence time of water in rivers and the atmosphere is estimated to be 16 and 8 days, respectively. Lakes store more freshwater than either rivers or the atmosphere, but take on average 17 years to refill. A summary of global water reservoirs is provided in Table 1.

USES OF WATER

Everyone depends on water. The water we use is either directly supplied by rainfall or withdrawn from the environment. Rainfall is critical for agriculture; rainfall supplies approximately 80% of the water used for agricultural production worldwide. Nonetheless, we tend to be most concerned about the 630 m^3/y of water that is withdrawn on average per person from surface water and groundwater sources for human purposes (FAO 2005). It is this water that both ensures the growth of our society and poses the greatest risks to our environment. Overall, two-thirds of the water withdrawn from the environment is used in agriculture, 23% by industry and 7% by households (Horrigan et al. 2002). The average annual water withdrawn per capita varies substantially among countries (Fig. 1), from as little as 6.4 m^3/y in the Central African Republic to greater than 5000 m^3/y in Turkmenistan (FAO 2005); these differences primarily reflect variations in the intensity of irrigated agriculture. In total, approximately 4000 km^3/y of water is withdrawn from surface water and groundwater sources worldwide to meet human needs. Of this roughly 20% is taken from groundwater (Boswinkel 2000).

Essentially all the water withdrawn for human activity eventually returns to the environment, though much of it is "consumed". Consumptive water use removes water from human access for some extended time through evaporation or its incorporation into products such as crops or livestock. It is estimated that more than 50% of the water withdrawn for agriculture is used consumptively (Margat and Andréassian 2008). In contrast, the majority of industrial and domestic water use is non-consumptive. For example, much of the water used for electric power plant cooling is returned to rivers after its use.

WATER AS A RENEWABLE RESOURCE

With the exception of fossil groundwater (which derives from climatic conditions of the geologic past), water is constantly being recycled by natural processes. The global water cycle (shown schematically in Figure 2) is driven by solar energy and gravity. It is estimated that 435,000 km^3/y of water evaporate from the world's oceans, of which 390,000 km^3/y return directly to the oceans by rainfall. A net of 45,000 km^3/y of water is transferred as vapour from

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TABLE 1 MAJOR EARTH-SURFACE WATER RESERVOIRS (AFTER GLEICK 1996)

Water reservoir	Water volume (10^3 km^3)	Percent of total water	Percent of fresh water	Mean residence time
Oceans, seas, bays	1,338,000	96.5	0	2500 years
Ice caps, glaciers	24,064	1.74	69	9700 years
Groundwater	23,400	1.69	–	1400 years
• fresh	10,530	0.76	30	–
• saline	12,870	0.93	0	–
Ground ice and permafrost	300	0.022	0.86	10,000 years
Lakes	176.4	0.013	–	17 years
• fresh	91	0.007	0.26	
• saline	85.4	0.007	0	
Atmosphere	12.9	0.001	0.04	8 days
Swamps	11.47	0.0008	0.03	5 years
Rivers	2.12	0.0002	0.002	16 days
Biological water	1.12	0.0001	0.003	4 hours

the oceans to the continents by wind. This 45,000 km^3/y is equal to the net difference between continental evapotranspiration (65,000 km^3/y) and precipitation (110,000 km^3/y), and this water eventually flows downstream through rivers and groundwater aquifers to the ocean, closing the global water cycle (Oki and Kanae 2006). Of this total, it is estimated that only 10%, or approximately 4500 km^3/y, replenishes groundwater (Church 1996), which accounts in part for the relatively long residence time of groundwater and the long-term risks in over-withdrawing water from this source (Konikow and Kendy 2005).

The 45,000 km^3/y net flux of water from the oceans to the continents, which flows through our rivers, streams and aquifers, constitutes our renewable water resource (Oki and Kanae 2006). If this total renewable water flux were divided evenly, approximately 6000 m^3 of water would be available for each inhabitant of the planet, which is about 10 times the current per capita usage. However, the renewable water flux is *not* distributed evenly, either in time or space. Water scarcity originates from an uneven distribution of rainfall, which leads to highly contrasting availability of water resources worldwide. The dramatic variation in average rainfall is shown by the worldwide rainfall distribution map in FIGURE 3. The Atacama Desert in Chile, the driest place on Earth, receives imperceptible rainfall each year. On the other hand, Mawsynram, Assam, India, receives over 1143 cm annually. As a result of this uneven distribution of water resources and population increases in arid and semi-arid regions, water shortages are becoming more and more widespread. Water shortages began in earnest in around 1900, when 2% of the world's population was subject to a chronic water shortage (<1000 m^3/capita/y). By 1960, this percentage had risen to 9%. Since then, the number of people subject to water shortages has increased rapidly, and in 2005, 35% of the world's population lived in areas with a chronic water shortage (Kummu et al. 2010).

HUMAN IMPACTS ON WATER QUALITY AND AQUATIC ECOSYSTEMS

In addition to its use for drinking, for irrigation and in transportation, water has been used from the earliest civilizations to the present for hygiene and sanitation.

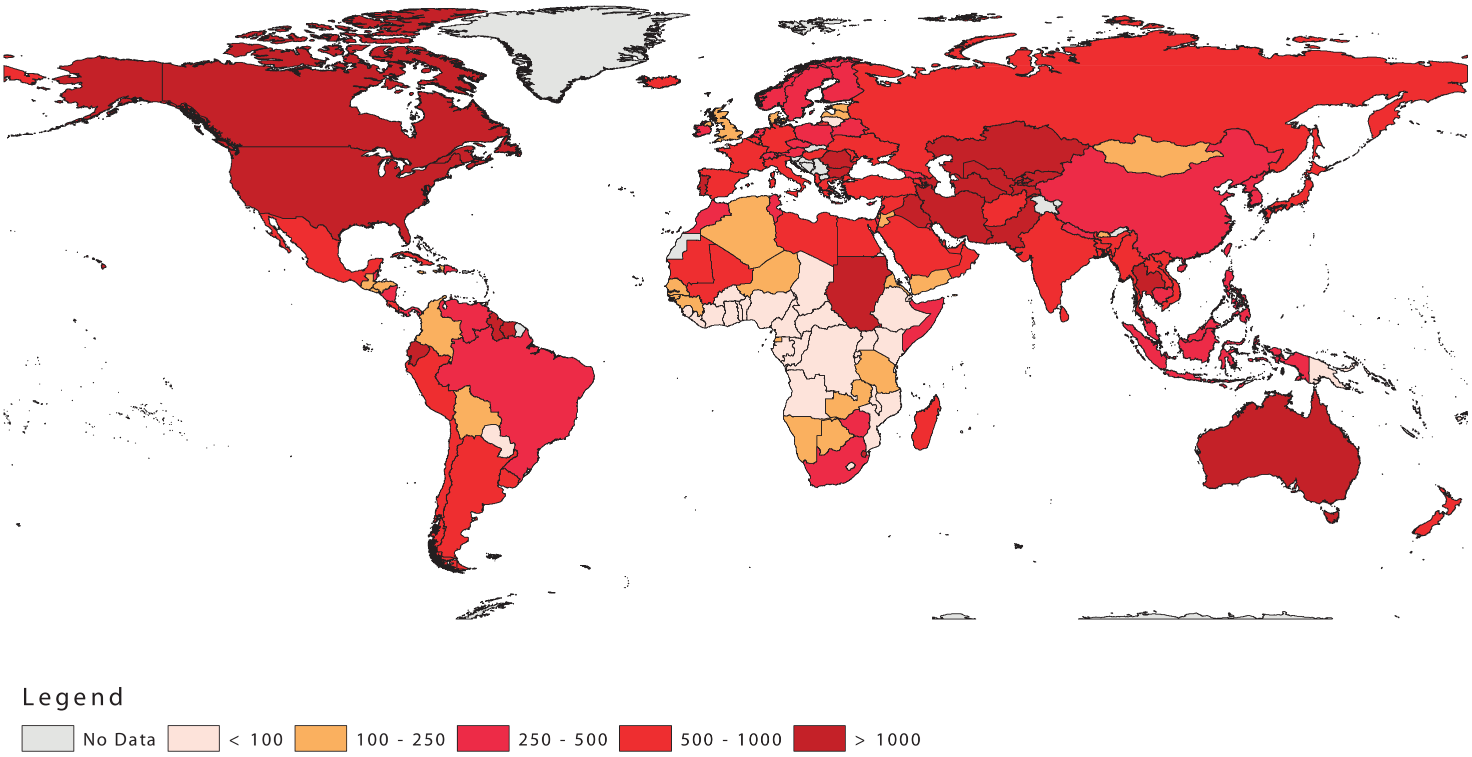


FIGURE 1 Water withdrawn from the environment per person in 2001 for agricultural, domestic and industrial purposes, in units of m^3/year. FROM FAO 2005

While the discharge of waste into surface waters provides a cheap and easy way to remove waste locally, it also degrades water quality, particularly for downstream users. In low-income countries today, more than 80% of municipal waste water is discharged into rivers, lakes and coastal areas without treatment (Schwarzenbach et al. 2010). Use of such polluted water is associated with a large number of health problems. Each year, poor water quality and management are responsible for 1.5 million deaths from diarrhoea, 100,000 deaths from helminth infections (intestinal parasites), and 15,000 deaths from schistosomiasis (a parasitic disease caused by ingesting trematode flatworms) (Gleick 1996; Kosek et al. 2003). The link between adequate sanitation and safe drinking water supply is examined by Johnston et al. (2011 this issue).

Mining and other extractive industries have had profound effects on water quality. As discussed by Gregory et al. (2011 this issue), massive quantities of water can be required, for example, to extract natural gas from shale. Saline deep groundwaters may also be discharged at the surface, degrading surface water quality. Industrial practices, including uncontrolled waste discharges, have also polluted groundwater and lake and river sediments. Some examples of toxic-metal pollution and remediation strategies are summarized by Zhu and Schwartz (2011 this issue).

The use of fertilizers and pesticides in agriculture and the disposal of agricultural wastes, particularly manure, constitute a diffuse source of pollution to surface water and groundwater. Although riverine fluxes of nutrients and pollutants are generally increasing, they can also decrease if anthropogenic retention (e.g. in reservoirs) and transformation processes exceed the additional sources of material (Meybeck 2003).

The excess withdrawal of water to address human needs can have grave consequences. Excess water removal from groundwater systems has been responsible for the extinction of whole civilizations (Schwartz and Ibaraki 2011 this issue). One of the most evident and environmentally devastating impacts of excess water withdrawal has been the diversion of water away from aquatic ecosystems. A classic example of this is the destruction of the Aral Sea in central Asia, an inland saltwater sea with no outlet. This sea, fed by two main rivers, the Amu Darya and the Syr Darya, was once the fourth-largest lake on Earth, covering 66,000 km^2. The Aral Sea has shrunk to less than 25% of its original size as a result of the construction of large dams across both rivers in the early 1960s to address irrigation needs (Waltham and Sholji 2001) (Fig. 4). As the water level of the Aral Sea dropped, its shoreline receded and its salt content increased tenfold, causing the decimation of native fish species, initiation of dust/salt storms, degradation of deltaic biotic communities and climate change around the former shoreline (Micklin 1988). The Aral Sea has now split into two sections, and although efforts are being made to restore a smaller northern section of the Aral, it is unlikely the larger southern part of the lake can be restored.

Similar devastation has occurred in Lake Chad, which was, in the 1960s, the fourth-largest lake in Africa, with a surface area of 26,000 km^2. The demand on the lake's water from the local population accelerated its shrinkage over the past 40 years. Irrigation projects and climate change have greatly decreased the flow of the Chari River, the main source of Lake Chad (Coe and Foley 2001). By 2000 its extent had fallen to less than 1500 km^2 (Fig. 5).

EFFECTS ON RIVERINE FLUXES

The flux of water from the continents to the oceans is being altered by changing climate and human activity (Vörösmarty et al. 2000). It is anticipated that average rainfall will decrease in currently dry regions and that, in many areas, extremes in rainfall, causing both floods and droughts, will become more frequent (Groisman et al.

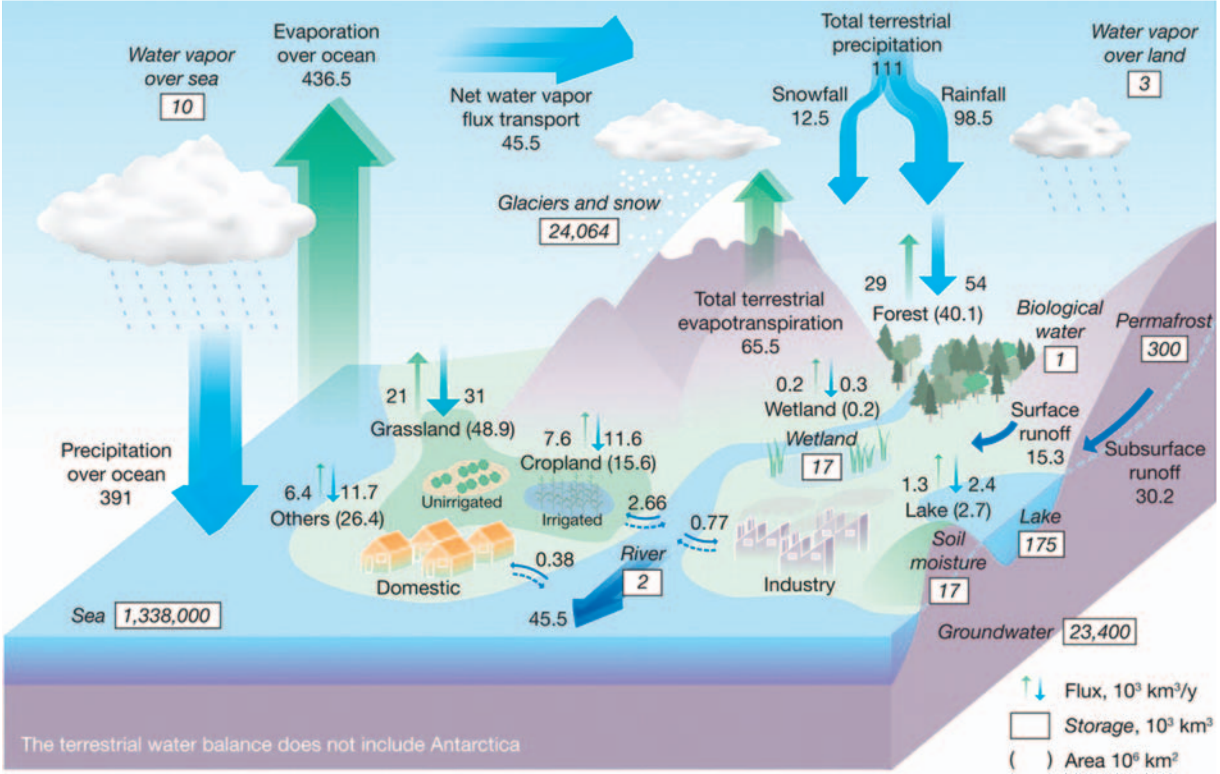


Figure 2 Schematic illustration of the global water cycle, from Oki and Kanae (2006). All fluxes are given in units of 100 km^3 per year and storage is given in 1000 km^3. Parentheses denote surface area in units of 10^6 km^2. Groundwater discharge is estimated to be about 10% of the total river discharge globally (Church 1996) and is included in river discharge. Reprinted with permission from AAAS

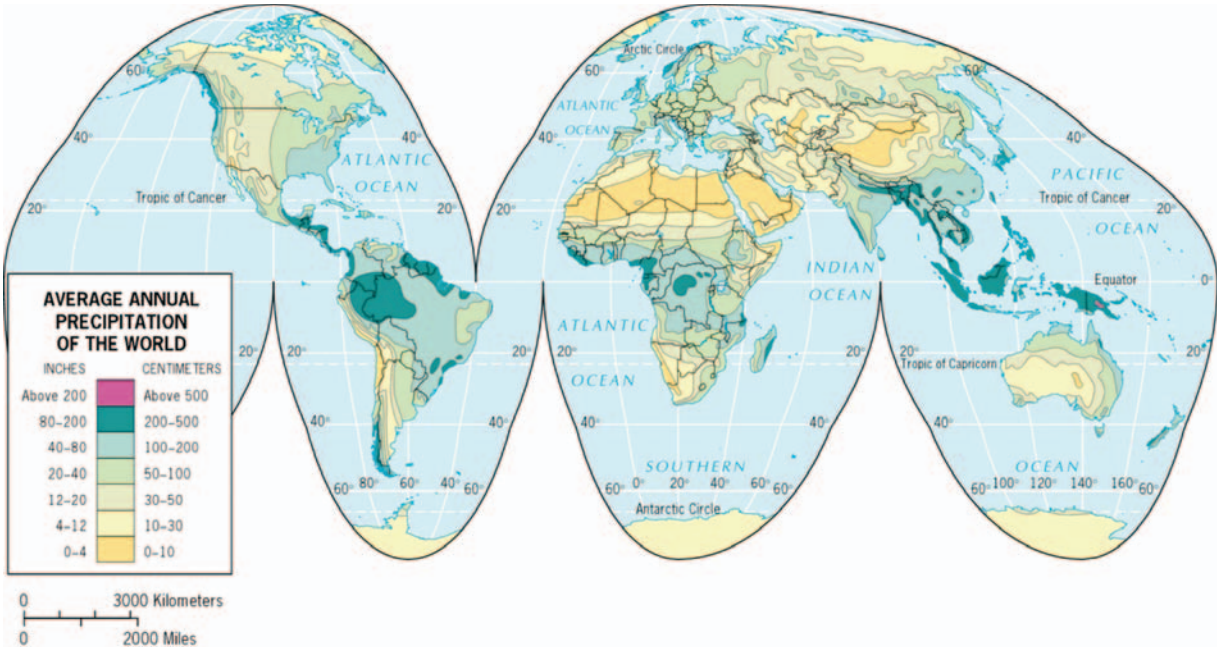


Figure 3 Global map of average annual rainfall. From FAO 2005

2005). Withdrawal of water by humans will also contribute to the decrease in river and groundwater recharge fluxes. Estimates suggest that the average global water flux to the oceans has decreased 2.7% worldwide due to irrigation and another 0.8% due to dams (Döll et al. 2009). These anthropogenic effects originate from the increased evaporation caused by irrigation and the presence of reservoirs. Such effects are more dramatic on the local scale; the combined effects of irrigation, river damming, and climate change has led to a decrease of more than 10% in average river discharge over one-sixth of the global land area (Döll et al. 2009).

Anthropogenic changes in water fluxes to the oceans may also affect the global cycles of some elements. The flow of water down rivers transports more than 7.6×10^{13} kg/y of elements in dissolved form and within suspended materials to the oceans (Viers et al. 2009). This process plays a major role in the global cycles of most elements, including phosphorus and nitrogen (Meybeck 1982; Vitousek et al. 1997; Filippelli 2008). Similarly the transport of calcium by rivers from the continents to the oceans and its subsequent precipitation as carbonate minerals is an essential component of the long-term carbon cycle, thereby influencing climate through the greenhouse effect (Berner et al. 1983; Gislason et al. 2006).

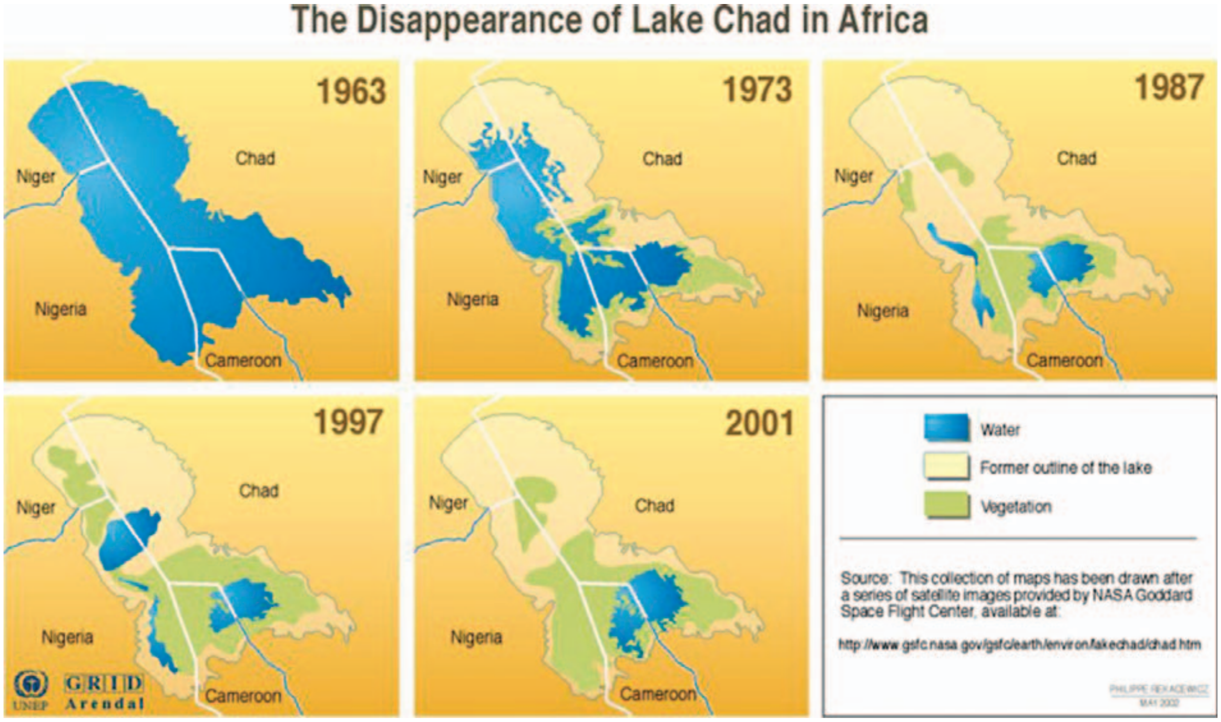
SOLUTIONS FOR THE FUTURE

In an attempt to address the growing need for water and to attenuate environmental damage, desalination is expanding rapidly (Shannon et al. 2008). A range of desalination processes are used worldwide, and the most common is reverse osmosis (Fritzmann et al. 2007). In reverse osmosis, water is forced through a membrane against an osmotic gradient by applied pressure. Salts become concentrated in a waste brine solution, which must be disposed of. In the 21,000 desalination plants in use today, almost 50% use seawater to produce fresh water and the rest use brackish water. Desalination plants currently operate in more than 120 countries. Technical improvements have enabled the cost to decrease substantially over the past three decades; the cost to desalinate 1 m^3 of seawater can now be US$1.00 or less (Yermiyahu et al. 2007). A large part of the cost, however, is due to energy consumption and can thus be highly volatile (Andrianne and Alardin 2002). The combination of lower cost and an increasing need for fresh water has led to a dramatic increase in desalination worldwide; between 1994 and 2004, world desalination capacity increased from 6.3 to 13 km^3/year (Gleick 2006). However, desalination currently supplies <0.3% of global water needs and thus makes only a small contribution to global requirements.

Water storage and transport may also provide a solution to the spatial and temporal mismatches between water supply and demand. Water transport, however, requires major investment by society and, unless it is gravity driven, can be energy intensive. Furthermore, evaporative losses during transport and storage can be considerable. An alternative is water conservation and reuse, which can be very


July - September, 1989
October 5, 2008

Figure 4 NASA aerial photos of the Aral Sea in 1989 and 2008. The Aral Sea has been shrinking as a result of the damming of the Amu Darya and the Syr Darya, its two main water sources. The width of the map is approximately 250 km. Photos courtesy of NASA



Source: This collection of maps has been drawn after a series of satellite images provided by NASA Goddard Space Flight Center, available at:

http://www.gsfc.nasa.gov/gsfc/earth/environ/lakechad/chad.htm

FIGURE 5 Maps showing the extent of Lake Chad from 1963 to 2001. The shrinking of Lake Chad has been attributed in part to changing local weather patterns and increased local water demand (Coe and Foley 2001). The width of the maps is approximately 250 km.

effective in increasing local water availability, and these practises are increasingly used in arid and water-scarce regions.

A key issue in promoting these solutions is price. The economic valuation of water is hugely variable and seemingly at odds with its societal importance (Vaux 2011 this issue). Most municipalities around the world favour cheap water over investment and conservation. The 2008 combined water and waste-water treatment price for domestic users ranged from \$8.69/m^3 in Copenhagen (Denmark) to <\$0.01/m^3 in Dublin (Ireland), Havana (Cuba), and Riyadh (Saudi Arabia), where water is heavily subsidized (GWI 2008). Particularly notable is the fact that the price of water for agricultural use is, in many countries, only a small fraction of that of municipal water supply (FIG. 6). This discrepancy reflects many factors, the political influence of agricultural lobbies certainly being among them. The low price of water discourages improvements in use efficiency.

Is there really a water crisis? In a sense yes; our current water policy is unstable and unsustainable. Yet, in contrast to non-renewable resources such as petroleum, we will not run out of water. The solution to this global water crisis is improved management of this valuable resource. Past failures in the management of water supply and water resources have resulted in environmental damage, the disappearance or pollution of major surface water bodies, and human suffering. Globally, renewable surface water and groundwater resources are sufficient to meet both human and ecosystem needs. Many local and temporal deficiencies can be addressed by storage, transport, increased efficiency, reuse and technological innovations, such as desalination. The key is to optimise these resources and technologies so that we can provide everyone with water at an affordable cost. Society requires the insight of our scientific community to provide the improved technology, monitoring and resource assessment required for assuring the cost reduction and water quality essential for addressing the global water crisis. Like all crises, the sooner the scientific community works towards solutions, the less grave the consequences will be. With this issue of *Elements*, we hope to energize our community towards creating such solutions.

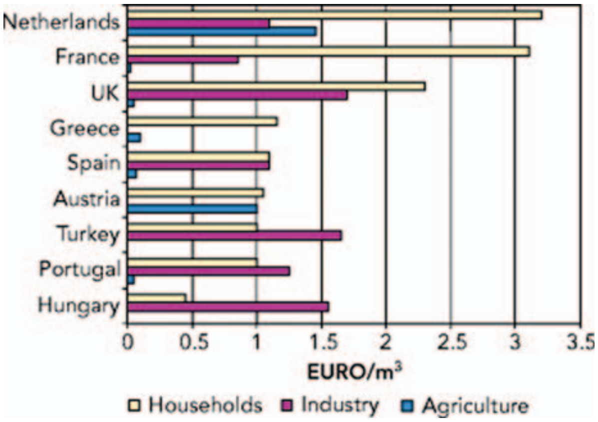


FIGURE 6 Water prices in selected countries during the late 1990s. SOURCE: WWW.EEA.EUROPA.EU/DATA-AND-MAPS/INDICATORS/WATER-PRICES

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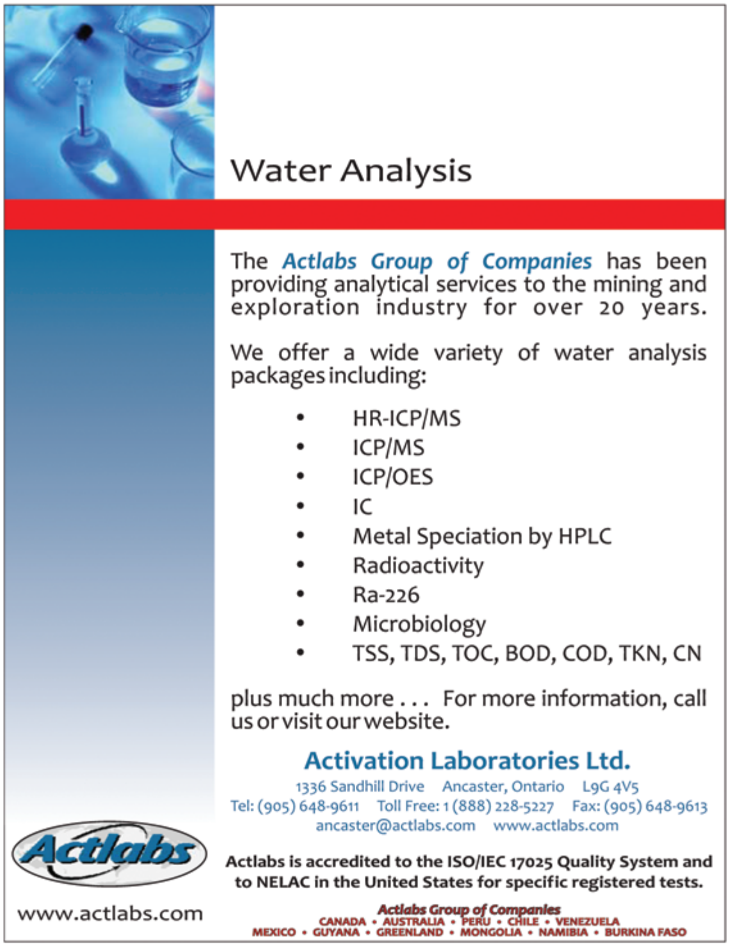

Water and Sanitation in Developing Countries: Geochemical Aspects of Quality and Treatment

Household water treatment for fluoride removal in Ethiopia

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Safe drinking water and basic sanitation are key elements of the Millennium Development Goals, a United Nations initiative. The microbial quality of drinking water is inherently linked to sanitation practices because fecal pathogens are the most common source of drinking water contamination in developing countries. Filtration of water through soil and aquifer sediments can provide natural protection against pathogens, and this makes groundwater an attractive option for safe drinking water supply. Groundwater quality may, however, be compromised by the leaching of natural chemical constituents from geologic materials. Conversely, geochemical processes provide the basis both for the removal of such contaminants and for the recovery of nutrients from wastewater through physicochemical treatment.

Keywords: Millennium Development Goals, arsenic, fluoride, sanitation, water treatment

SAFE DRINKING WATER: THE LINK TO SANITATION

Although diarrhea has become a rare and mainly inconvenient condition in developed countries, it remains a leading killer, especially of children, in other parts of the world. Each year 1.8 million children die before their fifth birthday because of diarrhea, nearly all in developing countries. Diarrhea kills more people than AIDS, tuberculosis, or malaria; it kills more children than all three combined. It is estimated that 88% of these deaths could be prevented by safe water supply, sanitation, and hygiene (Montgomery and Elimelech 2007; WHO 2008; Hunter et al. 2010).

The presence in drinking water of pathogens that cause diarrhea, cholera, and other diseases is nearly always caused by fecal contamination. Globally, 2.6 billion people use primitive sanitation (Fig. 1); open defecation is practiced by 1.1 billion people—more than 1 person in 5 in developing regions. Nearly 900 million people collect drinking water from vulnerable sources, such as rivers, ponds, and shallow open wells (Fig. 1). Almost half of the population of the world faces water scarcity, and problems of water quality and quantity are increasing (WHO/UNICEF 2010).

Although this situation seems dire, access to improved water sources (defined as those that are protected, by construction or intervention, from external contamination, particularly from fecal matter) and improved sanitation (defined by the hygienic separation of human excreta from human contact) has been steadily increasing (WHO/UNICEF 2010). Such improvements have been shown to decrease diarrheal disease significantly (Fewtrell et al. 2005). At the United Nations Millennium Summit in 2000, 187 countries made a commitment to achieve eight Millennium Development Goals (MDGs), including the target *"to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation."* Success in achieving this target is judged by the proportion of the population using an improved drinking water source and/or an improved sanitation facility. The world is on track to meet the target of 89% access to improved water sources: 1.8 billion people have gained access to improved sources since 1990. Progress in sanitation is slower. Even though 1.3 billion people have gained access since 1990, there is little chance of meeting the global sanitation target of 77% coverage by 2015 (WHO/UNICEF 2010).

Basic sanitation is particularly important because of the high pathogen loads that can be associated with feces (Feachem et al. 1983). Improper disposal of fecal matter results in the contamination of water resources, especially surface water. Throughout most of the world, ponds, lakes, and rivers have high fecal loads, and this causes diseases among people who must rely on these sources for their drinking water. Water collected from "improved sources" is not necessarily safe; moderate to heavy fecal contamination has been reported in dug wells, boreholes, and piped water systems (Moe et al. 1991; Godfrey et al. 2006). Even when water quality is good at the source, contamination before consumption can occur due to collection and transport in unclean storage containers and to contact with unclean hands and utensils (Wright et al. 2004). Good hygiene practices are thus a critical component of disease prevention.

Despite the human health hazards associated with feces, human excreta can also provide benefits. "Ecological sanitation" aims to recover nutrients, energy, and/or water for use in agriculture while preventing the spread of pathogens (Schönning and Stenström 2004).

CLOSING THE NUTRIENT CYCLE: PHOSPHORUS RECOVERY FROM HUMAN WASTE

Eutrophication (oversupply of nutrients resulting in excessive phytoplankton growth) and hypoxia (low dissolved-oxygen concentration) in inland and coastal waters are a result of excess loading of phosphorus associated with inadequate sewage treatment (Manning 2008). In addition, the phosphate in most commercial fertilizers is currently derived from mined, nonrenewable resources. Production

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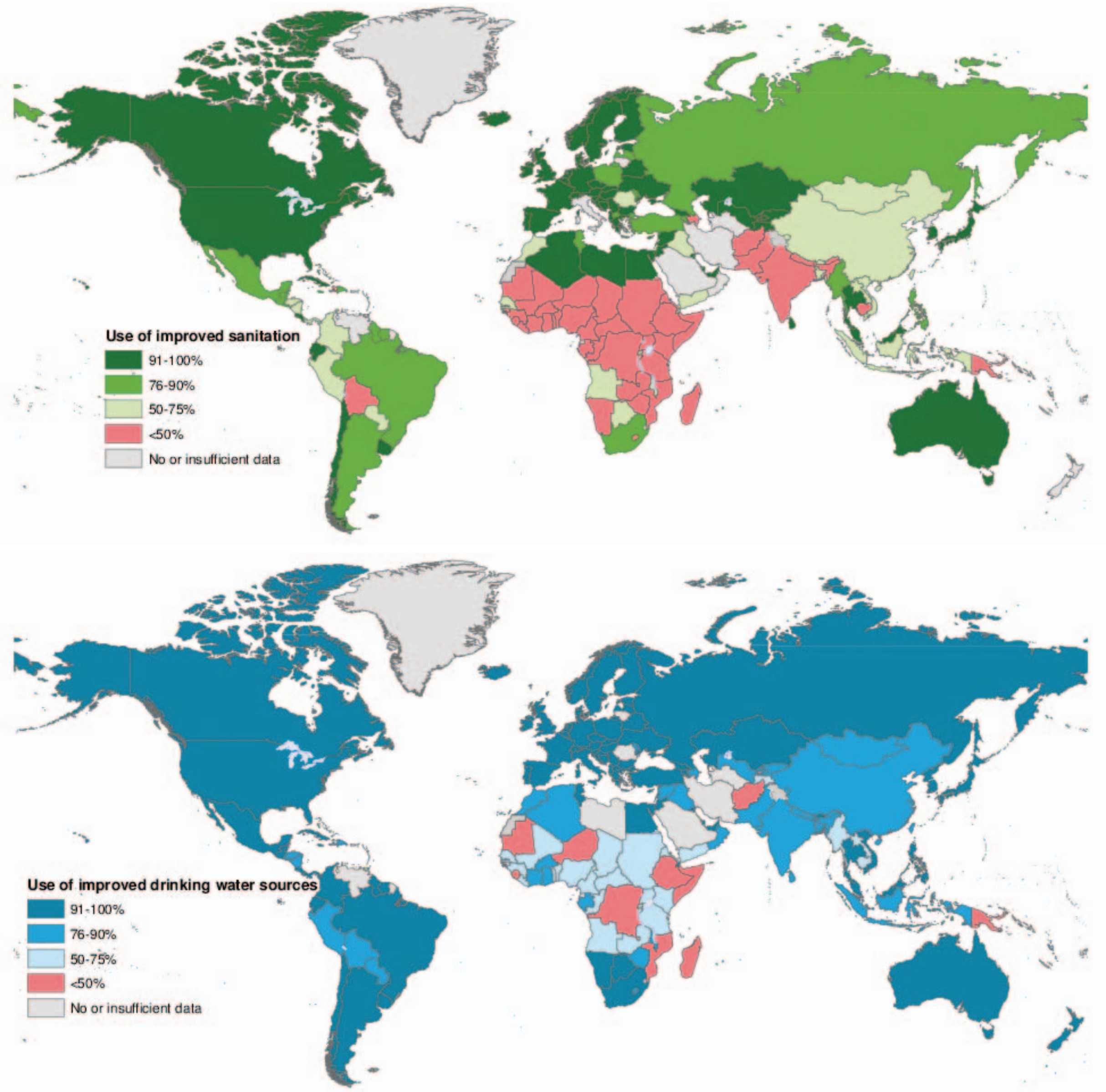

Figure 1 Worldwide use of improved sanitation (upper panel) and drinking water sources (lower panel) in 2008. See the text for definitions of improved sanitation and drinking water sources. Source: WHO/UNICEF 2010. Used with permission from WHO

of phosphate from these sources is expected to decline after 2030 (Cordell et al. 2009b), giving rise to a "peak phosphorus" phenomenon analogous to "peak oil." The possible consequences of this were foreshadowed in 2007–2008 when the price of fertilizer rose over 700% during a 14-month period. This provides a powerful incentive to recover phosphorus from crop residues, animal manure, and human excreta. A potential added benefit would be a reduction in harmful by-products of phosphate production, including radioactive phosphogypsum (Cordell et al. 2009a).

Urine is particularly rich in nutrients, as it contains high levels of phosphorus (740 mg/L), nitrogen (7700 mg/L), potassium (2200 mg/L), and sulfate (1500 mg/L) (Udert et al. 2003). The mineral struvite, $(NH_4)MgPO_4 \cdot 6H_2O$, has been recovered from wastewater in treatment plants in Japan and North America for some time (Parsons and Smith 2008). Arid and semiarid regions in developing countries, however, lack both the infrastructure and the water needed to operate such systems. Under these conditions, the precipitation of struvite from urine collected in urine-diverting toilets could produce fertilizer as a valuable product, thus promoting both food security and sanitation (Tilley et al. 2009b). Treatment can be performed at various scales (Fig. 2). Nutrients are recovered in a compact form that can be exported efficiently to agricultural areas. The concept of recovering value from excreta is not new, but current resource scarcity and economic incentives have made the concept worth revisiting, especially as a tool to help eradicate extreme poverty and hunger.

DRINKING WATER SUPPLY: THE RELATIVE ADVANTAGES OF SURFACE WATER AND GROUNDWATER

Drinking water supplies are provided by both surface water and groundwater, though in widely varying proportions. Globally, each source provides about 50% of drinking water needs, but in many countries groundwater is the principal drinking water source: approximately 70% in the European Community and nearly 100% in many developing regions (UNESCO/IHP 2004). In the United States, two-thirds of piped water (more in large cities) comes from surface water, but in rural areas, drinking water is frequently not obtained from public water suppliers and nearly all domestic self-supply is from groundwater (Kenny et al. 2009).

FIGURE 2 Pilot-scale installation in Nepal for the recovery of struvite from urine. Struvite was precipitated by the addition of bittern, a waste product from salt manufacturing, as a source of magnesium. After 10 minutes of mixing and 24 hours of settling, struvite was collected on a screen at the bottom of the reactor. SOURCE: TILLEY ET AL. 2009A; USED BY PERMISSION FROM EAWAG

Groundwater in rural settings is generally assumed to be protected from pathogens by natural filtration. This natural protection can, of course, be compromised by inadequate well completion or wellhead protection; inadequate filtration in, for example, karstic aquifer systems can also affect this protection (Macler and Merkle 2000). Despite these caveats, the benefit of protection from pathogens has been a major motivation in shifting drinking water sources from surface water to groundwater in developing countries.

The reliable availability of drinking water also varies geographically and seasonally and can be quite different for surface water and groundwater. Water table elevations can undergo substantial seasonal variations, and excessive pumping can draw the water table down below the level of shallow wells. Nonetheless, the availability of groundwater is often more reliable than that of surface water. Ephemeral streams are common in arid and semiarid areas, and surface waters can be diverted for irrigation or hydropower generation at the expense of downstream (and often transboundary) water supply.

The degradation of water resources is often obvious, even to casual visual inspection, in the case of surface waters. The degradation of groundwater resources is usually less apparent, making the assessment of actual or potential contamination a critically important activity (Zaporozec 2002). Groundwater contamination is often difficult or even impossible to reverse. Thus efforts must be made to protect groundwater from contamination related to, for example, the agricultural use of fertilizers and pesticides, mining and industrial activities, and improper disposal of solid waste and domestic wastewater.

Even in the absence of anthropogenic contamination, however, the quality of groundwater can be inadequate for its use as drinking water. Many groundwaters are brackish or saline. In such cases, taste alone precludes its use as drinking water without treatment. Naturally occurring substances in groundwater can, however, have serious adverse health impacts without any detectable taste or odor. These are generally inorganic substances derived from geologic materials and are referred to as geogenic contaminants. The two most important geogenic contaminants are arsenic (Ravenscroft et al. 2009) and fluoride (Fawell et al. 2006). Hundreds of millions of individuals are exposed to these geogenic contaminants at levels 10 to 100 times greater than drinking water standards. This exposure is associated with severe chronic health effects, including cancer (Hopenhayn 2006).

Geogenic Contaminants

The occurrence of geogenic contaminants in groundwater is related not only to the local and regional geology but also to the conditions that facilitate contaminant release from aquifer sediments. For example, elevated arsenic concentrations in groundwater are often associated with moderately reducing (i.e. iron-reducing) conditions, but arsenic can also be mobilized under oxidizing conditions at sufficiently high alkalinity (i.e. high-pH conditions) (Smedley and Kinniburgh 2002). Alterations in hydrologic conditions, specifically in recharge and extraction patterns, have also been implicated in the mobilization of arsenic (Neumann et al. 2010; Winkel et al. 2011).

Recent efforts at regional- and global-scale mapping have been successful in identifying parameters that can serve as reliable proxies for settings and conditions that favor mobilization of geogenic contaminants (Amini et al. 2008). In Sumatra, Southeast Asia, predictions of arsenic occurrence at concentrations above 10 µg/L based on regional geology and soil properties were verified by observations made in previously untested areas (FIG. 3) (Winkel et al. 2008).

The massive human exposure to arsenic in South and Southeast Asia highlights both the importance of geogenic contaminants and the need to exercise caution in exploiting new groundwater resources. Mapping and predictions can be useful tools in raising the awareness of potential threats but are obviously not substitutes for water-quality testing. The use of groundwater containing elevated concentrations of geogenic contaminants may, in some cases, be avoided by using other drinking water sources. Alternatively, appropriate water-treatment technologies may be used to produce drinking water that meets water-quality standards.

APPROPRIATE WATER-TREATMENT TECHNOLOGIES

In industrialized countries, surface water is routinely treated before distribution to the public, but the extent of groundwater treatment varies substantially. Limits to the natural protection afforded by groundwater supplies are reflected in the U.S. Ground Water Rule (GWR) (US EPA 2006). The GWR requires identification of groundwater sources that are vulnerable to fecal contamination and specifies corrective action for contaminated groundwater sources, which may include treatment (i.e. disinfection).

In developing countries, however, establishing effective drinking water treatment poses considerable challenges. In this context, the substitution of an alternative source of water is often viewed as a preferable option to treatment. As already mentioned, this strategy has been pursued in the massive shift from surface water to groundwater in many developing countries. More recently, a shift from shallow to deep wells has been both recommended and implemented as a measure to reduce exposure to arsenic-contaminated groundwater in Bangladesh (Ahmed et al. 2006).

A central issue in selecting treatment technologies in developing countries is that the infrastructure for water distribution is often inadequate or even nonexistent. This precludes the centralized model for water treatment that is most common in the urban and suburban areas of industrialized countries. The lack of water-distribution infrastructure has led to an emphasis on decentralized water treatment, even at the household level (Sobsey et al. 2008).

The household treatment of drinking water in developing countries for aesthetic purposes (e.g. turbidity removal) is not uncommon. In such cases, individuals are self-motivated to perform the treatment, and the lack of consistent performance has little consequence beyond aesthetics. The issue of consistent and effective treatment is both more consequential and more problematic when the intended outcome is a health benefit rather than an aesthetic improvement. For example, solar disinfection (SODIS) is a widely prac-

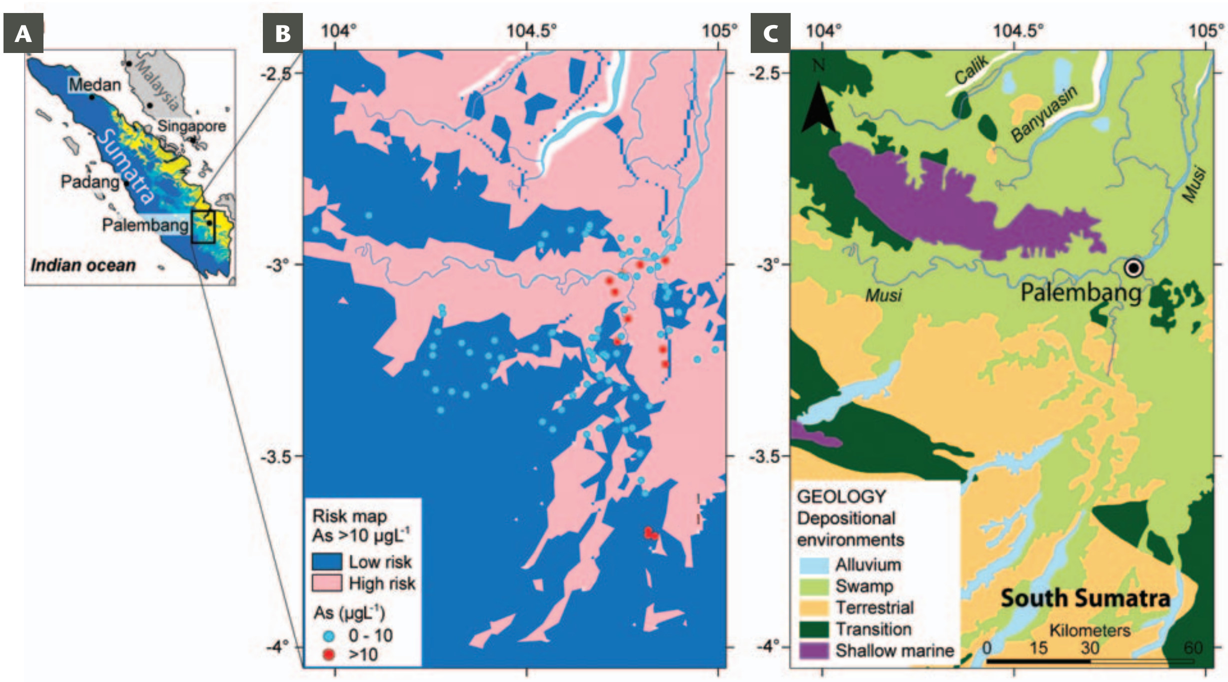

FIGURE 3 Map of Sumatra (**A**) and, for southern Sumatra, a map (**B**) showing areas where the risk of As occurrence at concentrations > 10 µg/L is high (probability > 0.4) or low (probability < 0.4) and measured As concentrations. These predictions and data can be compared with a geologic map (**C**). SOURCE: WINKEL ET AL. 2008, USED BY PERMISSION FROM THE NATURE PUBLISHING GROUP

ticed method of household water treatment in which transparent (usually plastic) bottles are filled with low-turbidity water and exposed to sunlight for six or more hours (www.sodis.ch). Despite the proven efficacy of pathogen inactivation by SODIS, the rates of both initial uptake and lapse from practice have been shown to be strongly influenced by the promotion methods. Consistent practice cannot be assumed but must be continually encouraged and carefully monitored (Moser and Mosler 2008).

Treatment Technologies for Geogenic Contaminants

In the case of geogenic contaminants, Vietnam provides a useful example in which a traditional practice adopted for its aesthetic benefits could also be effective in addressing the health risks posed by elevated arsenic concentrations in local groundwater. Rural households in Vietnam traditionally use sand filters to remove iron from groundwater because of its undesirable taste. An added benefit is efficient arsenic removal (average 80%) via the oxidation and adsorption of arsenic to iron phases that precipitate during filtration (FIG. 4). This process requires a sufficiently high iron concentration, is less effective in the presence of high levels of phosphate, and may not meet stringent drinking water standards in all cases. Nonetheless, sand filters have become a socially established technology with a proven record of decreasing arsenic exposure (Berg et al. 2006).

The challenges associated with establishing new practices for the removal of geogenic contaminants at the household level can be illustrated by the case of fluoride removal in Ethiopia. The problem of fluoride contamination in the Rift Valley is well known (Tekle-Haimanot et al. 2006). The deep and shallow wells used as drinking water sources in this region commonly have fluoride concentrations well above the World Health Organization (WHO) guideline value of 1.5 mg/L. This value is exceeded in over 41% of drinking water sources, and fluoride concentrations can be as high as 20 mg/L. Intake of moderate levels of fluoride causes dental discoloration and pitting, a condition affecting 80% of children in the Ethopian Rift Valley (Tekle-Haimanot et al. 2006). Higher exposures lead to crippling skeletal fluorosis, which is characterized by extreme bone deformation.

The mitigation of fluoride-contaminated groundwater used for drinking has recently become a priority issue for the Ethiopian government. Bone char has been identified as an inexpensive fluoride-removal filter medium, though saturation is commonly reached within a few months (FIG. 4). Filter life can be prolonged by the addition of soluble calcium phosphate salts, which promote the precipitation of hydroxylapatite and/or fluorapatite on the surface of the bone char (Jacobsen and Dahi 1997). This technology is acceptable to the local population but is not yet widely implemented. Among the issues that remain to be solved are the roles of government, the private sector, and nongovernmental organizations (NGOs) in the provision, monitoring, maintenance, and replacement of filters and filter media.

In general, issues that arise with household treatment include the reliability of performance, adequate maintenance and replacement of components, willingness and ability of households to pay for consumables, and appropriate disposal of residuals (e.g. spent filter material or solids collected from filter cleaning). Issues of operation and maintenance can be particularly challenging when there is no obvious signal of deteriorating performance (or even failure). Some of these issues may be more easily addressed at the community rather than the household level. Operation at the community level can achieve some economies of scale and can support some level of professionalization for operation and maintenance. One trade-off, however, is that shifting treatment away from the household means that the treated water must be transported from the site of treatment to the household; this burden traditionally falls to women and girls (FIG. 5). This investment of time (and the associated cost to the household) as well as other social factors that may influence patterns in water consumption have been found to be critical determinants in the use of deep wells in Bangladesh (Mosler et al. 2010). Although no treatment is involved in the use of deep wells, there is a decrease in convenience as compared with shallow wells located in an extended family compound.

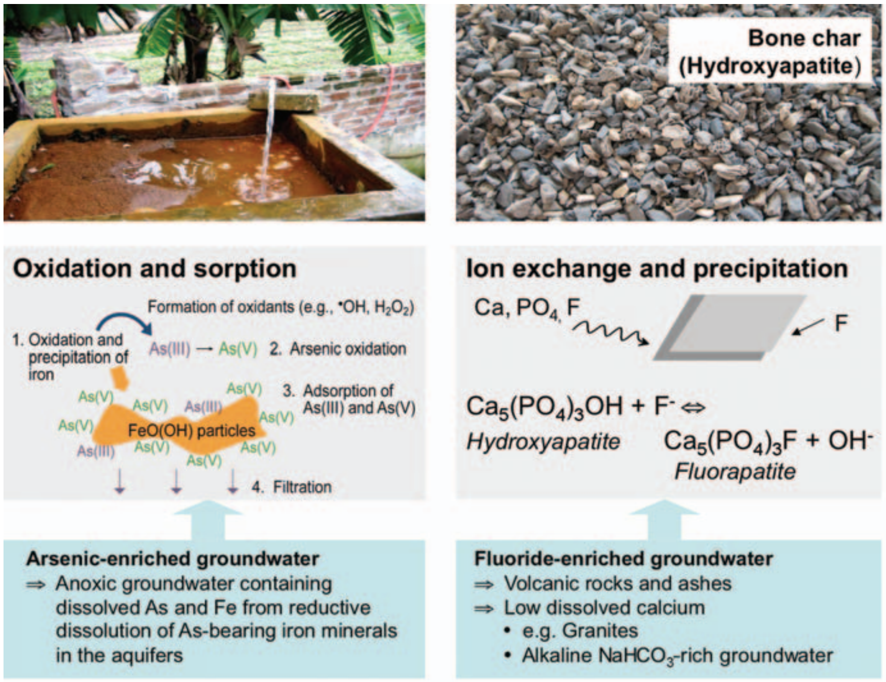

FIGURE 4 Comparison of treatments for the removal of arsenic (left) and fluoride (right). Arsenic is removed by sorption onto iron(III) oxyhydroxides formed by the oxidative precipitation of iron(II) that occurs naturally in reducing groundwater. Fluoride is removed by filtration through hydroxylapatite via a combination of ion exchange and precipitation processes.

FIGURE 5 Girls transport water treated for fluoride removal from a central facility to their homes. USED BY PERMISSION FROM EAWAG

ROLE OF THE PRIVATE SECTOR

Providing safe drinking water and basic sanitation is a complex task, which is complicated further by differences between dispersed rural communities and densely populated urban areas. Private water suppliers (vendors, tanker trucks, and bottled water) provide up to about 30% of the drinking water consumed in urban areas in Latin America (Gleick et al. 2002). Particularly in the late 1990s, large multinational companies began to enter the business of providing water and wastewater services at the municipal level in developing countries. This activity has been fraught with difficulties and has, in many cases, failed to realize the improvements in service and efficiency that were hoped for by the participating public authorities (Prasad 2007). This has led to a reevaluation of the potential for water-supply privatization, but it must be recognized that private-sector participation encompasses a number of different models that must be evaluated in specific contexts (WB 2006). It is important to note that the definition of "improved sources" currently excludes some provision by private water suppliers (e.g. tanker trucks) (WHO/UNICEF 2010). Ideally, the definition of improved water sources would be based on water quality, but monitoring water quality in developing countries poses major challenges.

Privatization in sanitation also plays a complex role in the service chain. Many households rely on private entrepreneurs to empty and transport the wastes from household pits and septic tanks. Although these entrepreneurs represent an important sector of the economy, they are commonly illegal, marginalized, and ostracized (Eales 2005). By failing to recognize the role of private entrepreneurs in sanitation, authorities waive their rights to control the subsequent disposal of collected sludge, a situation that endangers the health of the community. In dense urban slums where space does not permit household facilities, public toilets operated by NGOs or small businesses are common. Although not hugely profitable, they meet a serious need, provide local salaries, and may generate enough income to support spin-off activities. Water, nutrient, and energy harvesting at both the large and small scale has already proved lucrative for some entrepreneurs and is likely to become more attractive with increasing energy and fertilizer costs.

OUTLOOK

Providing safe drinking water and basic sanitation in developing countries is a complex task that demands engagement from many sectors. The MDGs are useful in that they give governments concrete targets to meet for both water and sanitation. The MDGs are, however, limited as they are based on pragmatic, operational definitions that, while amenable to monitoring, correspond only indirectly to the desired health outcomes. In addition, even if the targets are met, hundreds of millions of people will still lack access to safe drinking water and adequate sanitation. The expertise that geochemists can bring to this issue includes predicting the quality of groundwater and surface water, explaining the factors and processes that influence water quality, and assisting in the design and optimization of processes for water treatment and the recovery of nutrients from wastewater. Obviously this is only part of the solution, and providing safe water supply and adequate sanitation over the long term will also require that broader issues, such as community demand, local financing and cost recovery, and the operation and maintenance of technical systems, are addressed (Montgomery et al. 2009). Through collaboration with others, however, geochemists could make a valuable contribution to improving human welfare in this arena.

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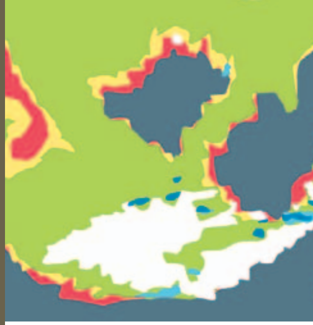

Hydrogeochemical Processes and Controls on Water Quality and Water Management

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The chemical constituents in water determine its potability, usability for agriculture and recreation, and interactions with biological systems. Anthropogenic processes have significantly influenced the geochemistry of water in many regions. Physical, chemical, and biological processes control the chemistry and chemical evolution of water in natural and contaminated systems. Advances in our ability to quantify these processes will improve our ability to manage our water resources, help us identify potential sources of contamination, and illuminate potential solutions to water-quality problems. Particularly impressive are the applications of chemical and isotopic tracers, which can track water movement and quantify water fluxes on the surface and in the subsurface. To better address societal needs, future advances will require a holistic approach to interpreting geochemical data.

Keywords: water resources, hydrogeochemistry, aqueous geochemistry, contaminants, isotopes, groundwater

INTRODUCTION

Hydrogeochemistry, a field combining hydrology and mineral/rock chemistry, is at the heart of many water resource issues for three reasons. First, chemicals and isotopes dissolved in water are excellent tracers for quantifying Earth's water reservoirs and the fluxes across reservoirs in the hydrologic cycle, both globally and locally (Fig. 1). Second, chemical knowledge is essential for understanding water-quality problems; for example, the concentrations and speciation of chemicals in water directly affect its potability and usability for agriculture and recreation. The deterioration of water quality can be either natural (geogenic) or human induced (anthropogenic). Third, possible modifications of hydrogeochemical processes that affect water quality are a key element in strategies for addressing future global warming and energy challenges.

One aspect of hydrogeochemistry concerns *water quantity and fluxes*. Hydrogeochemical data on water resources and fluxes are essential for sustainable management and for meeting human needs (see Table 1 in Oelkers et al. 2011 this issue, for water distribution in Earth's various reservoirs). Historically, studies of stable H and O isotopes have played a pivotal role in understanding the hydrologic cycle (Gat 1996). Ninety-eight percent of Earth's accessible freshwater reserves lie underground (as groundwater), but determining how much water can be "safely" extracted is challenging and controversial (Schwartz and Ibaraki 2011 this issue).

Geochemical tracers—such as Cl, the isotopes ^{14}C, ^{3}H, ^{36}Cl, ^{4}He, and ^{81}Kr, and the noble gases—have been used to estimate aquifer recharge rates and to determine groundwater ages (e.g. Phillips and Castro 2004). Trace gases and exotic isotopes have also allowed hydrogeochemists to use old water stored in aquifers as archives of paleoenvironmental information (Siegel 1991; Edmunds 2001). In recent years, we have recognized that submarine groundwater discharges into coastal oceans (Fig. 1), contributing 5–10% of freshwater inflows to oceans, as well as being a significant source of nutrients and pollutants for coastal ecosystems. These effusive fluxes to oceans are difficult to quantify with physical measurements, but geochemical tracers, such as the U/Th series radionuclides, prove to be effective tools (Swarzenski 2007).

Water quality refers generally to various chemical, physical, and biological characteristics. The required "quality" of water depends greatly on the purpose for which it is intended (e.g. drinking, swimming, or fishing), but it is mostly linked to drinking water standards (see Box 1). The connection between geochemistry and water quality is direct and obvious. The most important supplies of potable freshwater occur in the shallow subsurface. Accordingly, the geochemical processes that control the chemistry of freshwater bodies are closely coupled to microbiologic activities, climate forcing, atmospheric inputs, and physical transport processes.

The influence and importance of water quality on society are illustrated by the acute human health problems related to arsenic contamination of shallow wells in Bangladesh and southern India (Charlet and Polya 2006; Polya and Charlet 2009). High arsenic concentrations occur naturally in the sediments of the Ganges Delta, where arsenic compounds are adsorbed onto iron oxyhydroxide and

Box 1 EXAMPLES OF MAXIMUM CONTAMINANT LEVELS ALLOWED IN DRINKING WATER (MG L^{-1})

Chemicals	EU	WHO	USA	Primary Sources
arsenic	0.01	0.01	0.01	natural and industrial pollution
lead	0.01	0.01	0.015	plumbing, paints, fuels
nitrate	50	50	10 as N	agriculture
PCBs			0.0005	industrial products and wastes
Solids TDS*			500	natural

EU: European Union; WHO: World Health Organization; USA: US Environmental Protection Agency. * Secondary drinking water standard for total dissolved solids (TDS)

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sulfide minerals. Anthropogenic processes have led to the mobilization of the arsenic into shallow groundwater. Ninety percent of the local population use groundwater for drinking. As a result, about 21 million people are currently exposed to arsenic contamination and could suffer adverse health effects.

BIOGEOCHEMICAL PROCESSES AND FRESHWATER CHEMISTRY

The abundance and temporal-spatial distributions of chemicals and isotopes in freshwater are a result of the various hydrogeochemical processes occurring in the hydrologic cycle (Fig. 1).

Atmospheric Mass Inputs

Rainwater is chemically altered as it falls through the atmosphere. Rainwater dissolves and incorporates sea salt aerosols as well as sulfate, ammonium, and nitrate from natural and human sources such as power plants, automobile exhaust, smelters, and agriculture. Rainwater also equilibrates with atmospheric CO_2, which has a partial pressure of $10^{-3.4}$ bar, giving unpolluted rainwater a pH of around 5–6. This water can also be chemically altered as it reacts with dry particulate aerosols on the ground accumulated between precipitation events.

Processes at the Earth's Surface and in the Recharge Zone

The chemistry of most surface water and shallow groundwater is the result of water–rock–gas interactions. Water evaporation concentrates solutes and may lead to the crystallization of minerals such as calcite and gypsum. The combination of evaporation and mineral precipitation can lead to high Na^+, Cl^-, and/or SO_4^{2-} concentrations. Soil gases commonly have partial CO_2 pressures of $10^{-2.5}$ to $10^{-1.5}$ bar because of root respiration and organic matter decay. Water percolation through organic-rich soil can, therefore, further lower pH, leading to mineral dissolution. Weathering reactions in the soil zone include the dissolution of unstable silicates, ion exchange reactions, and clay mineral precipitation. Carbonate and sulfate mineral dissolution/precipitation and ion exchange reactions are fast, and water commonly establishes equilibrium with these minerals and mineral surfaces. In contrast, silicate mineral dissolution in nature is controlled by slow kinetics, and the precipitation of secondary clay minerals is an even more sluggish process.

Table 1 COMMON RANGES OF SOLUTE CONCENTRATIONS IN UNPOLLUTED FRESHWATER§

Element	Range (mmol L^{-1})	Sources
Na^+	0.1–2	Feldspar, rock salt, atmosphere, cation exchange
K^+	0.01–0.2	Feldspar, mica
Mg^{2+}	0.05–2	Dolomite, serpentine, pyroxene, amphibole, olivine, mica
Ca^{2+}	0.05–5	Carbonate, gypsum, feldspar, pyroxene, amphibole
Cl^-	0.05–2	Rock salt, atmosphere
HCO_3^-	0–5	Carbonates, atmosphere
SO_4^{2-}	0.01–5	Atmosphere, gypsum, sulfide
NO_3^-	0.001–0.2	Atmosphere, organic matter
H_4SiO_4	0.02–1	Silicates

§ After Appelo and Postma (2005)

These processes control the chemistry of potable surface water and shallow groundwater, which leads to waters commonly containing Ca^{2+}, Na^+, Mg^{2+}, K^+, HCO_3^-, Cl^-, SO_4^{2-}, and H_4SiO_4 as the major solutes. Table 1 summarizes common concentration ranges and sources of these constituents.

Redox Processes

Redox (oxidation and reduction) processes exert significant controls on freshwater chemistry, especially on the major elements O, C, S, N, and Fe and on trace contaminants such as U and As. Redox reactions involve electron transfer and result in valence changes. Globally, the driver of almost all redox reactions near the Earth's surface is photosynthesis. With few exceptions, the ultimate oxidant is O_2 and the ultimate reductant is organic matter. The redox condition of a hydrologic system is thus commonly determined by the supply of organic matter on the one hand and the supply of O_2 and other electron acceptors, such as sulfate and ferric iron, on the other.

The redox reaction sequence is determined by the relative Eh (oxidation potential) values of the redox reactions; an example of a reaction sequence is given in Table 2. When organic matter is added to a closed aqueous system, O_2 reduction occurs first, followed by NO_3^- reduction, and then, in order, MnO_2, $Fe(OH)_3$, and SO_4^{2-} reduction. Such a sequence can be monitored by the disappearance of O_2, NO_3^-, and SO_4^{2-}, and by an increase in NO_2^-, $N_2(g)$, Mn^{2+},

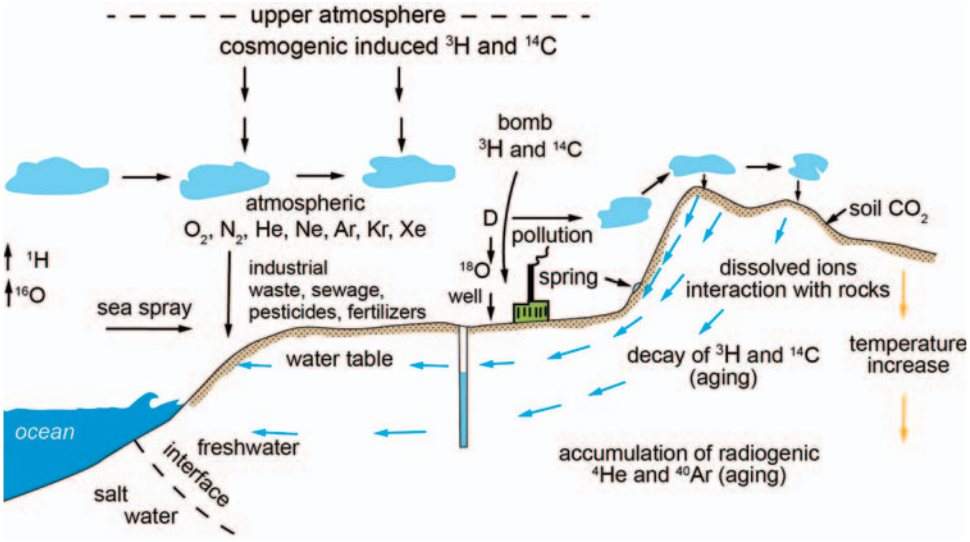


Figure 1 Mass sources and chemical processes in the hydrologic cycle. From left to right, ocean water evaporates and the moisture is enriched with ^1H and ^{16}O. Atmospheric water dissolves cosmogenic ^{14}C, ^{36}Cl, and ^3H, equilibrates with O_2, N_2, CO_2, and noble gases, and dissolves sea salts and industrial pollutants. Water condenses and precipitates, producing rain and snow enriched in ^2H and ^{18}O. Once on the ground, rainwater dissolves dry-deposit aerosols. As water enters the soil, it dissolves CO_2 from organic matter decay, and the acidified water dissolves carbonates and weathers silicate minerals. Underground and isolated from the atmosphere, ^{14}C and ^3H decay with time, permitting estimates of groundwater ages. Fresh groundwater in the coastal area interacts with salt water. Large withdrawals of freshwater from the subsurface can cause encroachment of salt water from the ocean. After Mazor (1991), reprinted with permission from Dekker

Table 2 SEQUENCE OF REDOX PROCESSES, OR REDOX LADDER, AT PH 7 AND 25 °C IN A NATURAL SYSTEM§

Reactions	Eh (V)	Assumptions
$O_2(g) + 4H^+ + 4e^- = 2H_2O$	0.816	$Po_2 = 0.2$ bar
$NO_3^- + 6H^+ + 5e^- = ½ N_2(g) + 3H_2O$	0.713	$[NO_3^-] = 10^{-3}$ M, $P_{N2} = 0.8$ bar
MnO_2 (pyrolusite) $+ 4H^+ + 2e^- = Mn^{2+} + 2H_2O$	0.544	$[Mn^{2+}] = 10^{-4.74}$ M
$NO_3^- + 2H^+ + 6e^- = NO_2^- + H_2O$	0.431	$[NO_3^-] = [NO_2^-]$
$NO_2^- + 8H^+ + 6e^- = NH_4^+ + 2H_2O$	0.340	$[NO_2^-] = [NH_4^+]$
$Fe(OH)_3 + 3H^+ + e^- = Fe^{2+} + 3H_2O$	0.014	$[Fe^{2+}] = 10^{-4.75}$ M
$SO_4^{2-} + 10H^+ + 8e^- = H_2S(aq) + 4H_2O$	-0.217	$[SO_4^{2-}] = [H_2S]$
$HCO_3^- + 9H^+ + 8e^- = CH_4(aq) + 3H_2O$	-0.260	$[HCO_3^-] = [CH_4]$

§ After Langmuir (1997)

e^- = electrons; Eh is in volts (V); square brackets = molar (M) concentration; P = partial pressure

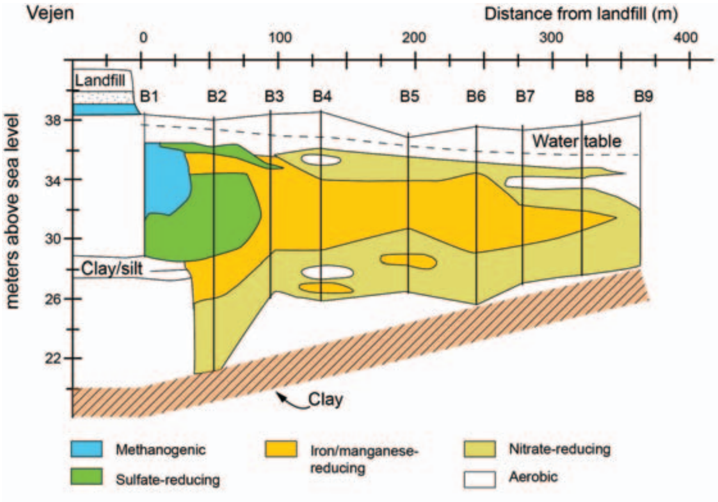


Figure 2 Redox zones characterized by water chemistry were developed in a sandy aquifer contaminated by organic contaminants leaking from the Vejen Landfill in Denmark (upper left). Groundwater flows from left to right, and the zonation is complicated by the distribution of NO_3^- and SO_4^{2-} in the mobile phase (water) and Fe and Mn oxyhydroxides in the immobile phases (aquifer matrix). B1 to B9 denote boreholes. After Lyngkilde and Christensen (1992), reprinted with permission from Elsevier

Fe^{2+}, H_2S, and CH_4 in water. This sequence has been observed in vertical profiles of eutrophic lakes, marine sediments, and aquifers, although it generally does not manifest itself in idealized or complete form. Redox zonation corresponds to successive dominance of different microbes that use different metabolic pathways according to the decreasing energy available from the reduction reaction (Chapelle 2000). In aquifers, redox zones can develop over hundreds of meters to several kilometers, as waters evolve along flow systems. Groundwater impacted by organic contaminants can also exhibit zonation. Figure 2 shows redox zoning developed from the leakage of landfill leachate into an aquifer; the zones are delineated based on the redox characteristics of the water. Generally, complete separation of zonation is not observed in groundwater, and various redox couples, as well as their respective microbial groups, may overlap.

Redox reactions affect water quality in many ways. For example, microbially mediated oxidation of pyrite and other sulfide minerals produces acid mine drainage, which has contaminated thousands of mountain streams around the world. The mobility of trace contaminants can depend on their redox state, as is the case for uranium. Hexavalent uranium (UO_2^{2+}) is mobile, particularly when complexed with bicarbonate. The reduction of U^{6+} to U^{4+} typically results in the precipitation of uraninite (UO_2), which immobilizes the uranium. This chemical reaction has been exploited in the bioremediation of uranium-contaminated groundwater. For example, in Oak Ridge, Tennessee, USA, where groundwater was contaminated by the disposal of uranium and nitrate wastes resulting from weapons production, the injection of nutrients (organic compounds) into aquifers stimulates microbial activity, which sequentially reduces O_2, NO_3^-, Fe^{3+}, SO_4^{2-}, and UO_2^{2+} (Istok et al. 2010).

Adsorption Processes

Adsorption to mineral surfaces, rather than mineral solubility, is the process that generally controls the concentration of most contaminants (e.g. F^-, As^{3+}, As^{5+}, Pb^{2+}, and UO_2^{2+}) that are present at the parts per million to parts per billion level in aquifers, soils, and sediments. Porous media in the subsurface have large mineral surface areas. Fe and Mn oxyhydroxides commonly play a major role in element adsorption; although they constitute a minor fraction of the bulk rock, soil, or sediment, their large surface areas and high reactivities make them efficient scavengers of trace metals and radionuclides. The fate and cycling of trace elements are, therefore, closely tied to the redox cycles of Fe and Mn. For example, arsenic release from iron mineral surfaces to groundwater in Bangladesh is thought to result from microbial reduction of iron minerals and subsequent desorption of arsenic (Neumann et al. 2010). Much progress has been made in understanding adsorption processes. Fe and Mn oxyhydroxides and many other minerals have charged surfaces in aqueous solution, and their surfaces are neutralized when ions such as H^+ and metals are adsorbed. The adsorption of cations can be regarded as a competition between cations and H^+ for surface sites (Drever 1997). At low pH, cation adsorption is minimal (Fig. 3a). As the pH rises, there is a relatively

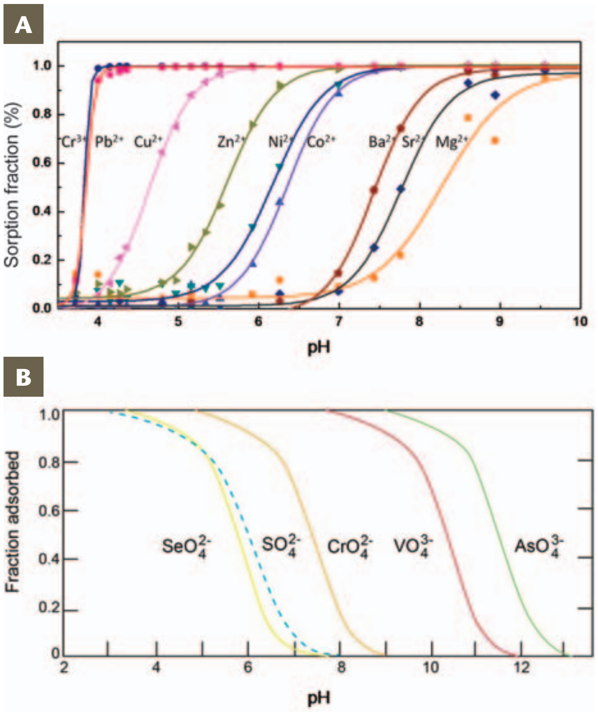


Figure 3 Adsorption of (**A**) metals and (**B**) anions onto the surface of ferrihydrite as a function of pH (the "sorption edges"). Metal sorption experiments were performed at ambient conditions, with 10 mmol L^{-1} $Fe(NO_3)_3$ in 10 mmol L^{-1} KNO_3 background solution, and metal concentrations of 1 ppm (Zhu et al. unpublished data). Anion edges in B are schematic. The exact locations of the edges will shift with different adsorbate/ferrihydrite ratios and background electrolyte solutions.

narrow pH range over which adsorption changes from near zero to essentially complete (Fig. 3a). These "adsorption edges" vary for different metals and shift according to different sorbate/sorbent ratios and background electrolyte concentrations. Anions compete with OH^- for adsorption sites, so their pH dependence is the opposite of cation adsorption (Fig. 3b). Anion adsorption is often complicated by changes in the speciation of the adsorbing element as pH changes.

Adsorption processes can explain why different metals have different mobilities in the environment, as shown in the Nickel Rim mine tailings site example, described in more detail below. However, modeling surface adsorption and trace element mobility in natural systems is a complex problem. The distribution of the adsorbents (Fe and Mn oxyhydroxides, organic matter, clays) in geological systems is spatially heterogeneous, and the Fe and Mn oxyhydroxides in the environment more often than not have different properties from those of the phases used in laboratory experiments. Reduction of Mn and Fe oxyhydroxides generally results in the release of adsorbed elements into water, as described above.

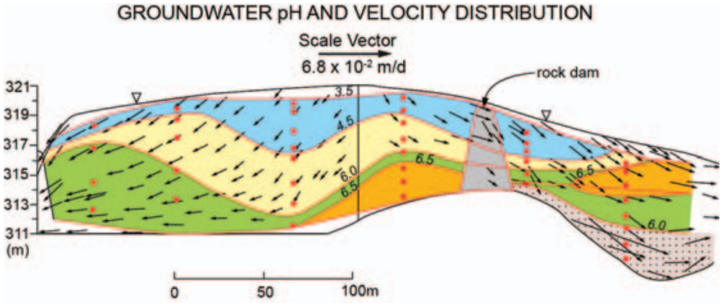


Figure 4 Distributions of pore water pH and simulated groundwater flow directions and velocities (shown by the oriented arrows of variable length) in a profile through the Nickel Rim mine tailings impoundment near Sudbury, Ontario, Canada. The red dots denote locations of pore water samples. The red lines show pH contours with pH values labeled above. The colored zones indicate zones of pH values controlled by successive buffer reactions (see Box 2). White: Fe oxyhydroxide, pH <3.5; blue: Al oxyhydroxide, pH 3.5–4.5; yellow and green: siderite and calcite, pH 4.5–6.0/6.5; and orange: calcite, pH > 6.5. Note that the vertical and horizontal scales are different. After Johnson et al. (2000), reprinted with permission from Elsevier

ANTHROPOGENIC INFLUENCES ON WATER QUALITY

Point-Source Contamination: The Nickel Rim Mine Tailings Impoundment, Sudbury, Canada

Inappropriate disposal of hazardous materials can lead to groundwater and surface water contamination. When originating from a single, well-defined source, such a contamination is referred to as a "point-source" contamination. The groundwater contamination from the Nickel Rim Ni–Cu mine tailings site near Sudbury, Canada (Johnson et al. 2000) is illustrative of thousands of point-source problems throughout the world.

The oxidation of sulfide minerals, principally pyrrhotite, has generated acidic waters with pH values as low as 2.1 and high concentrations of Fe (up to 9800 mg L^{-1}), SO_4^{2-} (24,000 mg L^{-1}), Al (1130 mg L^{-1}), Ni (688 mg L^{-1}), and other dissolved constituents (Johnson et al. 2000). Groundwater flow through the tailings is mainly horizontal, with velocities of 4–8 m y^{-1} (Fig. 4). As the acidic water flows, its chemistry evolves remarkably within a short distance. Distinct pH zones with values of around 3.0, 4.1, 5.6, and 6.7 are developed as the acidic water reacts with calcite and aluminosilicates in the tailings and is buffered by reactions with iron oxyhydroxides, aluminum hydroxide, siderite, and calcite, respectively (Fig. 4; see Box 2).

Box 2 REACTIONS AND PROCESSES AT THE NICKEL RIM TAILINGS IMPOUNDMENT

Microbially mediated oxidation of sulfide:

$Fe_{(1-x)}S$ (pyrrhotite) $+ (2-0.5x)O_2 + xH_2O \rightarrow (1-x)Fe^{2+} + 2xH^+ + SO_4^{2-}$

or

$Fe_{(1-x)}S + ½O_2 + 2H^+ \rightarrow (1-x)Fe^{2+} + S^o + H_2O$

$S^o + 3/2O_2 + H_2O \rightarrow 2H^+ + SO_4^{2-}$

Successive buffer reactions due to dissolution of carbonates:

pH ≈ 3: $Fe(OH)_3$ (ferrihydrite) $+ 3H^+ = Fe^{3+} + 3H_2O$

pH ≈ 4.1: $Al(OH)_3$ (gibbsite) $+ 3H^+ = Al^{3+} + 3H_2O$

pH ≈ 5.6: $FeCO_3$ (siderite) $+ H^+ = Fe^{2+} + HCO_3^-$

pH ≈ 6.7: $CaCO_3$ (calcite) $+ H^+ = Ca^{2+} + HCO_3^-$

Other chemical reactions:

Weathering of biotite, pyroxene, amphibole, and plagioclase in acidic water

Jarosite precipitation and decomposition

Gypsum precipitation

Concentrations of dissolved metals, such as Ni, Cr, and Co, are attenuated by coprecipitation with and adsorption onto Fe and Al hydroxides. Jarosite [e.g. $KFe_3(SO_4)_2(OH)_2$] and gypsum also precipitate, and their accumulation, together with iron oxyhydroxides in the oxidation zone, forms "hardpan" that cements the tailings.

This case illustrates the link between hydrogeochemistry and traditional mineralogy, petrology, and geochemistry: understanding the overall processes requires careful mineralogical characterization of the system and the buffer reactions that occur (see Zhu and Anderson 2002).

Worldwide, there are thousands of sites contaminated by mining wastes and mine tailings. While decommissioning and remediation have been going on for decades in developed countries, remediation of such sites in developing countries and emerging economies is just starting or has not yet begun. The recent disaster resulting from the breach of a bauxite residue impoundment in Hungary, which allowed 200 million gallons of sludge to flow through waterways and into the Danube River, is a harsh reminder of the potential magnitude of these problems (Bakhshi 2011). The incident caused 9 deaths and injuries to 122 people. The sludge had a pH of 13 and extinguished most life in local rivers.

Non-Point-Source Contamination of Lake Taihu, China

Contamination of groundwater and surface water can also originate from non–point sources. These problems are often directly related to the application of fertilizers and pesticides, urban runoff, or waste disposal in and around large cities (Johnston et al. 2011 this issue). Of particular concern are macronutrients (e.g. NO_3^- and PO_4^{3-}) and agrochemicals (e.g. herbicides and insecticides).

The problems resulting from non-point-source as well as point-source contamination can be illustrated using the example of Lake Taihu (Fig. 5a), the third-largest freshwater lake in China. The lake has an area of about 2340 km^2 and an average depth of about 1.9 m; some 40 million people live in the lake's 36,500 km^2 basin. The lake is the main source of drinking water for Wuxi and neighboring cities. The area contributes 14% of China's gross national product. In the summer of 2007, the two million residents of Wuxi found odorous water coming from their taps. Volatile sulfide chemicals, including methyl thiols, dimethyl sulfide, dimethyl disulfide, and dimethyl trisulfide, were the source of the odor. These contaminants originated from the decomposition of a massive cyanobacterial bloom caused by the eutrophication (SEE BOX 3) of Lake Taihu (Zhang et al. 2010).

The 2007 crisis at Lake Taihu illustrates how stresses associated with eutrophication can push an aquatic system beyond the tipping point, with severe consequences (see Prepas and Chartette 2005 for a discussion of eutrophication problems worldwide). The excessive loading (input) of nutrients to Lake Taihu comes from point sources such as untreated domestic sewage effluents and from non–point sources like the intensively fertilized agricultural lands around the lake and urban runoff. High nutrient input to the lake and warm temperatures created conditions promoting phytoplankton blooms (FIG. 5B). Nitrogen stable isotope studies show that riverine N inputs in winter are influenced by the discharge of human sewage into rivers and the lake (Townsend-Small et al. 2007). In spring, however, wastewater inputs to the lake are matched by fertilizers, atmospheric contributions, and/or N_2-fixation sources. During the rainy season, rainwater NO_3^- concentrations are high and isotopically enriched compared to other potential sources, indicating that rain may be a significant or even dominant source of N to the lake at that time of the year.

The International Lake Environment Committee, in cooperation with the United Nations Environment Program, undertook a survey of 217 lakes worldwide and found that 54% of lakes in Asia are eutrophic, compared to 41% in South America and 28% in Africa (Jørgensen 2001). The greatest water-quality problems are found in countries with large populations but scarce financial resources. The regulation of nutrients to protect drinking water supplies is urgently needed (see Johnston et al. 2011).

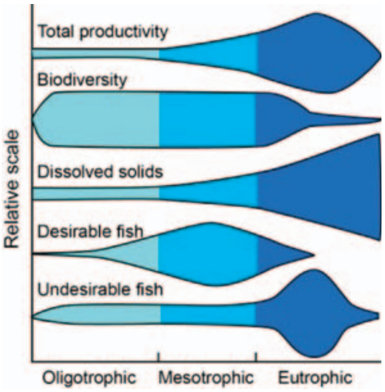
NEW OPPORTUNITIES AND CHALLENGES FOR HYDROGEOCHEMISTRY

Progress in hydrogeochemical research has produced major insights into both natural and anthropogenically impacted hydrologic systems. While we will not presume to predict where the next areas of innovation and discovery will be, we will mention a few areas presenting new opportunities and challenges.

Box 3 TROPHIC STATES OF LAKES AND RIVERS

Oligotrophic	waters with a low supply of nutrients and low organic production
Mesotrophic	waters with a moderate supply of nutrients and moderate organic production
Eutrophic	waters with a high supply of nutrients and hence a rich organic production

Changes of characteristics of lakes with various degrees of eutrophication:



Effects of Global Warming

Rising temperatures, the loss of glaciers and ice caps, the increasing scale and frequency of flood events, and rising sea levels due to global warming have important implications for water resources (IPCC 2007). For example, rising sea levels can increase saltwater intrusion into coastal aquifers (FIG. 1) and decrease the amount of freshwater available in coastal regions, where a large proportion of the world's population lives. Changes in precipitation, flow, and temperature can also significantly alter water chemistry in rivers, thereby affecting aquatic ecosystems. Increased temperature also affects in-lake chemical processes (IPCC 2007). Climate change will affect groundwater recharge rates and groundwater depth. However, as IPCC (2007) points out, knowledge of current groundwater conditions is poor, which hinders our ability to quantify the impact of climate change on groundwater resources.

Emerging Economies and Developing Countries

Knowledge in hydrogeochemistry has proven to be critical in the environmental remediation of contaminated waters in developed countries. However, these advances are only beginning to be exploited in emerging economies and developing countries. The case of Lake Taihu and the arsenic epidemic in Bangladesh and southern India, described above, illustrate the potential magnitude of water-quality problems. In China, remediation strategies for surface waters and groundwaters contaminated by mining and manufacturing activities are currently being contemplated. We can expect a future surge of research and remedial activities in countries like China, India,

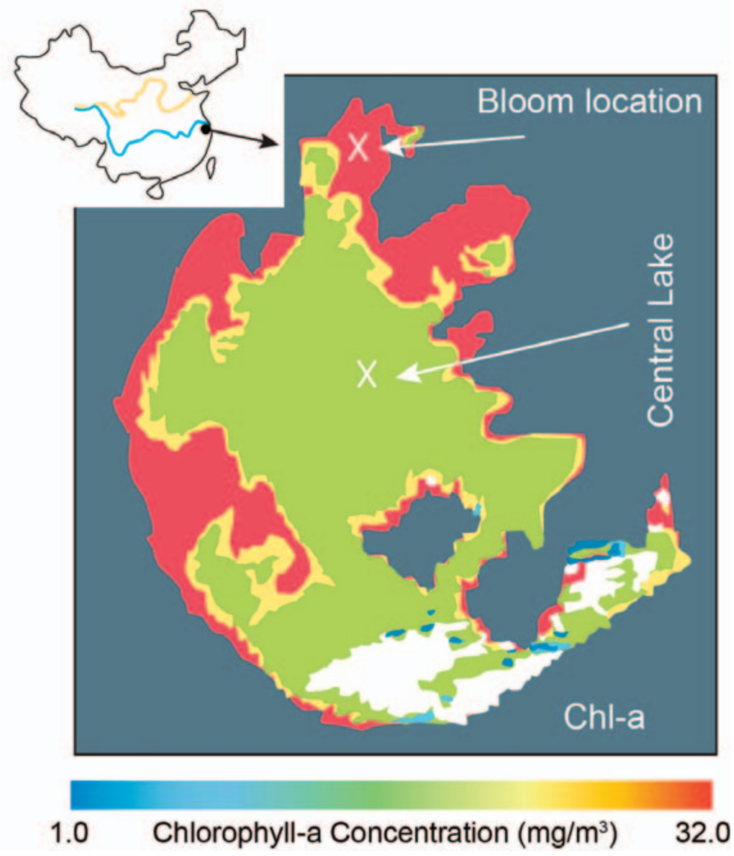


FIGURE 5 Lake Taihu is located in the Yangtze River delta in eastern China. The lake has experienced high nutrient loading from illegal industrial discharges, domestic waste water, aquaculture, and agriculture, especially from rivers to the north and west. Data from the moderate-resolution imaging spectrometer (MODIS) was useful in estimating chlorophyll-*a* concentrations, which are indicative of the extent of algal blooms. MODIFIED FROM WANG AND SHI 2008

Korea, South Africa, and Brazil. As "necessity is the mother of invention," we can expect more innovations and discoveries in addressing water-quality issues.

Future Anthropogenic Threats to Our Water Supply: Alternative Energy and Climate-Mitigation Strategies

Hydrogeochemistry is a critical aspect in society's search for "solutions" to energy- and water-resource problems. For example, storing excess surface water in the subsurface, a process known as *aquifer storage and recovery*, has emerged as an increasingly attractive water-management strategy for a warming climate (NRC 2008a). However, injected water can potentially react with the host rock and release toxic metals, such as As, Fe, Mn, U, and Ni, into the recharged (and eventually recovered) waters. First-generation biofuels will increase the use of fertilizers and pesticides, which could significantly increase non-point-source contamination of surface water and groundwater (NRC 2008b). Geological carbon sequestration is likely to become a key strategy to reduce carbon emissions by injecting CO_2 into deep subsurface geological formations (IPCC 2005). However, the buoyant CO_2 may escape via preferred pathways, such as unplugged or poorly sealed abandoned wells or fractures, and reach a shallow aquifer that is a source of drinking water. The dissolution of CO_2 into potable water decreases its pH and potentially liberates toxic metals (Little and Jackson 2010). Clearly, each of these factors can adversely affect water quality and supply; the consequences of each risk need to be considered before altering hydrogeochemical systems in order to help resolve other societal problems.

In short, to make hydrogeochemistry a truly useful tool for solving society's urgent water-resource challenges, a holistic approach to interpreting geochemical data must be taken. Being "holistic" means that we understand that the observed distribution of constituents and isotopes in water is the result of a complicated set of interrelated geochemical, physical, and biological processes and variable climate forcing. Significant advances and an expansion of the field are to be expected if we embrace the challenges of water management for a thirsty world.

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Groundwater: A Resource in Decline

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Around the world, groundwater sources are in decline due to overpumping and pollution. History informs us that as water supplies are lost so are civilizations. Such was the case with the Garamantian civilization, which thrived in the western Libya desert from 500 BCE to 400 CE, then disappeared when the groundwater ran out. Present-day mining of groundwater from large aquifers in the United States, North Africa, and China illustrates this problem. In less than a century, pressures from food production and population growth are leading to declines in supplies that appeared to many as inexhaustible. In many countries, there can be no replacement for declining water resources. Food scarcity and health epidemics, leading to societal decline, are likely outcomes as people chase dwindling water supplies.

Keywords: groundwater resources, aquifers, water shortages, Garmantian civilization, contamination

INTRODUCTION

Groundwater is an attractive and readily available source of freshwater. Not surprisingly, the rate of withdrawal of groundwater around the world has increased substantially, as technologies for high-capacity wells and broad distribution have developed. Now, groundwater is commonly mined from aquifers big and small at rates far in excess of natural replenishment. Moreover, increasing populations, with their associated agricultural and industrial activities, create sources of pollution that further limit supplies of water.

In her book *Last Oasis*, Sandra Postel describes a few "signs of trouble"—declining groundwater levels and dry rivers and lakes—as freshwater supplies reach their natural limits (Postel 1997). These signs are now more prevalent and foreshadow the decline of aquifers and their contribution to irrigated agriculture, the largest consumer of water. For most nations, running out of water through overuse and contamination has tremendous societal implications. As the next section discusses, the rise-and-fall of human civilizations is rich with examples of collapses when water shortages stressed societies with limited resiliency.

What will the future look like? Postel is optimistic that "*the 'last oasis' of conservation, efficiency, recycling, and reuse is large enough to get us through many of the shortages on the horizon*." We are not so sure. There is a continuing, hell-bent assault on groundwater, attempting to wring more water from this dwindling and degrading source. The societal adjustments required for sustainable groundwater use may ultimately only be achievable when shortages of water shock the social structure of some of the world's most populous countries.

WATER AND SOCIETY

Half the world's people now live in cities and are anchored to their water-supply systems. Los Angeles uses local groundwater but imports the bulk of its supply from surface waters in Owens Valley, the Sacramento-San Joaquin Delta, and the Colorado River, hundreds of kilometers away. Beijing, which has relied historically on local supplies, is now tapping the Yangtze River 1000 km to the south. In less than a century, societies have developed the technological tools needed to grow their cities seemingly without regard for natural limits on the availability of local water supplies. Readers interested in a detailed review and assessment of issues affecting water can refer to the report *The World's Water*, published every two years (e.g. Gleick 2008).

In the past, human behavior had to be much more flexible. Consider the human occupation of Saharan Africa over the past 10,000 years. This area was influenced by swings in climate as the East African Monsoon periodically shifted northward and turned desert lands into a savannah with small lakes and streams. As this formerly desert region became wetter between about 8500 BCE and 5300 BCE, humans migrated there from population centers along the Nile River (Kuper and Kröpelin 2006) and transitioned to a pastoral lifestyle with domesticated livestock. Drier conditions from 5300 BCE to 3500 BCE forced a retreat to highland refuges and back to the Nile River (Kuper and Kröpelin 2006). Without an ability to counter drier conditions, people adapted by moving to reliable supplies. The Garamantian civilization (500 BCE to 400 CE), located in the western part of modern-day Libya (Fig. 1), provides an instructive exception.

Ancestors of the Garamantians also relied on small lakes during the wetter times about 6000 years BCE. Rock art shows the transition to pastoral lifestyles (White and Mattingly 2006). As drying reduced surface-water supplies between 3000 and 1000 years BCE (Fig. 2), "It must have taken huge ingenuity to maintain their herds and lifestyles" (White and Mattingly 2006). Fortunately, the technology to use groundwater arrived just in time to replace dwindling surface waters. In the first millennium BCE, Persians created a tunnel-based system (called *qanats* or *foggaras* in Libya) to develop groundwater supplies from alluvial fans (Fig. 2).

The Garamantian civilization thrived for almost a millennium using *foggaras* to supply water. They transitioned to a rich agricultural society with eight major towns; an active

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system of trade, including slaves from sub-Saharan Africa; arts; and an organized political system (Keys 2004). A combination of military and political will provided the slaves necessary to build and maintain the *foggaras*. From about 100 BCE to 100 CE, about 750 km of tunnels and access shafts were constructed (Keys 2004). The Garamantian civilization overcame the climate shift that turned Saharan Africa back into desert. But in the end, the climate won out. Groundwater declined, and eventually it became impossible to deepen the tunnel systems. Water shortages led to food shortages, population decline, political instability, and the end of the Garamantian civilization (Keys 2004).

The history of the Garamantians provides an instructive lesson on what can happen when water runs out. Their technological prowess and economic power could not ultimately deal with the collapse of the groundwater supply.

WHY GROUNDWATER IS AN ATTRACTIVE SOURCE OF WATER

Within the hydrologic cycle, water occurs in key reservoirs and in fluxes between these reservoirs (Oelkers et al. 2011 this issue). Most freshwater globally resides in ice caps and glaciers ($26{,}350 \times 10^3$ km^3) and groundwater ($15{,}300 \times 10^3$ km^3) (Trenberth et al. 2007). Water storage in rivers and lakes is small, some two orders of magnitude less than groundwater volume. Moreover, a significant fraction of this water flows in isolated rivers (e.g. in South America and the Arctic) and as a practical matter is unavailable.

Groundwater is by far the most readily available water resource. Although surface water can be very important locally, it comes with limitations. For example, the availability of surface water can fluctuate markedly according to monsoon or snowmelt cycles. Constructed reservoirs can accommodate this seasonality, but often at the cost of large evaporative losses and expensive infrastructure. Surface waters are also vulnerable to cycles of drought. The naturally small storage of surface waters means that declines in precipitation quickly translate into reductions in streamflows. The huge volumes of water stored in aquifers together with slow rates of natural depletion make groundwater a much more resilient supply.

The quantities of water stored in major aquifer systems are impressively large. Figure 1 shows the High Plains Aquifer (HPA) of the central United States, the Nubian Sandstone Aquifer System (NSAS) of northeastern Africa, and the Quaternary Aquifer of North China (QANC). The HPA covers approximately 450,000 km^2 and has a mean thickness of about 60 m. The total amount of water stored in the HPA is about 4000 km^3, roughly equivalent to Lake Huron, the world's fifth-largest lake. The rate of current recharge, or natural replenishment of the HPA, is small: the present relatively large supply is related to higher precipitation associated with the last glaciation.

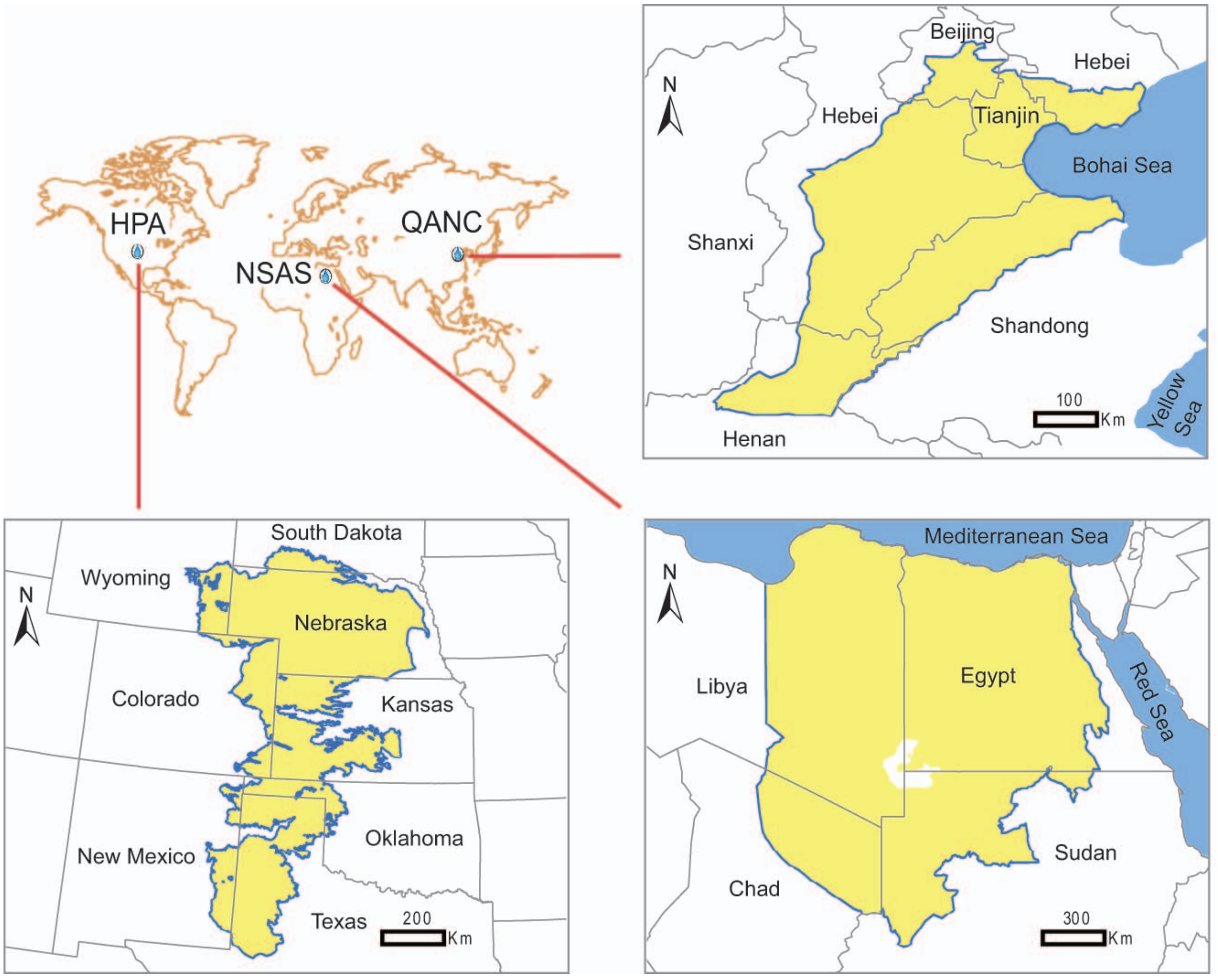

Figure 1 Three of the largest and most important aquifers in the world (shown in yellow): the High Plains Aquifer of the Midwestern United States (HPA), the Nubian Sandstone Aquifer System of northeastern Africa (NSAS), and the Quaternary Aquifer of North China (QANC)

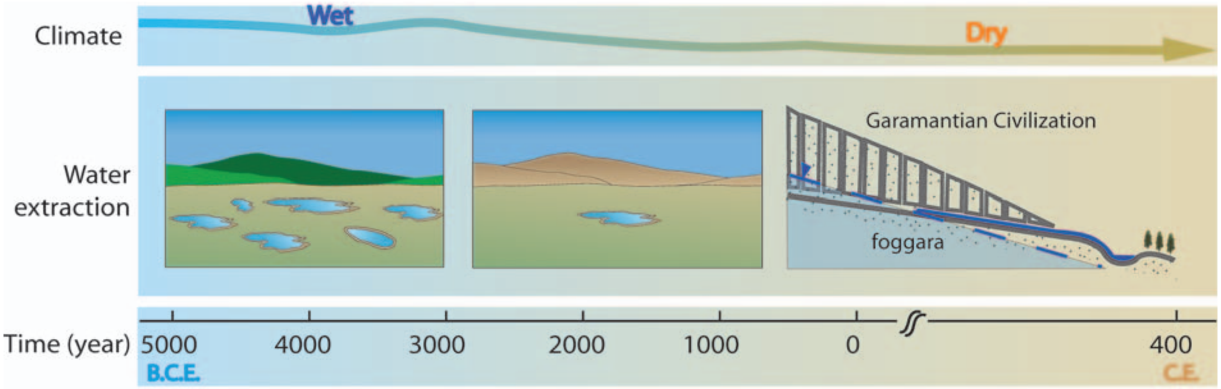

FIGURE 2 In Libya the climate shifted from wet to dry between about 3000 BCE and 1000 BCE. Small surface water bodies declined and had disappeared by about 1000 BCE. In spite of these dry conditions, the Garamantian civilization thrived for another thousand years through the construction of *foggaras*, which tapped groundwater sources (White and Mattingly 2006).

The NSAS has an areal extent of approximately 2.2 million km^2 across Egypt and parts of Libya, Chad, and Sudan (FIG. 1). The aquifer is comprised of sandstone beds, with minor siltstone and carbonates, and is 100 to 650 m thick. Estimates of the volume of stored water range between 150,000 and 375,000 km^3, with about 5–10% considered recoverable from more permeable units. Like the HPA, the water was recharged during wetter conditions several tens of thousands of years ago. Now, the region is arid with negligible recharge.

The QANC is comprised of a sequence of Quaternary piedmont, floodplain, and coastal sediments 350 to 500 m thick (FIG. 1). The aquifer extends over about 141,000 km^2 and likely contains about 15,000 km^3 of water. Although the region is dry, the aquifer is being replenished along the piedmont of the Taihang Mountains.

Aquifers have two important advantages compared to surface waters. First, flow systems provide natural distribution systems that move water from upland recharge areas to distant and often drier regions with small evaporative losses. For example, the NSAS moves water more than 1500 km across parts of Sudan and the western desert of Egypt. Second, the very large size of these kinds of aquifers makes them slow to lose their stored water if recharge declines. Water levels are adjusted by flow to discharge areas. In large aquifers, such adjustments can continue over thousands of years until a new equilibrium water level is established. The pattern of readjustment in water level is exponential, producing relatively rapid, early changes that slow down with time. A parameter called the time constant (τ) describes the pace of aquifer readjustment. For example, if the time constant is 1000 years, about 63% of any readjustment takes place over that time. Five τ (5000 years in the example) is required for about 99.3% of the total adjustment in water level.

The time constants for large aquifer systems are usually quite large. For example, Schwartz et al. (2010) found a τ value of 10,000 years for a large flow system at Yucca Mountain in Nevada (USA). By implication, then, aquifers like the HPA and NSAS, although currently without much recharge, can still contain appreciable water stored from glacial times when recharge was much higher.

GROUNDWATER VULNERABILITY

Humans have developed the capability to deplete groundwater orders of magnitude faster than natural discharge processes and at rates far exceeding natural replenishment. In the HPA and the QANC, irrigated agriculture is producing significant lowering in groundwater levels. The HPA has experienced water-level declines of >35 m in Kansas, Oklahoma, and the Texas Panhandle (Alley et al. 1999; FIG. 3), with withdrawals since 1950 of about 312 km^3. Water levels in the QANC are also declining at an unsustainable rate. Foster et al. (2004) show extensive areas with >40 m of decline (FIG. 3). There are hopes that massive south-to-north water diversions might arrest these declines, especially in the vicinity of Beijing.

Exploitation of the NSAS has been somewhat slower. This is now changing in Libya with the “Great Man-Made River Project,” which is expected to mine an estimated 2.4 km^3/y of groundwater from western and southern Libya and move it to the populous Mediterranean coast. This project, described by Muammar al-Gaddafi as the Eighth Wonder of the World, will involve more than 1300 wells and thousands of kilometers of pipeline. Advocates argue that sustainability will come from the resulting advanced knowhow and wealth, which are seen as steps toward more permanent solutions. Libya is one of the countries in the Middle East, through their oil and natural gas resources, that can “turn oil into water” by means of expensive, energy-intensive technologies like seawater desalination.

Intensive extraction of groundwater often creates unintended impacts on surface waters. The inherent coupling of groundwater and surface waters means that groundwater consumed for irrigation reduces the flow in streams that normally receive natural inflows of groundwater. Sophocleous (1998) showed that groundwater exploitation in Kansas produced a decline in perennial stream reaches. Large areas in northwestern China are being impacted by desertification as runoff from mountain areas is intercepted for irrigation, leading to a loss of surface flows and an increased reliance on groundwater (Ji et al. 2006). In the Heihe River basin, desert areas are expanding as surface waters are lost and riparian vegetation declines. Dust blowing from western China now spreads to Korea, Japan, the North Pacific Ocean, and occasionally North America (Ding and Li 2005).

Groundwater is also vulnerable to contamination, which often restricts its usability without expensive treatment. Modern agriculture is capable of contaminating shallow aquifers with fertilizer and pesticides. In the HPA, enhanced recharge in irrigated regions has mobilized natural Cl and NO_3^- from the unsaturated zone and transported trace quantities of pesticides into shallow groundwater (Gurdak et al. 2009). Similar contamination is evident in the QANC. In a 13,472 km^2 study area near the Bohai Sea, shallow groundwater is being impacted with increases in NO_3^-,

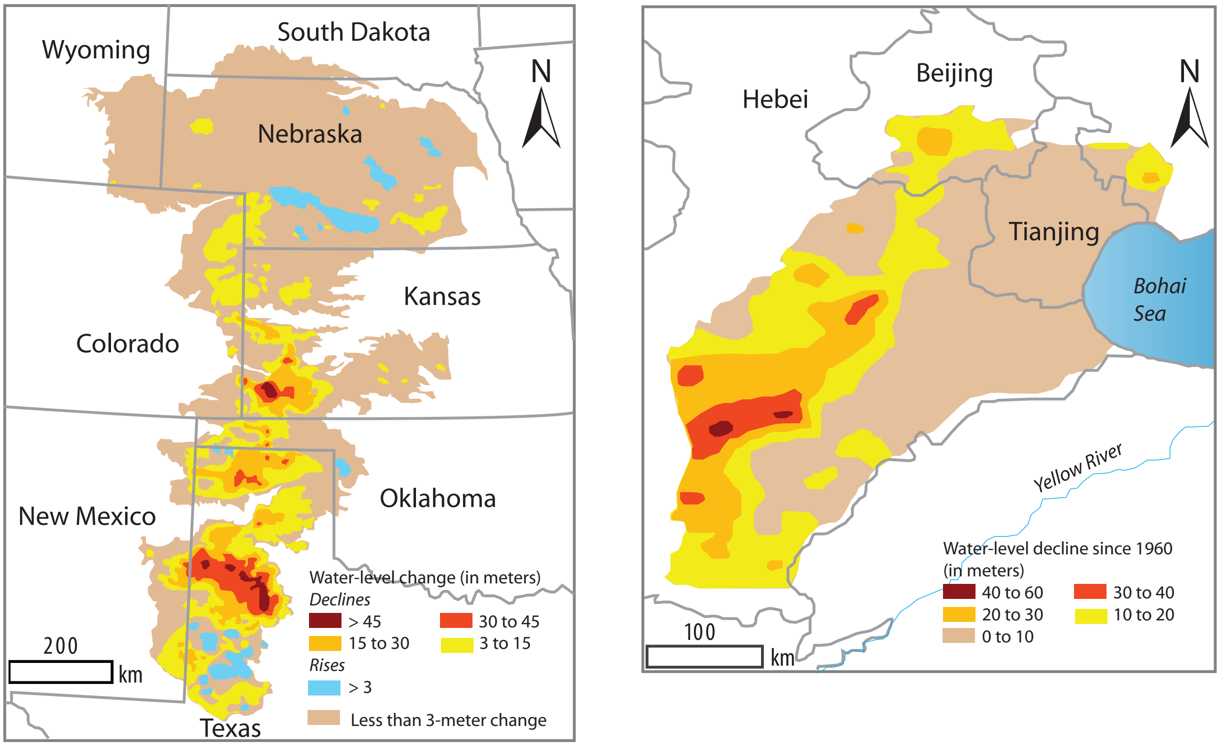

Figure 3 These maps show that irrigation from groundwater sources has locally produced water-level declines in excess of 40 m in both the High Plains Aquifer (HPA) and the Quaternary Aquifer of Northern China (QANC). Lesser impacts occurred over wider areas. Data for the HPA cover the period 1950–1998 (modified from Alley et al. 1999). Data for the QANC cover the period 1960–2000 (modified from Foster and Garduno 2004).

total dissolved solids, Fe, and other contaminants (Domagalski et al. 2001). Zhu and Schwartz (2011 this issue) examine anthropogenic influences on water quality more broadly within the hydrologic cycle.

Shallow aquifers worldwide exhibit similar contamination, due to irrigated agriculture. Fortunately, only younger groundwater (<100 y) is potentially contaminated. However, aquifers often have limited capability to attenuate the impacts of contamination (e.g. NO_3^- and dissolved salts in the HPA; Gurdak et al. 2009), so impacts are likely to keep accumulating through time unless there is a fundamental change in farming practices.

Contamination also comes from pumping-induced invasion of freshwater aquifers by saline water. Commonly, this problem develops from overpumping of aquifers along seacoasts. However, pumping can also induce upward (or downward) flows of saline formation water. For example, across significant parts of the QANC, 200 to 400 m of brackish water overlies much fresher groundwater at depth. Overpumping of the deeper groundwater is likely inducing a downward flow of brackish water (Foster and Chilton 2003).

Groundwater is usually thought of as being free of biological contaminants, such as pathogenic microbes, because of the filtration of colloidal particles. However, shallow aquifers have been contaminated by human enteric viruses and other pathogenic microbes. Fractured or gravelly aquifers are particularly susceptible to contamination from sewage related to wastewater disposal, leaking landfills, or septic tanks.

In his recent book, *Planet of Slums,* Mike Davis describes the worldwide growth of cities. “In 1950, there were 86 cities in the world with a population of more than one million; today there are 400, and by 2015 there will be at least 550” (Davis 2006). By 2006, more people lived in cities than in the countryside. In the United States, more than 75% of people live in urban areas. Urbanization is accelerating worldwide, and the growing cities are producing an immense impact on the urban hydrologic cycle. For example, rain running off roads, parking lots, and other surfaces, which accumulate the detritus of cities, constitutes a significant non–point source of pollution. Trace metals, nutrients, and organic contaminants are transported in the atmosphere and accumulate on urban surfaces (dry deposition). Metal particulates are also generated from the wearing of brakes and tires on cars and other vehicle components, fluid leakage, and pavement degradation. Organic contaminants are generated from engine exhausts, fuel and oil leaks, and the weathering of asphalt compounds. Road salt, used for melting ice on roads, is a major source of inorganic salts. It is not surprising then that runoff and wash-off of contaminants from these surfaces is a key cause of water-quality degradation of streams in urbanized watersheds. What is less obvious is that some of this contaminated urban storm water ends up recharging aquifers beneath cities, in essence providing the urban counterpart to non–point source agricultural contamination. In some places (e.g. Long Island, New York), recharge of runoff in cities is promoted through infiltration basins.

An assorted set of human health issues also accompany urban groundwater problems. In Karachi, Pakistan, local groundwater now provides an important alternative source of drinking water for the population, which now tops 18 million (Rahman 1996). Yet, untreated sewage has contaminated shallow groundwater because the urban infrastructure is insufficient for handling human wastes. This is also the case in Mexico City, where leakage from unlined sewage canals and irrigation with untreated wastewater threaten deeper groundwater. The potential health problems resulting from comingling the water supply and waste-disposal systems in poor megacities could be enormous.

The extent of contamination in aquifers and the resulting impact on society are really only understood in richer countries, where monitoring and data collection are underway. The successful National Water Quality Assessment Program in the United States, run by the U.S. Geological Survey, illustrates the significant cost and level of effort required to carry out even a preliminary assessment of water-quality issues.

THERE IS NO VIABLE PLAN B FOR GROUNDWATER

The term *Plan B* is commonly used to describe the backup plan when some primary plan falters. In all too many countries, the backup plan for addressing a declining local water supply is to find "new" water to import. In essence, Plan B for water hasn't changed for at least 2000 years, since the Garamantian civilization.

The scope of potential projects is breathtaking, exceeding those already mentioned. In the United States, depletion of the Mississippi Valley Alluvial Aquifer in Arkansas, which is used to irrigate rice crops, is driving efforts for major surface-water diversions; the city of Las Vegas is looking to pipe groundwater from sources more than 280 km away; and a scheme has been proposed to pipe groundwater from the HPA in the Texas Panhandle about 400 km to Dallas. The National River Linking Project in India proposes to connect 30 rivers with approximately 3000 storage reservoirs to form a large South Asian water grid. This project is seen as one approach to deal with problems driven by a decline in water supply and rapid increases in the energy costs for pumping groundwater. In the Persian Gulf region of the Middle East, countries rely on desalination of seawater for their water supplies.

Technology-driven megaprojects like these are unlikely to keep up with continuing population increases. The costs of building and operating systems to exploit new water sources are now competing with the rapidly escalating costs of national social programs in education, medical care, and pensions, and of state security. Moreover, supplies of "cheap power" from thermoelectric, coal, and other sources to run these megasystems are becoming less available, as the full environmental cost of energy production is being understood.

Plan B is also the title of a series of books, written by Lester Brown, that describe possible ways to address environmental problems. The third book in this series is noteworthy for its appraisal of the continuing environmental slide. In the preface, Brown (2008) writes, "Our world is changing fast. When *Plan B 2.0* went to press two years ago, the data on ice melting were worrying. Now they are scary. Two years ago, we knew there were a number of failing states. Now we know that number is increasing each year. Failing states are an early sign of a failing civilization."

While both Brown and Postel provide optimism for the future, the probability that human impacts on groundwater can be arrested seems small. Most conservation efforts and technology enhancements are occurring only in the richest countries. Water levels in aquifers around the world continue to decline, driven by relentless pressures from urbanization, expanding populations, and increasing energy costs. Groundwater still remains for the taking in most places at little cost, with impacts that are slow to be noticed. The predictable surprise will be supply crises driven by shocks on supply systems that are losing their resiliency. Historically, societies declined when the water ran out, and they will continue to do so.

ACKNOWLEDGMENTS

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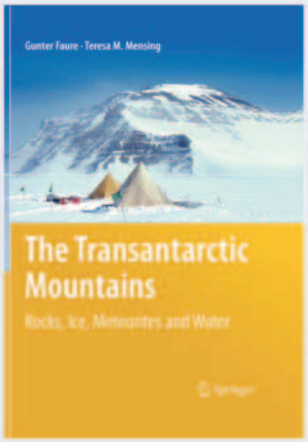
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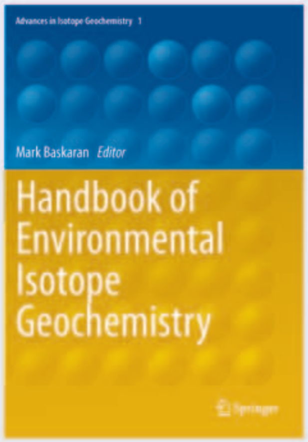
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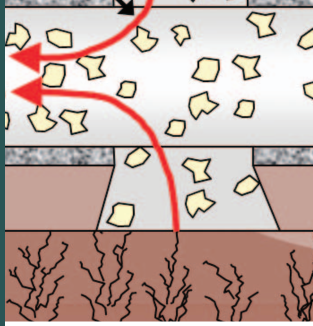

Water Management Challenges Associated with the Production of Shale Gas by Hydraulic Fracturing

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Development of unconventional, onshore natural gas resources in deep shales is rapidly expanding to meet global energy needs. Water management has emerged as a critical issue in the development of these inland gas reservoirs, where hydraulic fracturing is used to liberate the gas. Following hydraulic fracturing, large volumes of water containing very high concentrations of total dissolved solids (TDS) return to the surface. The TDS concentration in this wastewater, also known as "flowback," can reach 5 times that of sea water. Wastewaters that contain high TDS levels are challenging and costly to treat. Economical production of shale gas resources will require creative management of flowback to ensure protection of groundwater and surface water resources. Currently, deep-well injection is the primary means of management. However, in many areas where shale gas production will be abundant, deep-well injection sites are not available. With global concerns over the quality and quantity of fresh water, novel water management strategies and treatment technologies that will enable environmentally sustainable and economically feasible natural gas extraction will be critical for the development of this vast energy source.

Keywords: shale gas, hydraulic fracturing, produced water, flowback

INTRODUCTION

Natural gas plays a central role in meeting the demand for energy around the world. This versatile, readily transportable fossil fuel has long been used for residential and industrial heating, steam production, and thermoelectric power production. While coal remains the dominant fuel source for electric power production, economic, technological, regulatory, and environmental drivers have shifted the focus of new electrical power generation towards natural gas. Currently, natural gas is the fuel source for 21% of electricity production and for 24% of the total energy demand in the United States (EIA 2011). Over the next 25 years, these proportions are expected to remain constant or increase. Global demand for natural gas is on the rise as well. For example, natural gas currently provides 4% of China's energy, and that country's goal is to increase the amount of natural gas used to 8% of the energy supply by 2020 (Peoples Daily Online 2010).

The main advantages of natural gas are its widespread availability, its ease of transport, and its efficient and clean combustion. Also, natural gas combustion yields lower emissions of greenhouse gases and other pollutants relative to coal combustion for equivalent amounts of power generation (Jaramillo et al. 2007).

To meet the growing demand for natural gas, energy companies have greatly expanded their exploration and development of unconventional natural gas resources, such as coalbed methane, tight sands, and shale gas. The fastest-growing source of natural gas is shale gas, which is projected to be the largest contributor to growth in natural gas production in the United States for the next 25 years (EIA 2011). The same is true in many other nations, as recent assessments of global shale gas resources indicate substantial technically recoverable resources in many countries, including China, Argentina, Mexico, South Africa, and others (Fig. 1).

SHALE GAS DEVELOPMENT

Shale gas is natural gas entrapped in shale and is distinct from gas in other low-permeability reservoirs and from "conventional" gas (Fig. 2). Shale is a fine-grained, clastic sedimentary rock composed of clay minerals and silt-sized particles, and may contain other minerals such as quartz, calcite, and pyrite. The shale formation is both the source and the reservoir for the natural gas, which is predominantly methane (~90%) but may also contain other hydrocarbons, CO_2, nitrogen, H_2S, and rare gases (Lapidus et al. 2000). The gas is held in natural fractures and pore spaces or adsorbed onto the organic material and minerals in the formation (Jenkins and Boyer 2008). Shale lacks sufficient natural permeability for the recovery of gas at rates suitable for large-scale production. Therefore, wellbores must be lengthened and fractures must be engineered to enable commercial viability (Jenkins and Boyer 2008).

New drilling and well-completion technology for gas production from shale formations evolved in the Barnett Shale in Texas, and its economic success has led to the rapid exploration of shale formations in many countries and has greatly increased the estimates of global natural gas reserves in the world (EIA 2011). Estimated reserves in the United States increased 35% between 2006 and 2009, largely the result of revised estimates of recoverable gas from shale formations, in particular the Marcellus Shale in the Appalachian Basin (Navigant Consulting 2008). With recoverable gas quantities nearing 500 trillion cubic feet (Tcf) (14 trillion cubic meters) (Engelder and Lash 2008) and estimated production rates near 30 billion cubic feet (Bcf) per day by 2030 (Moniz et al. 2010), the Marcellus

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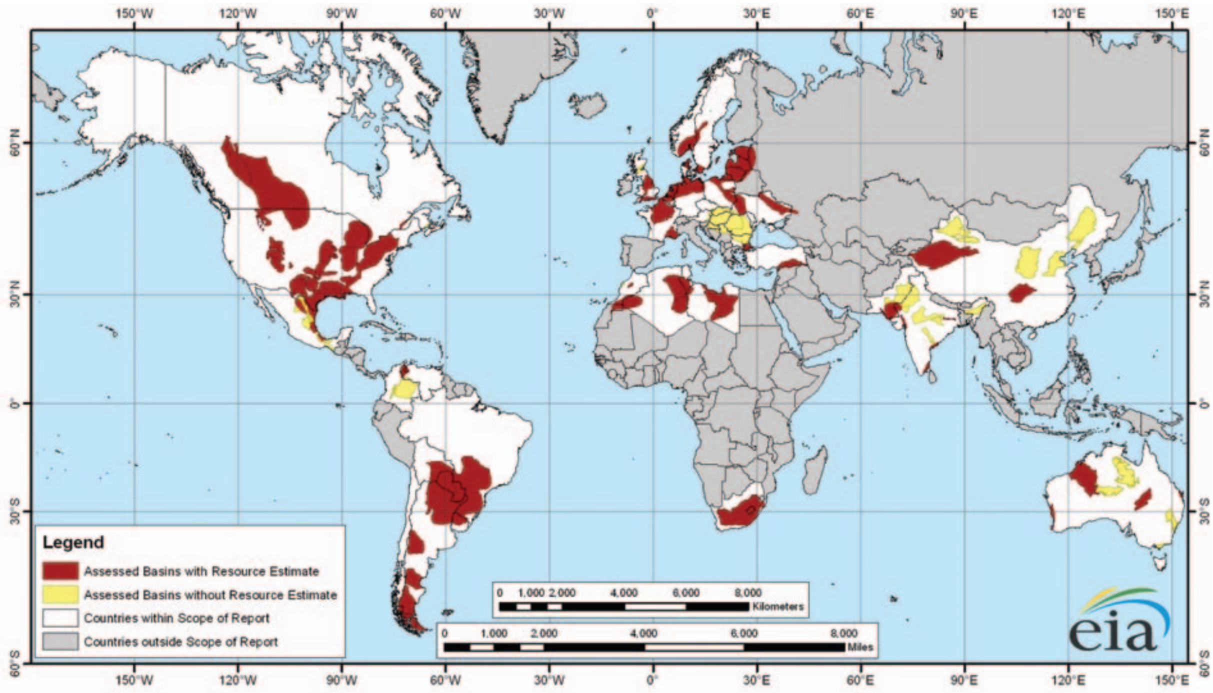


FIGURE 1 Map of world shale gas resources assessed by the United States Energy Information Administration. FROM EIA 2011

Shale has the greatest economic potential among the shale formations in the United States.

The technological and economic feasibility of gas production from the Barnett Shale in Texas has led to a rapid development of natural gas resources in the United States. Annual production volume has increased from 0.2 Tcf in 1998 to 4.9 Tcf in 2010 (FIG. 3), and is expected to grow more than threefold over the next decade and eventually represent 24% of the total natural gas production in the United States (EIA 2011).

DRILLING AND HYDRAULIC FRACTURING

Economically viable gas production from shale is achieved by horizontal drilling followed by hydraulic fracturing (FIG. 4). Horizontal drilling greatly increases the length of contact between the shale gas formation and the wellbore relative to a conventional vertical well, and a single horizontal well may replace 3 or 4 vertical wells (Arthur et al. 2008). Decreasing the number of wells decreases production costs and environmental risks associated with pad-site construction, drilling, and well development, and contributes to the economic feasibility of shale gas production. Hydraulic fracturing, or "fracking," involves the introduction of aqueous fracturing fluid at a rate sufficient to raise the downhole pressure above the fracture pressure of the formation rock. The stress induced by the pressure creates fissures and interconnected cracks that increase the permeability of the formation and enable greater flow rates of gas into the well. After hydraulic fracturing is performed, the pumping pressure is relieved and the fracture fluid returns to the surface through the well casing. This water is referred to as "flowback." Hydraulic fracturing is commonly a one-time event, performed in stages. However, additional hydraulic fracturing may be performed over the lifetime of the well if necessary and economically viable.

FIGURE 4 provides an overview of the hydraulic fracturing process used in a typical shale formation. A typical hydraulic fracturing procedure in the Marcellus Shale uses 7000 to 18,000 cubic meters of fracturing fluid (Arthur et al. 2008). Fracturing fluid for shale gas is most commonly a mixture of water, "proppant," and chemical modifiers (TABLE 1). Proppants are small particles of sand or engineered materials, such as resins or ceramics, that flow with the fracturing fluid and hold the fractures open, maintaining porosity as the pressure decreases in the formation with the return of fracturing fluid and gas to the surface (FIG. 4, INSET). The mixture of chemical modifiers is determined by site characteristics. It is important to note that the constituents listed in TABLE 1 are never all used simultaneously during hydraulic fracturing. Recent hydraulic fracturing in the Marcellus Shale has included only three

TABLE 1 VOLUMETRIC COMPOSITION AND PURPOSES OF THE TYPICAL CONSTITUENTS OF HYDRAULIC FRACTURING FLUID. DATA COMPILED FROM VARIOUS SOURCES (EPA 2004; API 2009)

Constituent	Composition (% by vol)	Example	Purpose
Water and sand	99.50	Sand suspension	"Proppant" sand grains hold microfractures open
Acid	0.123	Hydrochloric or muriatic acid	Dissolves minerals and initiates cracks in the rock
Friction reducer	0.088	Polyacrylamide or mineral oil	Minimizes friction between the fluid and the pipe
Surfactant	0.085	Isopropanol	Increases the viscosity of the fracture fluid
Salt	0.06	Potassium chloride	Creates a brine carrier fluid
Scale inhibitor	0.043	Ethylene glycol	Prevents scale deposits in pipes
pH-adjusting agent	0.011	Sodium or potassium carbonate	Maintains effectiveness of chemical additives
Iron control	0.004	Citric acid	Prevents precipitation of metal oxides
Corrosion inhibitor	0.002	n,n-dimethyl formamide	Prevents pipe corrosion
Biocide	0.001	Glutaraldehyde	Minimizes growth of bacteria that produce corrosive and toxic by-products

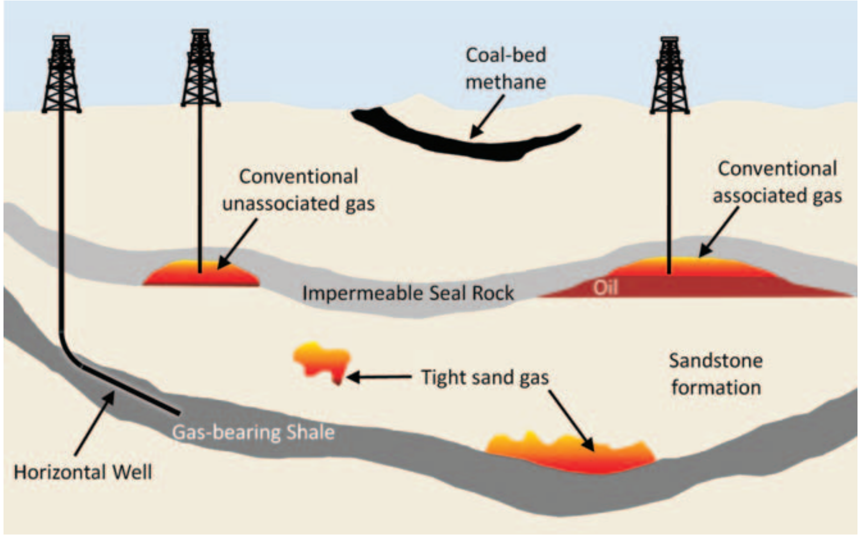


Figure 2 The types and common orientations of onshore natural gas resources. Modified after USGS National Assessment of Oil and Gas Fact Sheet, http://pubs.usgs.gov/fs/fs-0113-01/fs-0113-01.pdf

of these constituents: a friction reducer, a scale inhibitor, and an antimicrobial agent.

During the flowback period, which usually lasts up to two weeks, approximately 10 to 40% of the fracturing fluid returns to the surface (Arthur et al. 2008). The volume of flowback depends on the formation characteristics and operating parameters during development of the well. Once active gas production has begun, aqueous and nonaqueous liquid continues to be produced at the surface in much lower volumes (2–8 m^3/day) over the lifetime of the well. This wastewater, known as "produced water," contains very high TDS concentrations, as well as heavy and light petroleum hydrocarbons that may be separated and recovered (GWPC and ALL Consulting 2009).

ENVIRONMENTAL CHALLENGES AND WATER MANAGEMENT OPTIONS

The grand challenge that natural gas producers must address is how to preserve the favorable economics of shale gas production while maintaining responsible stewardship of natural resources and protecting public health. The goals of the natural gas developers and the goals of those responsible for human and environmental health protection are intimately connected by water, including its use, management, and disposal.

Water Resources

The drilling and completion of wells require large quantities of water. Drilling of the vertical and horizontal components of a well may require 400–4000 m^3 of water for drilling fluids to maintain downhole hydrostatic pressure, cool the drillhead, and remove drill cuttings. Then, 7000–18,000 m^3 of water are needed for hydraulic fracturing of each well. These large volumes of water are typically obtained from nearby surface waters or pumped from a municipal source. In regions where local, natural water sources are scarce or dedicated to other uses, the limited availability of water may be a significant impediment to gas resource development.

Management of Flowback Water

Flowback of the fracturing fluid occurs over a few days to a few weeks following hydraulic fracturing, depending on the geology and geomechanics of the formation. The highest rate of flowback occurs on the first day, and the rate diminishes over time; the typical initial rate may be as high as 1000 m^3/d (GWPC and ALL Consulting 2009). The composition of the flowback water changes as a function of the time the water flowing out of the shale formation was in contact with the formation. Minerals and organic constituents present in the formation dissolve into the fracturing water, creating a brine solution that includes high concentrations of salts, metals, oils, greases, and soluble organic compounds, both volatile and semivolatile (Table 2). The flowback water is typically impounded at the surface for subsequent disposal, treatment, or reuse. Due to the large water volume, the high concentration of dissolved solids, and the complex physicochemical

Table 2 TYPICAL RANGE OF CONCENTRATIONS FOR SOME COMMON CONSTITUENTS OF FLOWBACK WATER FROM NATURAL GAS DEVELOPMENT IN THE MARCELLUS SHALE. The data were obtained from flowback water from several production sites in western Pennsylvania[1].

Constituent	Low[2] (mg/L)	Medium[2] (mg/L)	High[3] (mg/L)
Total dissolved solids	66,000	150,000	261,000
Total suspended solids	27	380	3200
Hardness (as $CaCO_3$)	9100	29,000	55,000
Alkalinity (as $CaCO_3$)	200	200	1100
Chloride	32,000	76,000	148,000
Sulfate	ND[5]	7	500
Sodium	18,000	33,000	44,000
Calcium, total[4]	3000	9800	31,000
Strontium, total	1400	2100	6800
Barium, total	2300	3300	4700
Bromide	720	1200	1600
Iron, total	25	48	55
Manganese, total	3	7	7
Oil and grease	10	18	260
Total radioactivity	ND[5]	ND	ND

1 Data compiled by Elise Barbot, University of Pittsburgh, and Juan Peng, Carnegie Mellon University

2 "Low" concentrations are from early flowback at one well. "Medium" concentrations are from late flowback at the same well for which the "low" concentrations are reported.

3 "High" concentrations are the highest concentrations observed in late flowback from several wells with similar reported TDS concentrations.

4 Total concentration = dissolved phase + suspended solid phase concentrations.

5 Not detected

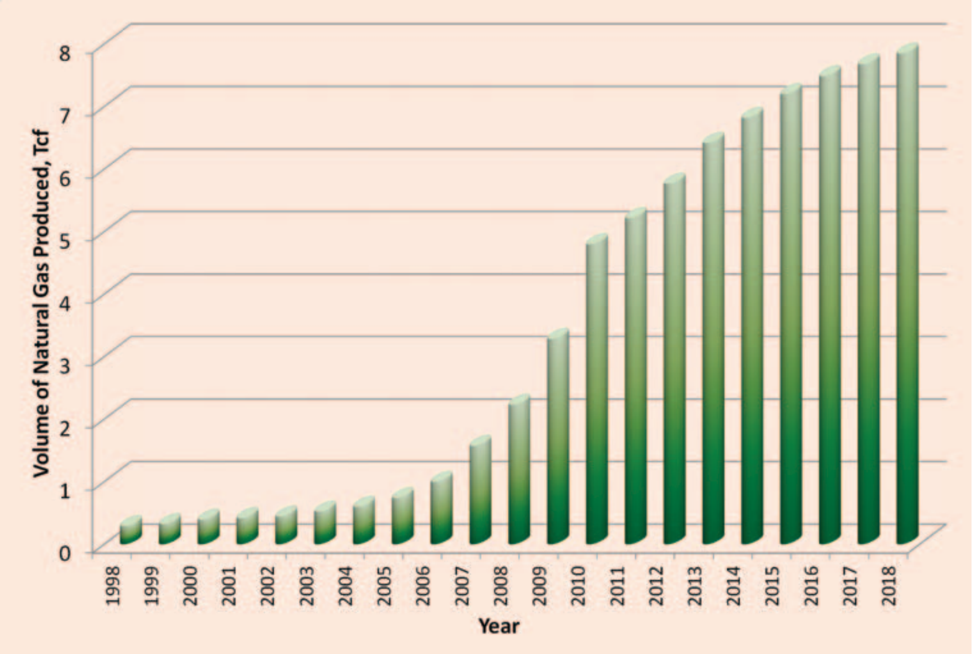


Figure 3 Actual and projected production of natural gas from shale in the United States in trillions of cubic feet (Tcf). 1 Tcf = 28 trillion liters. Data from U.S. Department of Energy Information Administration 2011 (EIA 2011)

composition of the flowback water, there is growing public concern about management of this water because of the potential for human health and environmental impacts associated with an accidental release of flowback water into the environment (Kargbo et al. 2010).

Treatment technologies and management strategies for flowback water are based on constraints established by governments, economics, technology performance, and the appropriateness of a technology for a particular water. Past experience with produced and flowback waters is used to guide developers towards treatment and management options in regions of new production (Kargbo et al. 2010). Flowback water management options for some shale plays, such as the Marcellus, are confounded by high concentrations of total dissolved solids in the flowback water, geography, geology, and a lack of physical infrastructure (Arthur et al. 2008; Kargbo et al. 2010).

Underground Injection

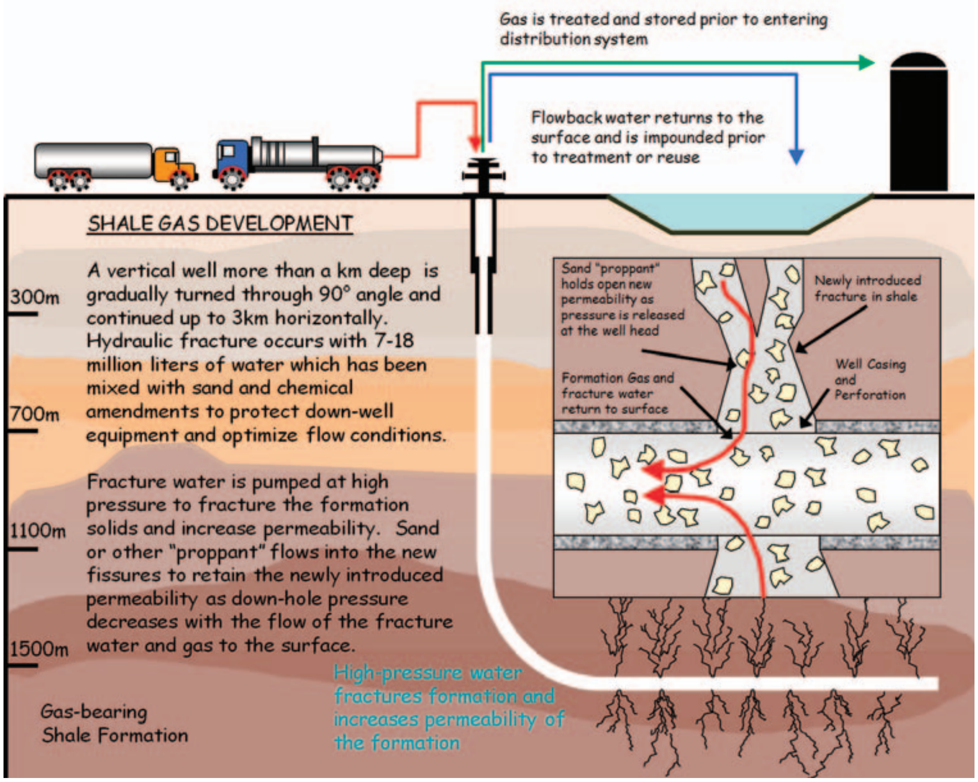
Most produced water from oil and gas production in the United States is disposed of through deep underground injection (Clark and Veil 2009). When underground injection is utilized, such operations are performed using Class II (disposal) underground injection control wells as defined by the U.S. Environmental Protection Agency (Veil et al. 2004). However, the availability of adequate deep-well disposal capacity can be an important constraining factor for shale gas development. In Texas, there were over 11,000 Class II disposal wells in 2008, or slightly more than one disposal well per gas-producing well in the Barnett Shale (Tintera 2008). In contrast, the whole state of Pennsylvania has only seven Class II disposal wells available for receiving flowback water. The Marcellus Shale is a large resource that will eventually be exploited by a large number of producing wells. Although the number of underground-injection disposal wells in Pennsylvania is expected to increase, shale gas development is currently occurring in many areas where insufficient disposal wells are available, and the construction of new disposal wells is complex, time consuming, and costly (Arthur et al. 2008). As a result, other solutions for flowback water management are necessary.

Discharge to Publicly Owned Treatment Works (POTWs) for Dilution Disposal

Although discharge and dilution of flowback water into publicly owned municipal wastewater treatment plants (POTWs) has been utilized (e.g. Penn Future 2010), this is not an adequate or sustainable approach for managing flowback water. The amount of high-TDS flowback water that can be accepted by POTWs is usually limited by regulation. For example, in many POTWs in Pennsylvania, the amount of oil and gas wastewater must not exceed 1% of the average daily volume of waste handled by the POTW. In addition, discharge limits in Pennsylvania for TDS are set at 500 mg/L to insure the quality of the processed product. In general, the volume of flowback water that can be sent to POTWs is small compared to the volume of flowback water generated during rapid well drilling and well development.

Reverse Osmosis

Reverse osmosis (RO) is a well-known treatment method for producing drinking water and high-purity industrial water. In the RO process, water is passed through a semipermeable membrane under pressure and a treated water of high quality is produced, along with a concentrate that requires disposal. This separation process removes material ranging from suspended particulates down to organic molecules and even monovalent ions of salt (Xu and Drewes 2006). In trials of RO treatment of flowback water, the volume of concentrate for disposal has been reduced to as low as 20% of the initial volume of flowback water (ALL Consulting 2003). Driven by mechanical pressure, RO is energy intensive. Even with favorable energy prices, the treatment of flowback water using RO is considered to be economically infeasible for waters containing more than 40,000 mg/L TDS (Cline et al. 2009). For high-TDS waters, vibratory shear-enhanced processing (VSEP) has been applied to membrane technologies (Jaffrin 2008). In VSEP, flat membranes are arranged as parallel discs separated by gaskets. Shear is created by vibrating a leaf element tangent to the membrane surface. The created shear lifts solids and fouling material off the membrane surface, thereby reducing colloidal fouling and polarization of the membrane (New Logic Research 2004). VSEP technology has been used successfully in the treatment of produced water from offshore oil production (Fakhru'l-Razi et al.



A vertical well more than a km deep is gradually turned through 90° angle and continued up to 3km horizontally. Hydraulic fracture occurs with 7-18 million liters of water which has been mixed with sand and chemical amendments to protect down-well equipment and optimize flow conditions.

Fracture water is pumped at high pressure to fracture the formation solids and increase permeability. Sand or other "proppant" flows into the new fissures to retain the newly introduced permeability as down-hole pressure decreases with the flow of the fracture water and gas to the surface.

FIGURE 4 Overview of how hydraulic fracturing is used to produce natural gas from shale. The inset box illustrates the process at the horizontal well. MODIFIED AFTER A GRAPHIC BY AL GRANBERG FOR PROPUBLICA

2009). However, the salt concentrations in offshore produced waters are far lower than those expected during shale gas extraction.

Thermal Distillation and Crystallization

The high concentrations of TDS in flowback water may limit the use of membrane technology, but such water is well suited to treatment by distillation and crystallization (Doran and Leong 2000). Distillation and crystallization are mature technologies that rely on evaporating the wastewater to separate the water from its dissolved constituents. The vapor stream is passed through a heat exchanger to condense the gas and produce purified water. Distillation removes up to 99.5% of dissolved solids and has been estimated to reduce treatment and disposal costs by as much as 75% for produced water from shale oil development (ALL Consulting 2003). However, as with RO, distillation is an energy-intensive process. Thermal distillation may treat flowback water containing up to, and in some cases even exceeding, 125,000 mg/L of TDS, but even the most modern technology is limited to low flow rates (300 m^3/d), necessitating the construction of large storage impoundments (Veil 2008). For example, flowback water from the Marcellus Shale gas sites can be produced at rates of 3000 m^3/d or higher. Recent developments include using mechanical vapor-recompression systems to concentrate flowback water, which can be done at a fraction of the cost of conventional distillation because the heat of the compressed vapor is used to preheat the influent. Further water evaporation to create dry mineral crystals (i.e. crystallization) will improve water recovery and create salt products that might be reused as industrial feed stocks. Crystallization is a feasible approach for treating flowback water with TDS concentrations as high as 300,000 mg/L, but it has high energy requirements and large capital costs.

Other Treatment Options

Several other technologies have been or are being developed for treating flowback water, but each has its limitations. Falling into this category are ion exchange and capacitive deionization (Jurenka 2007), which are limited to the treatment of low-TDS water; freeze–thaw evaporation, which is restricted to cold climates; evaporation ponds, which are restricted to arid climates; and artificial wetlands and agricultural reuse (Veil et al. 2004), which are greatly limited by the salinity tolerance of plant and animal life.

On-Site Reuse for Hydraulic Fracturing

One of the most promising technologies for management of flowback water is its reuse in subsequent hydraulic fracturing operations. Flowback water is impounded at the surface and reused either directly or following dilution or pretreatment. Reuse is particularly attractive in regions where deep-well disposal options are limited or where the availability of make-up water for hydraulic fracturing is limited. The reuse of flowback water has the benefit of minimizing the volume of such water that must be treated or disposed of and greatly reduces environmental risks while enhancing the economics of shale gas extraction.

Potentially limiting factors for reuse are the chemical stability of the viscosity modifiers and other constituents of hydraulic fracture water in the brine solution and the potential for precipitation of divalent cations in the wellbore. The effectiveness of friction reducers may be decreased at high TDS concentrations (Kamel and Shah 2009). The development of additives that retain their effectiveness in brine solutions are likely to expand the opportunity for reuse of flowback water for subsequent hydraulic fracturing.

The divalent cations in the flowback water are solubilized from formation minerals and can form stable carbonate and sulfate precipitates in the wellbore if the flowback water is reinjected. This may potentially reduce gas production from the well. In particular, barium and strontium form very low-solubility solids with sulfate, while high calcium concentrations may lead to calcite formation. Depending on the quality of the flowback water, pretreatment to reduce the divalent cation concentration by precipitation may be necessary.

OUTLOOK

Natural gas production from deep shale formations by hydraulic fracturing has been growing exponentially in the United States. With growing global energy demands and expanding discovery of global shale resources, similar trajectories for global shale gas production are expected. Hydraulic fracturing uses thousands of cubic meters of water for fracturing fluid at each well and therefore has the ability to strain local freshwater resources. The water that returns to the surface is a brine solution with very high concentrations of salts, metals, oils, and greases, and it is commonly impounded at the surface prior to treatment, reuse, or disposal. If not responsibly managed, the release of flowback water into the environment can have a range of impacts.

While many options are available for the treatment of flowback water, many are limited by high capital and operating costs. The most widely used option for management of flowback water is deep-well injection disposal. However, in regions where deep-well injection sites are not available, a widely practiced alternative is precipitation softening for a partial reduction of TDS, followed by reuse of the flowback in subsequent hydraulic fracturing procedures.

While shale gas appears to be an abundant resource in many countries, it will remain untapped without favorable economics for its production. The economics of shale gas development is a complex multivariate optimization, with water resource management as a critical input. It is important to note that optimized strategies for one basin or locality may not apply in others. Environmental, geographical, geological, economic, social, and political considerations will ultimately determine the water management solutions that will enable production of shale gas resources while protecting that locality's other natural resources.

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Water Conservation, Efficiency, and Reuse

Installing a low-flow showerhead can save half the water used in a standard shower.

Henry Vaux Jr.*

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Global water scarcity is intensifying. Economizing on water use will be an important aspect of any effective response. Water recycling and reuse technologies offer possibilities for more extensive use of water, depending on cost. Institutional responses, such as the use of rational pricing and the creation of water markets or exchanges, promise to improve water-use efficiency. Consumer education is a simple and inexpensive means of economizing on water in the urban and agricultural sectors. Rationing is effective in managing short-term interruptions such as drought. Point-of-use technology will also offer opportunities for economizing on many water uses.

Keywords: water reuse, pricing water, water markets, education, point-of-use technology, water economizing

INTRODUCTION

During most of the modern era, the typical response to increased demands for water has been to augment developed water supplies. Indeed, throughout much of the 20th century, the prevailing practices of water resource management placed heavy reliance on the construction of dams and canals to impound (store) and convey (distribute) water, as well as on the development of additional groundwater resources. Over the last three decades it has become increasingly clear that the pervasive problem of water scarcity cannot be met simply by developing additional supplies. As demand has continued to grow, water available for development has become increasingly scarce. The costs of development have risen disproportionately because low-cost sites and supplies have already been developed and because the costs of civil works have increased faster than the rate of inflation. Additionally, it is now well understood that impoundment and conveyance facilities cause adverse environmental consequences that may be very costly.

The demand for water is driven primarily by population and economic growth. In virtually all regions of the world, water requirements will grow in the next decades. Simultaneously, supplies will remain relatively constant or decline because of water pollution and contamination, the persistent overdrafting of aquifers, and adverse changes in the patterns of precipitation that have occurred in some areas. While all regions will experience water scarcity to some degree, for some countries it is especially acute (Fig. 1). By 2025, as water scarcity intensifies, more countries will be severely short of water.

In these circumstances, increasing attention has been devoted to more careful management of water to reduce average water use. The water thus saved can be devoted to new and emerging uses. This method of management is frequently characterized as demand management or, simply, water conservation. This paper is devoted to a consideration of various methods of water conservation. The next section contains some brief observations on terminology. It is followed by sections devoted to water-conserving technology, pricing and markets, and other conservation measures.

A QUESTION OF DEFINITION

The term "conservation" has different meanings for different people. To some, "conservation of natural resources" means using fewer resources, or saving them for the future. To others, the phrase means managing the resources in an optimal way to achieve some objective. To still others, it is synonymous with the concept of the "wise use" of resources. The difficulty with this latter definition is that "wise" is also subject to varying interpretations. To minimize confusion or eliminate it altogether, it is important, then, to define the term "conservation" precisely.

In this paper, "conservation" is taken to be synonymous with the concept of economizing. When one economizes on the use of some good or service, one uses less of it. Economizing usually occurs in response to increases in the price or value of some resource, but not always. Economizing can occur in two different ways. First, less of the resource (or good or service) in question is used and some of the benefits that were previously enjoyed are foregone. Second, the resource may be used differently or more intensively so as to obtain either increased benefit from a constant level of resource use or the same benefit from a reduced level of resource use. Either of these methods of economizing reduces the level of resource use and results in some proportion of historical-use levels becoming available to serve new uses. In the remainder of this paper the term "economizing" will be used in place of the word "conservation."

RECYCLING AND REUSE: THE ROLE OF TECHNOLOGY

The potential for water to be recycled and reused depends upon whether the initial use is consumptive or not. Consumptive use occurs when the use to which water is put entails a change from the liquid phase to the gaseous phase. Agricultural water use in which the water is evapotranspired by a plant is an example of consumptive use. When this occurs the water so used cannot be used further or reused. Nonconsumptive use does not entail a phase change and the water is available for subsequent use. Thus, in irrigated agriculture, water that is not evaporated or

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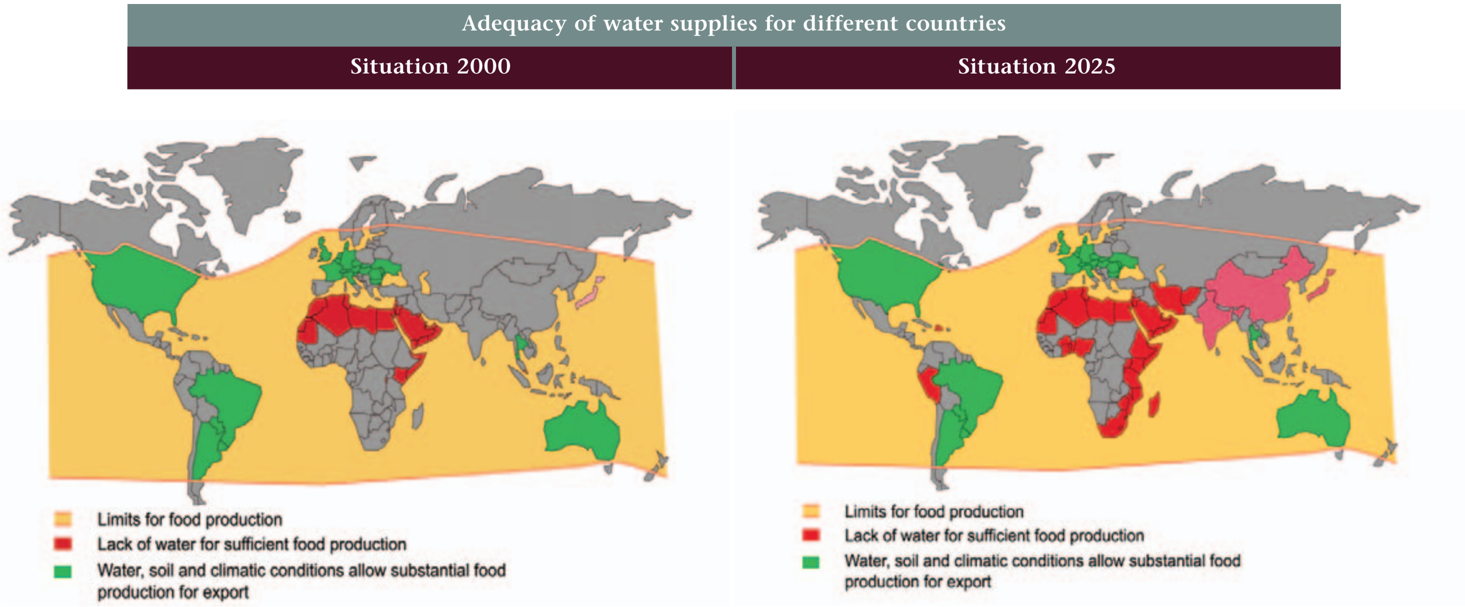

Figure 1 Countries subject to extreme water scarcity and the effect of water supply on food production. Within the arable regions of the world, countries in grey have sufficient water to meet their needs but not enough for export. From Zehnder (2002)

transpired and runs off the field may be available for further use. Industrial and household wastewaters are also examples of water that is not consumptively used. In some regions the potential addition to water supplies of recycled industrial and domestic wastewater may be significant. In the southwestern United States, for example, supplies could be augmented by 5–10% by recycling industrial and domestic wastewater. And, of course, in-stream water uses, such as to support navigation and environmental amenities, are also nonconsumptive.

The recycling and reuse of irrigation water occur both intentionally and unintentionally. Where water is expensive or otherwise scarce, irrigators have a strong incentive to use every drop to which they are entitled. Where soils are heavy and infiltration rates low, water tends to run off. Such runoff can be captured in tailwater pits and either pumped to the head of the same field for reuse or used elsewhere. Similarly, water that percolates deeply beyond the root zone is often a significant source of groundwater recharge. This latter example of reuse may be either intentional or unintentional.

The potential for recycling and reuse of industrial and household wastewater is governed by cost considerations, which are in turn a function of the quality of the wastewater itself. Thus, for example, the quantity of water diverted for industrial purposes in the United States declined significantly following enactment of national water-quality standards and discharge control. The explanation lay in the fact that once industrial firms had treated wastewater to achieve the quality required by discharge regulations, the additional cost of restoring the quality to the point where it could be reused was quite modest. Most firms found it economical to simply reuse their treated wastewater as feed water for their industrial processes.

Household and industrial wastewater that is discharged to centralized sewer systems can be recycled and reused depending upon the level of treatment and the costs. In countries such as the United States, where surface water–quality standards and discharge regulations are in place, wastewater from sanitary (and in some cases, storm-water) sewers must be treated to meet these discharge standards. This water may sometimes be suitable for uses that do not require very high quality. For example, treated wastewater is often used for landscape and crop irrigation, for which little or no additional treatment is required.

Today, wastewater treatment technology has advanced to the point where household and industrial wastewater can be cleaned so as to meet the standards prescribed for household use. For example, the Orange County Water District, located in Southern California, produces significant quantities of water from wastewater, and this recycled water is recharged to local aquifers from which it is ultimately extracted to serve household needs. The district employs several technologies, of which the most advanced feature artificial membranes that are used in a reverse osmosis process to clean the water prior to direct injection into the underlying aquifer. These technologies are relatively costly and can be employed economically only under certain conditions.

The Orange County Water District of Southern California has been a pioneer in reclaiming wastewater for potable reuse. The filtration facilities shown in Figure 2 are part of a larger set of facilities that allow for direct injection of reclaimed water as well as percolation to the underlying groundwater. This example of wastewater recycling and reuse is economically attractive both because the cost of the least-cost alternative supply is relatively high and because the regional wholesale supplier offers subsidies to retail suppliers who develop alternative supplies in lieu of wholesale supplies (Mills 2010). The example illustrates the fact that recycling technologies now available are economical when alternative supplies are either costly or unavailable. Wastewater can be recycled in relatively simple and inexpensive ways, such as percolating it through the soil to underlying aquifers. This technique is frequently referred to as soil-aquifer treatment. More expensive technologies employ some combination of filtration, chemical treatment, and the use of synthetic membranes (Gregory et al. 2011 this issue). In this case, the treatment technology selected usually depends on the quality of water required (National Research Council 2008).

Water scarcity will continue to intensify, leading to higher costs for new or reallocated supplies. Simultaneously, the cost of advanced wastewater-treatment technology is likely to decline as new and better technologies are developed. Both of these trends will combine to increase the number

Figure 2 Water reuse facilities in Orange County, California

and frequency of circumstances in which wastewater recycling and reuse will be attractive. In the arid and semiarid southwestern United States, available surface waters are now fully allocated among existing agricultural, environmental, municipal, and industrial uses. Recycled water represents the sole source of unallocated water that will be available to serve new or growing uses in the future.

PRICES AND MARKETS

Water that is diverted and made available for consumptive use is virtually never given a scarcity value. Two important implications follow. First, the price paid by users is simply the cost of capturing, treating, and transporting the water. In some instances, the price will include a charge to cover the costs of wastewater treatment services, but there is no value assigned to the water itself. Second, by implicitly assigning a value of zero to the water itself, managers and purveyors are signaling to consumers that water is freely available. Given that water is scarce and that its scarcity is intensifying, policies that suggest it is freely available are perverse. Moreover, almost without exception, assigning a price or scarcity value to water induces economizing behavior on the part of consumers, thereby making additional water available to serve new residents or other uses.

It has been clearly established that when water is priced, the demand for virtually all uses of water in terms of quantities taken is responsive to the price. This means that as the price of water increases the quantity of water used diminishes. Elasticity is the measure of the sensitivity of water demand to price. Most estimates of elasticity show that water use is responsive to price but not enormously so. Typically, the demand for water for domestic use is less sensitive to price than is the demand for agricultural use. Nevertheless, assigning even a modest scarcity value or price to water will likely result in modest reductions in water use (Hanemann 1997, 2006; Schoengold et al. 2006).

Water can be priced administratively or it can be priced through the interaction of the market forces of supply and demand. Some representative water costs are provided in Oelkers et al. (2011 this issue). In the United States water prices are typically established administratively, and it would be relatively straightforward to include a scarcity value for water in the administered price. The scarcity value could be estimated or inferred and, in any event, would likely be an approximation of the true value. Water utilities and other purveyors typically establish water rates to reflect the average cost of capturing, treating, and delivering the water. This is done to ensure that the costs that must be defrayed by the utility or purveyor are fully covered by the aggregate revenues. Again, it would be a relatively simple matter to include in this rate an average scarcity value for the water used.

Pricing according to average cost has one significant shortcoming. In many situations today, the incremental cost or value of water is higher than the average value. This reflects the fact that as more water is developed the cost increases. The cost of recycled wastewater, for example, is higher than the cost of river water, which is simply diverted, treated, and piped to the consumer. When, for pricing purposes, the cost of expensive water is simply averaged in with the existing, less expensive, water costs, the resulting rate is lower than the incremental cost. Again, this lower rate signals to the consumer that water is more plentiful than it is in reality. Incremental costs may sometimes be difficult to estimate, but increasing block rates, such as those used by electric utilities, can mimic incremental costs and bring about the kind of economizing behavior that true marginal or incremental cost pricing would induce. The use of incremental pricing, or some reasonable approximation, results in efficient use of water in the sector where it is practiced. Thus, incremental pricing for urban water supplies results in efficient use in cities. Efficient allocation means that water is devoted to its highest-valued uses *within the sector in question*.

The development and use of water markets, whether formal or informal, ensure that water is efficiently allocated among the various water-using sectors: urban, industrial, agricultural, and environmental. Reasonably well-working markets also help to ensure that the emerging prices reflect, at least approximately, the scarcity value of the water. Markets work by facilitating the exchange of water from relatively low-value to relatively higher-valued uses. Market exchanges are strictly voluntary, and both buyer and seller are made better off as a consequence of the exchange: the seller obtains more for the water by selling or leasing it than could be made by putting it to its highest-valued use. The buyer is made better off because the purchased water is available more cheaply than any alternative source of supply and because the price of the purchased water is lower than the value that can be obtained by the buyer by putting it to the desired use. All of these conditions obtain when water is traded in markets.

Market exchanges are not restricted to the transfer of water rights. Water can be sold on spot markets for a one-time transfer. Many spot sales tend to be arranged and executed informally. Water can be leased for specified periods of time. Water can also be the subject of contingency contracts in which the buyer pays the seller a fee for the right to purchase the water when needed. Purchases, if and when they occur, require that an additional price be paid. Thus, for example, an urban region might execute contingency contracts with an agricultural supplier to ensure that domestic supplies are available during droughts.

Where markets work relatively freely, the allocation of water among sectors is said to be efficient. That is, there is no allocation other than the allocation that maximizes the value of the water in and among uses. As an empirical matter, most exchanges occur either within the agricultural sector or between the agricultural and urban sectors. In the latter case, at equilibrium, the price that the agricultural seller receives for the water plus transport and treatment costs is exactly equal to the price paid by the urban buyer. The existence of water markets ensures that water can be moved from low-valued uses to existing or emerging high-valued uses. In the absence of markets, low-valued uses may continue to be served, while water is unavailable to support higher-valued uses (National Research Council 1992).

Despite their appeal, markets have some shortcomings. Without special arrangements, environmental uses of water cannot compete on the same basis as urban, industrial, and agricultural uses. Environmental uses of water, which provide environmental services [such as water purification, environmental stability (pest control), and biological diversity] and environmental amenities, are sometimes referred to as public goods. That is, when one provides an environmental service to a single person, it is in effect provided to many or all people irrespective of whether they pay. The consequence is underinvestment in the development of such benefits because the value cannot be captured from consumers who ride for free. There are a variety of remedies. These include: (1) special funds, usually publically appropriated, that can be used to buy water for environmental uses; (2) a tax on the proceeds from other water transfers, which is used to fund water purchases for environmental purposes; and (3) special protections or designations, usually the result of legislative action, that protect allocations of water for environmental purposes by preventing such waters from being sold for consumptive uses (National Research Council 1992).

Additional problems with market-based water transfers include adverse impacts on people who are not party to the transfer negotiation and who may suffer as a result. Thus, people who depend on downstream flows may suffer as a consequence of a transfer to which they are not party and which would reduce downstream flows. Similarly, market transfers could result in adverse impacts on water quality because the dilution capacity of the stream is reduced. Market institutions for the exchange of water must be carefully designed to ensure that environmental uses are accommodated; that third party impacts, if any, are small; and that there are no other unanticipated or unaccounted-for impacts.

OTHER ECONOMIZING METHODS

Education

Water use declines when consumers are knowledgeable about where their water comes from and how much they use. Indeed, it appears that the more consumers know about the origin, nature, treatment, and cost of the water resources on which they depend, the more careful and economizing they are about use. Bruvold (1988) showed that metropolitan consumers in California, who are well informed about the origin of their domestic water and the costs of moving and treating it, tend to economize on its use, often by as much as 15–20%. This analysis was extended to major communities in the western United States by Michelsen et al. (1999), who showed that such reductions tend to be pervasive. In major metropolitan areas, utilities attempt to educate people about where their water comes from, how supplies are affected by drought, the quality of their water supplies, and the impacts of the water treatment and disinfecting systems used.

Traditional methods of reporting water consumption make it difficult for consumers to understand how much they use. Frequently, the amount of water consumed, as reported on utility bills to which rates are applied, is reported in unspecified and undefined units. In these circumstances, most consumers have no understanding whatsoever of their consumption level. When billing information includes rates of consumption in familiar units, such as gallons per day or gallons per month, consumers have a much clearer understanding of consumption levels and tend to use less than those who lack this information. Another frequent and helpful practice is to provide information on past as well as current levels of consumption. For example, a monthly bill might contain clear information on the consumption during the month in question as well as during the same month a year earlier.

Educational measures such as these are low in cost and simple. They are helpful in obtaining initial reductions in water consumption, which seem to occur when people first become aware of their rate of consumption. They are also helpful in facilitating adaptation to drought conditions. This is particularly true when special pricing or rate rules are imposed during drought periods in an effort to reduce consumption. Consumer education is one of the least costly means of inducing economical use of water (Michelsen et al. 1999).

Rationing

One usually thinks of water rationing in terms of the developing world. Yet, intelligently designed rationing systems can be employed as water-economizing measures in developed countries as well. Rationing works best as a response to temporary shortages. Rationing over the longer term begets black markets, which can be difficult to identify and regulate. The regulations needed to enforce rationing over the long term are frequently cumbersome and often difficult to enforce, particularly with respect to the indoor use of water. Rationing is thus well suited to the management of drought situations. Successful rationing schemes usually involve restrictions on outdoor water use (such as irrigation of the landscape on even-numbered days) where violations and violators are easy to observe. In addition, voluntary rationing, which can include restrictions on bathing and other indoor water uses, has also been successfully employed as a drought-management tool. Water use for outdoor purposes declined substantially during the drought of 1987–1992 in California, for example.

Rationing is frequently practiced in irrigated agriculture where the quantities to be delivered each year may be dependent on precipitation levels. Early in the year, growers are given an indication of how much water is likely to be available. This permits some flexibility and allows growers to adapt by fallowing some land or switching to less-water-intensive crops. In recent years, great progress has been made in learning how to irrigate permanent crops when water is rationed (Fereres et al. 2003). In most instances, crop yield will be reduced but the quality of the yield will be protected. The rationing of irrigation water is more easily practiced over the long term because reduced water deliveries can be anticipated. It is obviously undesirable to ration household deliveries of water where basic needs for drinking, cooking, and sanitation may be jeopardized.

Point-of-Use Technology

Employing point-of-use technology that reduces water flow or hardware that otherwise reduces water use are other ways of economizing on water use. Thus, low-flush toilets, low-flow showerheads, and flow restrictors can reduce the quantity of water used for various household purposes. In the future, recycling technologies that employ separate plumbing may make the use of gray water attractive for household landscape irrigation. Although the opportunities for economizing on industrial water use are more limited because of the current high level of recycling, some new point-of-use technologies may be very attractive to industry. This will be especially true where the costs of such technologies are outweighed by reduced water and wastewater treatment costs.

Point-of-use technology in agriculture can also result in significant savings. Closed-conduit irrigation technologies—sprinkler and drip irrigation—can overcome inherent water-use inefficiency in light soils, with the result that yields can be maintained or increased with a constant or reduced amount of irrigation water. Mulching techniques that reduce evaporation from the soil surface are also promising. Appropriate regimes of moisture-stressing crops—providing crops with less water than is optimal for their needs—are also important point-of-use technologies. Such regimes promote fruiting and fruit quality and often restrict vegetative growth that contributes nothing to crop productivity. Significant investment in the development of such technologies is being made, which should enhance the ability of growers to economize on water use.

CONCLUSIONS

As water scarcity intensifies in the face of future population and economic growth, the prospects of developing supplemental water supplies in both arid and humid regions will decline. Increasingly, water users will be confronted with the need to manage water more carefully so as to economize on its use. New and existing technologies will provide some help. Recycling and reuse technologies can help to extend existing supplies, allowing them to be used in ways that increase productivity. New and existing point-of-use technologies can be similarly helpful in the domestic, industrial, and agricultural sectors. However, if the full promise of demand management is to be realized, it will be important to employ softer institutional paths to economizing on water. Educating water users on supply characteristics, use levels, and practices for economizing is likely to be low in cost and highly effective. Pricing and markets can also have a significant role in "rationalizing" water use so as to ensure that the maximum value is obtained from limited supplies. Finally, rationing provides opportunities for managing temporary reductions in water supply in virtually all water-using sectors.

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NEW LEADERSHIP FOR THE IAGC

The IAGC Board has selected a new vice-president and six new Council members, all of whom assumed their duties at the conclusion of the IAGC business meeting held in Guanajuato, Mexico, during the Water–Rock XIII symposium in August 2010.

IAGC Vice-President

Richard B. Wanty of the U.S. Geological Survey is the new IAGC vice-president. Rich received his PhD in geochemistry from the Colorado School of Mines and has since been a research chemist for the U.S. Geological Survey in Denver, Colorado. Rich's research focuses on mineral and energy resources, trace element geochemistry, drinking water quality, radionuclide geochemistry, and various other topics. His recent research has been on the environmental effects of historic mining; the determination of natural baseline geochemistry of metal isotopes, especially Fe, Cu, and Zn; and landscape geochemistry. Rich is an associate editor of *Applied Geochemistry* and served as an editor for the proceedings of the 11th and 12th Water–Rock Interaction international symposia. Rich has also been a visiting professor at the University of Cagliari and a research professor at the Colorado School of Mines.

Welcoming New Council Members

Ian Cartwright, of Monash University, Australia, has been studying geochemical processes for 25 years. While much of Ian's original work involved understanding crustal fluid flow, his recent work has dealt mainly with groundwater and surface water systems. He uses environmental stable and radiogenic isotopes together with major-ion geochemistry to determine large-scale flow in aquifers, the origin and evolution of solutes, groundwater mixing, and groundwater–surface water interaction. Ian oversees the Monash University Stable Isotope Facility and is also involved in collaborative research in paleoclimatology, diagenesis, and global element cycles.

Janet S. Herman is a full professor in the Department of Environmental Sciences and Director of the Program of Interdisciplinary Research in Contaminant Hydrogeology at the University of Virginia in Charlottesville, Virginia, USA, where she joined the faculty in 1982. Janet obtained her BS in geological sciences (1977) and PhD in geochemistry (1982) at Pennsylvania State University. Her research interests are low-temperature aqueous geochemistry, water–rock interactions, and coupled hydrogeological and geochemical processes. She has been an associate editor of *Applied Geochemistry* and has convened technical sessions at Water–Rock Interaction symposia.

Thomas Kretzschmar is a hydrogeochemist in the Department of Geology at the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Mexico. Previously at the Autonomous University of Ciudad Juárez and the Cd Juárez water utility (JMAS), he studied the hydrochemical development and the chemical distribution of groundwater for the local water supply. During his stay at the JMAS he developed a hydrochemical model for the Boson del Hueco aquifer and became familiar with the environmental needs of the region of Cd Juárez. Thomas is an affiliated researcher and a professor at the University of San Diego, where he is participating in a multidisciplinary research project regarding watershed analysis in the US Virgin Islands. He was the secretary general of the Water–Rock XIII Symposium held in Guanajuato, Mexico, in August 2010.

Philippe Negrel is head of the Isotope Geochemistry Unit and project leader for isotopes in the Metrology Monitoring Analysis Department at the Bureau de Recherches Géologiques et Minières (BRGM), France. Since 2005, he has chaired the Isotope Techniques for Understanding Water Quality Impacts of Wetlands Expert Group for the International Atomic Energy Agency. His research focuses on the application of isotopes in environmental studies.

Martine M. Savard joined the Geological Survey of Canada in 1990 and applied her expertise to the study of Pb–Zn carbonate-hosted deposits in Canada, Morocco, and Peru. She contributed to the development of new exploration strategies for petroleum in eastern Canada. Martine is an adjunct professor at the Centre Eau Terre Environnement of the Institut National de la Recherche Scientifique and is the head of the Delta-Lab, a stable isotope laboratory now dedicated to solving environmental issues. She is pursuing research on the sustainable development of groundwater in the context of intense agriculture. Last year, Martine organized the 8th Applied Isotope Geochemistry Working Group meeting at the Manoir Richelieu in La Malbaie, Quebec, Canada.

Teodóra Szőcs is the head of the Department of Hydrogeology at the Geological Institute of Hungary (MAFI), Hungary. She has worked in the hydrogeochemical and modeling branch of the Department of Hydrogeology. Her main research areas include survey and hydrogeochemical evaluation of shallow and deep groundwaters, with emphasis on arsenic, water–rock interaction, and hydrogeological modeling of flow systems. She is the national representative for Hungary in the EuroGeoSurveys' Water Resources Expert Group and national president of the Hungarian chapter of the International Association of Hydrogeologists.

PHD STUDENT RESEARCH GRANTS

The IAGC Student Research Grant program is to assist PhD students in geochemistry to undertake and acquire geochemical analyses in support of their research based upon receipt of a meritorious proposal. Here are the three recipients of an IAGC PhD Student Research Grant for 2010:

G. P. Gurumurthy of the Department of Civil Engineering at Mainipal Institute of Technology (India) received a grant of US$500 in support of his dissertation research "Major Ion, Trace Element, and Organic Carbon Geochemistry of the Nethravathi River, Southwest Coast of India."

Lindsay MacKenzie of the Department of Geosciences at the University of Montana (USA) received a grant of US$1000 in support of her dissertation research "Using Geochemistry and Sedimentology to Determine the Taphonomy of the Chengjiang Biota, Yuanshian Formation, Yunnan Province, China."

Christina Puscas of the Department of Geology at the University of South Florida (USA) received a grant of US$2500 in support of her PhD dissertation "Hypogene Caves along the Cerna Valley, Romania."

Geochemical Society

www.geochemsoc.org

GEOCHEMICAL NEWS 145 – CURIOSITY

The Geochemical Society's online publication *Geochemical News* has returned with a series of articles on the instrumentation for the upcoming Curiosity Mars Science Lab. The issue's authors include Paul Mahaffy, Bethany Ehlmann, David Blake, and Roger Wiens. The publication is available online or as a free, downloadable pdf file at www.geochemsoc.org/publications/geochemicalnews/.

CALL FOR NOMINATIONS FOR 2012 OFFICERS

The Nominations Committee of the Geochemical Society is seeking names of potential nominees for vice-president and three director positions; these postings will begin on January 1, 2012. The potential nominees should have established reputations of leadership in geochemistry and be willing to devote considerable time and effort to the work of the Society. Suggestions may be communicated by July 31, 2011, to any member of the 2012 Nominations Committee or to the GS business office. More information regarding the duties and responsibilities of Board positions can be found on the Geochemical Society website.

GEOCHEMICAL CAREER CENTER

The Geochemical Society's Geochemical Career Center offers an easy-to-use and highly targeted resource for online employment connections!

Featured Job

Postdoctoral Position
*University of Maryland, College Park, USA**

The Isotope Geochemistry Laboratory in the Department of Geology at the University of Maryland invites applications for a one-year position in isotope geochemistry. International candidates will be considered.

For more details and to apply, please go to: http://jobs.geochemsoc.org/jobs/.

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* Post open through July 5, 2011

Geochemical Society Business Office
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Fax: 314-935-4121
Website: www.geochemsoc.org
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21st Annual
V.M. Goldschmidt
Conference
Prague, Czech Republic
August 14-19, 2011

Watercolour "Prague, the City of a Hundred Spires" by [illegible]

www.goldschmidt2011.org

Mineralogical Association of Canada

www.mineralogicalassociation.ca

GAC-MAC ST. JOHN'S, MAY 27–29, 2012: MARK THE DATE

The year 2001 was the last time the Geological Association of Canada and the Mineralogical Association of Canada (GAC-MAC) annual meeting was held in Newfoundland. It was my very first time in Newfoundland, and I fell under the spell of the youngest province of Canada, aka The Rock, as most of its visitors do. Still vivid in my mind are the memories of the hospitality of its people, the pride of the Earth science community in hosting the meeting, the fine houses in St. John's, a wonderful boat trip to see the puffins, the good food, the music scene, and the pubs on George Street. So I am looking forward to the 2012 meeting, and I extend an invitation to all to attend this medium-sized meeting; about 1200 registrants are expected. The local organizing committee, under the chairmanship of Alana Hinchey and MAC representative Steve Piercey, has concocted an exciting technical program, including 2 short courses and an especially attractive program of field trips (7 day trips and 11 pre- and postconference trips, 3 to 5 days in length).

Social highlights will include an **Evening Banquet** of fine dining and memorable Newfoundland entertainment. Special events will include a **Lobster Feast**—a chance for lobster lovers to enjoy the finest that the North Atlantic has to offer—and a **Pub Night**, providing an opportunity to enjoy the sights and sounds of historic downtown St. John's.

The accompanying guest program includes a boat tour highlighting North America's oldest European settlement; Cape Spear Lighthouse and whale-watching tours; a day tour of the communities of the northeastern Avalon Peninsula; and a visit to the Bell Island Mine, once the world's largest submarine iron ore mine. The end of May is a fine time to tour this Atlantic province, so consider extending your visit after the conference.

A sampling of special sessions and field trips on offer is presented below, but make sure to view the full program at www.stjohns2012.ca.

See you there!

Pierrette Tremblay

A Sampling of the Program

Field Trips

- Neoproterozoic epithermal gold mineralization of the Northeast Avalon Peninsula – Greg Sparkes
- Environmental and urban geology of the St. John's area – Norm Catto
- Accreted terranes of the Appalachian Orogen in Newfoundland: In the footsteps of Hank Williams (5 days) – Cees van Staal, Alexandre Zagorevski
- Volcanogenic massive sulphide deposits of the Appalachian Central Mobile Belt (5 days) – Steve Piercey, John Hinchey
- Meguma Terrane revisited: Stratigraphy, metamorphism, paleontology, and provenance (3 days) – Sandra Barr, Chris White
- The Grenville Province of southeastern Labrador and adjacent Québec (5 days) – Charlie Gower
- Geotourism and the coastal geologic heritage of the Bonavista Peninsula: Current challenges and future opportunities (3 days) – Amanda McCallum, Sean O'Brien

Special Sessions and Symposia

- Tectonic style in Precambrian orogens: How far back in time do uniformitarian plate tectonic principles work? – Toby Rivers, David Corrigan
- Unravelling the tectonic evolution of deeply exhumed orogens, with special reference to the Proterozoic Grenville and Sveconorwegian orogens – Toby Rivers, Aphrodite Indares, Jenny Andersson, Bernard Bingen
- Building the North American continent: A perspective from Precambrian basins – Andrey Bekker, Rob Rainbird, David Corrigan
- Proterozoic mineralization: Exploring Ni–Cu, BIF, REE, and U mineralization – Derek Wilton, Trevor MacHattie
- Collision tectonics and terranes: The Appalachian-Caledonian experience; the Hank Williams Memorial Symposium – Cees van Staal, Steve Johnston
- Volcanogenic massive sulfide (VMS) deposits of the Appalachian-Caledonian orogen – Steve Piercey, Reg Wilson, Jim Walker, Sean McClenaghan
- Gold metallogeny of the North Atlantic borderlands – Hamish Sandeman, Kay Thorne
- Unconventional shale-gas systems – Joe Macquaker
- Cold-water carbonates: Ancient and modern – Evan Edinger
- Facies models and beyond – Peir Pufahl
- Urban geochemistry – Trevor Bell
- Impact structures on the land and in the heavens – James Whitehead
- Geochemical exploration for rare earths and rare metals – Stephen Amor
- Metal solubility in mineralizing fluids and ore-forming silicate melts – Jacob Hanley, Zoltan Zajacz

Short Courses

- Quantitative mineralogy and microanalysis of sediments and sedimentary rocks – Paul Sylvester
- Mineral deposits of the northeast Appalachians and northeast Laurentia: A Newfoundland and Labrador perspective – Derek Wilton, John Hinchey

2011 AWARDS

The Mineralogical Association of Canada presented most of its 2011 awards at its annual luncheon on May 26 during the GAC-MAC annual meeting in Ottawa. The Peacock Medal was presented during the meeting's gala evening. We reproduce excerpts of citations below.

Martin A. Peacock Medal to Daniel J. Kontak

The Peacock Medal, the highest honor bestowed by the Mineralogical Association of Canada, was awarded to Daniel J. Kontak for his contributions to the field of mineral deposits geology. From 1986 to 2006, Dan was employed as a mineral deposits geologist for the Nova Scotia Department of Natural Resources. In 2006 he moved to Sudbury, Ontario, to take up a faculty position as an economic geologist at Laurentian University, where he currently teaches and conducts research. Dan's research interests are varied, but his forte is in mineral deposit geology. He has demonstrated expertise in integrating data from geochemistry, igneous petrology, structural geology, ore petrology, geochronology, stable isotope geochemistry, mineral chemistry, and fluid inclusion research to solve some of the most complex and significant problems in ore deposits research, most recently the origin of pegmatites and their associated fluids. Daniel's contributions are eloquently expressed in over 160 scientific papers and 15 short course presentations on mineral deposit modeling. He has received the MAC Hawley Medal twice, once in 1990 for his research on the East Kemptville topaz–muscovite leucogranite, and again in 2002 for his contribution to understanding the petrogenesis of peraluminous aplite sheets, which are ubiquitous throughout Earth history. Daniel is committed to the well-being of our science, as demonstrated by editorships for the Canadian Institute of Mining and Metallurgy, *Atlantic Geology*, *The Canadian Mineralogist*, and *Economic Geology* and by his involvement in the Mineralogical Association of Canada.

Young Scientist Award to David A. Fowle

The Young Scientist Award is presented to a young scientist who has made a significant international research contribution in a promising start to a scientific career. The 2011 award was presented to David A. Fowle.

David burst onto the stage of geochemical research with three papers arising from his undergraduate studies at the University of Western Ontario (completed in 1996). This was followed by highly productive graduate work at the University of Notre Dame (PhD in 2000), a postdoctoral fellowship at the University of Wisconsin–Madison, and his appointment to a faculty position at the University of Windsor (2001). He was awarded a Tier 2 Canada Research Chair in 2002, which he held until 2006 when he moved to a faculty position at the University of Kansas. David has more than 30 refereed publications in his research theme of the microbiologic controls on geochemical and ecological patterns and processes. His initial research was in the laboratory, but as his work matured, he has increasingly focused on the natural environment. He is a multidisciplinary scientist who is comfortable working in collaborative environments. David is an accomplished experimentalist, a field scientist, and an exceptional research team leader and teacher. He is emerging as a leader in the study of the interaction of biota with minerals and other natural solid phases, a field that is important for understanding and mitigating anthropogenic impacts on Earth's surface. David Fowle is richly deserving of the Mineralogical Association of Canada's Young Scientist Award.

The Hawley Medal to Joel D. Grice for the best paper published in The Canadian Mineralogist *in 2010*

Grice JD (2010) The role of beryllium in beryllosilicate mineral structures and zeolite formation. Canadian Mineralogist 48: 1493-1518

Recognizing the mineralogical diversity, structural complexity, and technological importance of beryllosilicate minerals, and intent on improving upon past approaches, Joel D. Grice has developed a highly informative method for classifying beryllosilicate minerals. Fundamental building blocks are the key to ordering knowledge of these complex structures, which in combination with vertex symbols and coordination sequences have shed new light on the structural relationships. Grice's study provides an exhaustive examination of beryllosilicate mineral topologies, as well as revealing illustrations and commentary. It provides new knowledge concerning topological densities and the frequency of topological rings across the series of structures. The paper will prove to be a seminal contribution to the mineralogy of this complex group. Joel Grice has been selected as the recipient of the 2010 Hawley Medal for the paper judged by a panel of peers to be the best published in *The Canadian Mineralogist* in 2010.

Joel Grice has been Curator of Minerals and Researcher at the Canadian Museum of Nature since 1976. In 1995, he was elected chairman, Commission on New Minerals and Mineral Names, IMA, and he held this position for two terms.

Mineralogical Society of Great Britain and Ireland

www.minersoc.org

FROM THE GENERAL SECRETARY

As of January this year, I have taken over from Mark Hodson as the General Secretary of the Mineralogical Society. One thing that I'd particularly like to encourage during my time in this position is collaboration: not just among our members or between us and other societies, but even wider, among academics, industry and government. Mineralogy has a significant part to play in many of the challenges that the world faces today, as is often highlighted by *Elements* – water resources are just one important example. So much research carried out by mineralogists has great societal relevance, from understanding the resources of critical metals needed for the development of new technologies, to sequestering CO_2 through mineralization and the remediation of contaminated land. Yet still, membership in the Mineralogical Society – and attendance at our conferences – is overwhelmingly dominated by academics. I hope that we can expand our horizons and that the Society can do more to foster links between our members and the world outside. Already, since I took over from Mark, we have responded to a government inquiry into strategic metals. I'd welcome any suggestions that *Elements* readers may have about broadening our links with government and industry, and I look forward to hearing from you!

An initiative by Society member Dr Richard Harrison, in which we seek input from all sectors, i.e. academia, industry and government, is the "100 Most Important Questions in Mineralogy". See page 209 in this issue of *Elements* for details and visit our web page for further information: www.minersoc.org.

Kathryn Goodenough
General Secretary, Mineralogical Society

SCIENCE COUNCIL

The Mineralogical Society has been awarded licensed-body status by the Science Council. What this means is that the Society is now in a position to award Chartered Status (CSci) to qualified members.

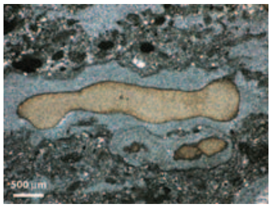
CSci represents a single chartered mark for all scientists and recognises high levels of professionalism and competence in science. There are currently around 15,000 Chartered Scientists working in a vast array of settings and across all scientific and related sectors. Being chartered is the mark of professional recognition. Being a Chartered Scientist allows all scientists working at the full professional level to be recognized on an equal footing. The status gives an assurance of current competence through mandatory revalidation and encapsulates the interdisciplinary nature of science in the 21st century. By benchmarking professional scientists at the same high level, CSci aims to re-engage public trust and confidence in science and scientists. CSci is equivalent in terms of standing to CGeol, CEng, etc.

Applicants must demonstrate various competencies, including the ability to deal with complex issues and communicate their conclusions to a range of audiences. They must show originality in problem solving and substantial autonomy in planning and implementing tasks. Through a commitment to continuing professional development, Chartered Scientists will continue to advance their knowledge, understanding and competence throughout their careers.

Further information will be made available in due course, and it is expected that the first applications for chartered status will be made in late 2011.

Clay Minerals Group – Frontiers in Diagenesis: Clay and Carbonate Facies and Their Diagenetic Pathways in Reservoir Rocks

Department of Earth Sciences, University of Cambridge, Cambridge, UK



The Cambridge Diagenesis Conferences have been a forum for academia and the hydrocarbon industry to consider the interfaces between new ideas, what is thought to be known, and what is established. As in previous meetings, the 2011 conference will encourage the free exchange of ideas and observations, with particular emphasis on young researchers. We welcome all topics related to the clay and carbonate facies and their diagenetic pathways in reservoir rocks. There will be contributions on the following general themes:

- Diagenetic development of reservoir rocks, including shale gas reservoirs
- Relating early diagenetic signals to geochemical and biological evolution, including a session devoted to the late Proterozoic
- Rates and mechanisms of chemical transfer in diagenetic systems
- Timing of geological events within diagenesis, including a session on Upper Cretaceous chalk

Suggestions for other themes are welcome; contact C. Jeans (cj302@cam.ac.uk) or Nick Tosca (njt41@cam.ac.uk).

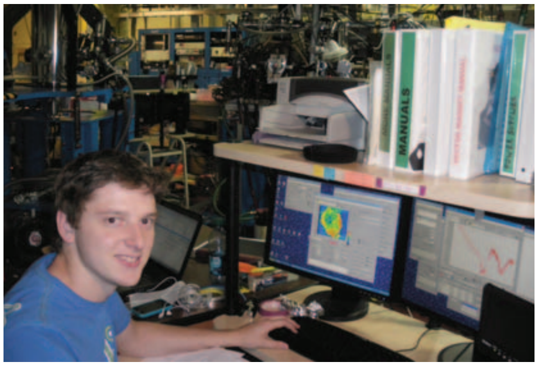
Register online at: www.minersoc.org/pages/groups/cmg/cmg.html.

MINERALOGICAL SOCIETY STUDENT BURSARIES FOR 2011

Bursaries for 2011 have been awarded to the following students: L. Bullock, E. Derbyshire, P. Doyle, R. Ellen, A. Ellis, F. Enea, L. Greenwood, E. Nicholson, K. Preece and C. Sarkar.

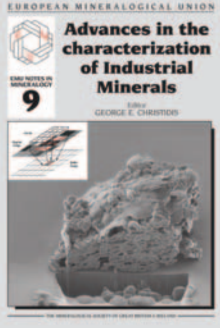
MINERALOGICAL SOCIETY SENIOR BURSARIES FOR 2011

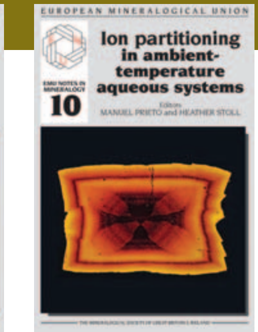
Senior Bursaries have been awarded to the following scientists: M. Brown, V. Coker, F. Cooper, K. Dobson, F. Wall and J. Wheeler.



James Byrne, 2010 bursary winner

PUBLICATION NEWS





EMU Notes in Mineralogy Series

Since last year, the Mineralogical Society has become co-publisher of the EMU Notes in Mineralogy series. Three books in the series have been published so far:

- EMU-8: *Nanoscopic Approaches in Earth and Planetary Sciences* Frank E. Brenker and Gunter Jordan (eds)
- EMU-9: *Advances in the Characterization of Industrial Minerals* George E. Christidis (ed)
- EMU-10: *Ion Partitioning in Ambient-Temperature Aqueous Systems* Manuel Prieto and Heather Stoll (eds)

The fourth book, arising out of the 2011 EMU School, will be published in June/July 2011. All of these books, and others, are available from the Society's online bookshop; visit our website at www.minersoc.org.

Landmark Series

The keenly awaited fourth in the series of Landmark books is nearing the final stage of completion. *Landmark Papers: Granite*, by J. C. Clemens and F. Bea, will be available shortly on our website, www.minersoc.org.

Volumes 1 to 3 are also available for purchase:

Volcanic Petrology, by I. S. E. Carmichael
Structure Topology, by F. C. Hawthorne
Metamorphic Petrology, by B. W. Evans

These are priced at £32 for members of the public, or at £18 for members of the Society. Join now!

Mineralogical Magazine

The August issue of *MinMag* will contain a thematic set of papers arising out of the September 2010 meeting "Nuclear Waste Management: Research Challenges for the Future". The papers of the issue will be made available on an open access basis and will include the Hallimond Lecture:

- ACTINIDES IN THE NUCLEAR FUEL CYCLE: ROLE OF MINERALOGY AND GEOCHEMISTRY – R. C. Ewing

Plutonium waste cannisters

Principal Editors

Roger Mitchell and Peter Williams are now firmly installed as the joint Principal Editors of the journal, and the handover from Mark Welch is complete. We will maintain our short submission-to-publication times and will continue to publish in full colour.

Peter Williams

Roger Mitchell

Production Editor

The Society has appointed a new Production Editor. He is Dr David Green and is based in Manchester, UK. His e-mail address is green@minersoc.org.

Open Access

Please note that the excellent review paper by Peter Burns, "Nanoscale uranium-based cage clusters inspired by uranium mineralogy", from which the cover image of the February issue was taken, is available to all on an **open access** basis. Access to the paper on our site is unrestricted, and the author is at liberty to post copies on his personal website and on departmental or repository sites. If you'd like more information about publishing your paper in this way, please contact Kevin Murphy (kevin@minersoc.org) or the Production Editor.

Clay Minerals

The contents for the June 2011 issue of the journal are as follows:

- NATURAL ZEOLITES FOR STYRENE OLIGOMERISATION – S. owalak and A. Jankovska
- PREPARATION OF MAYA BLUE ANALOGUES USING NATURAL ZEOLITES – S. Kowalak and A. Zywert
- PREPARATION AND RIETVELD REFINEMENT OF AG-EXCHANGED CLINOPTILOLITE – L. Dimova, O. Petrov, M. Kadiyski, N. Lihareva, A. Stoyanova-Ivanova and V. Mikli
- PHYSICAL AND MECHANICAL CHARACTERISTICS OF CEMENT MORTARS AND CONCRETES WITH ADDITION OF CLINOPTILOLITE FROM BELI PLAST DEPOSIT (BULGARIA), SILICA FUME AND FLY ASH – V. Lilkov, I. Rostovsky and O. Petrov
- RHEOLOGICAL, POROSIMETRIC, AND SEM STUDIES OF CEMENTS WITH ADDITIONS OF NATURAL ZEOLITES – V. Lilkov, O. Petrov and Y. Tzvetanova
- MATHEMATICAL MODELLING OF THE SORPTION DYNAMICS OF RADIONUCLIDES BY CLINOPTILOLITE-CONTAINING TUFFS IN PERMEABLE REACTIVE BARRIERS – V.A. Nikashina, I.B. Serova, E.M. Kats, N.A. Tikhanov, M.G. Tomachev and P.G. Novgorodov
- STUDY OF THE POZZOLANIC ACTIVITY AND HYDRATION PRODUCTS OF CEMENT PASTES WITH ADDITION OF NATURAL ZEOLITES – V. Lilkov, O. Petrov, V. Petkova, N. Petrova and T. Yzvetanova
- BINARY CATION EXCHANGE INVOLVING K^+, NA^+, BA^{2+}, AND CA^{2+} IN CLINOPTILOLITE AT 30 AND 95 °C: A CALORIMETRIC STUDY – N. Petrova, L. Filizova and G. Kirov
- ZEOLITIZED TUFFS IN PEDOTECHNIQUES TO IMPROVE SOIL RESILIENCE AGAINST THE IMPACT OF TREATMENT BY MUNICIPAL SEWAGE: BUDGET OF NUTRIENT AND NOXIOUS CATIONS – G.F. Capra, A. Buondonno, G. Coppola, M.G. Duras, S. Vacca and C. Colella

The Clay Minerals Society

www.clays.org

THE PRESIDENT'S CORNER

Paul Schroeder

I don't know about you, but it seems I can only communicate with my teenage kids when they are away if I send them a text message; likewise, they send me their news only via text messages. I tell them that someday a very smart person is going to invent a device that will record your voice, convert it to text (using some highly sophisticated recognition software and artificial intelligence), transmit the data, and convert the text message back to a sound that emulates your voice, thus eliminating the need to type messages and divert your eyes to read tiny printed texts. I say, "Really cool, huh?" They emphatically reply, "Yes!" I say, "It's already been discovered and it's called a phone! Try using it!"

In science, I call this discovery phenomenon "revol-looping," which is defined as coming up with a revolutionary idea after a long systematic research effort, only to realize that the idea has already been around for years. Not to be a hypocrite, I've done my fair share of revol-looping, which is why I tell my students that three days in the library is worth three months in the lab. The Clay Minerals Society provides a unique opportunity to minimize revol-looping in biological and physical sciences by virtue of our Source Clays Repository. Being clay scientists, we appreciate the amazing nanoarchitecture in clay mineral interlayers, tubes, and modulated structures, which are now being seen as analogs for synthetic nanomaterials. We also know clay minerals serve as essential components in natural microbiological systems that require some form of assistance by either pushing or pulling electrons, protons, and trace elements. As microbiology and nanotechnology rapidly expand, we need to keep a commensurate supply of clay mineral reference materials ready for the future. The Source Clay Minerals Committee does a fine job at keeping this resource alive. Special thanks go to pioneers Paul Kerr, George Brindley, Bill Moll, and Bill Johns for fostering the program, as well as to numerous other CMS members who have since championed the Source Clays effort.

CMS members can help maintain the repository. Here are few ways you can contribute: (1) Purchase and use the Source Clays for quality control in the lab, for teaching students, and in your personal research. (2) Promote the Source Clays to colleagues outside of clay science. Ask your neighboring microbiologist or nanotechnologist if they are using CMS Source Clays and give the link to our website. (3) Volunteer to help maintain the supply of CMS Source Clays. Supplies dwindle and periodically need to be replaced. Source Clays are natural materials; therefore, diligent site supervision is needed to direct sample collection and shipment to the Source Clay home, currently at Purdue University. Collection sites are often remote and may change with reclamation practices. If you are familiar with a source clay collection site or can think of a new one, then contact a Source Clay Committee member or contact me.

Along the lines of communication, have you heard the news? Someone invented this really clever device that transmits voice to voice so you can actually hear what the other person is saying. It's called the phone! Please feel free to use it with me, and I'll try to minimize my revol-looping. Cheers.

Paul Schroeder (schroe@uga.edu)
President, The Clay Minerals Society

The Clay Minerals Society
Annual Meeting, 25–30 September 2011
Lake Tahoe, Nevada, USA

CMS Workshop "Trace Elements and Clays: Occurrence, Analysis and Applications": 25 September

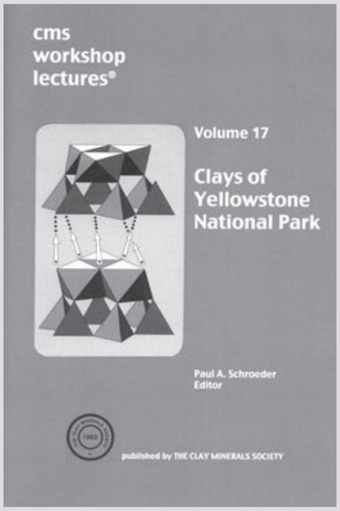
Technical sessions: 26–29 September

Field trips: 30 September

See the CMS website for more information: www.clays.org.

RECENT VOLUMES IN THE CMS WORKSHOP LECTURES SERIES

- Clays of Yellowstone National Park (2010)
- Carbon Stabilization by Clays in the Environment (2009)
- Clay-based Polymer Nano-composites (2007)
- Methods for Study of Microbe-Mineral Interactions (2006)
- The Application of Vibrational Spectroscopy to Clay Minerals and Layered Double Hydroxides (2005)
- Molecular Modeling of Clays and Clay Minerals (2003)
- Teaching Clay Science (2002)



Association of Applied Geochemists

www.appliedgeochemists.org

FROM THE PRESIDENT


Paul Morris

On receipt of this copy of *Elements*, many AAG members will be finalising plans for attending the Association's 25th International Applied Geochemistry Symposium in Rovaniemi, Finland. Membership in AAG includes more than receipt of the society's two journals, *Geochemistry: Exploration, Environment, Analysis* and *EXPLORE* (as well as *Elements*). For many members, the biennial symposium is a strong drawcard to the Association, as it offers the opportunity to not only keep up to date with the applied aspects of geochemistry but also to meet up with fellow practitioners from around the world. The willingness of members to voluntarily organise these meetings and the geographic diversity of the AAG membership allow these biennial meetings to be held in diverse locations in both hemispheres. This means that members are exposed to new geology and to the novel ways in which geochemistry can be applied in mineral exploration and environmental management.

As with most scientific associations, AAG's day-to-day business – including the organisation and running of its symposia – is looked after by volunteers. Most serve for a few years in one capacity, some do several years in several capacities, and then there are the exceptional ones who have a long association in a variety of roles. At this year's IAGS meeting, the AAG will honour Eion Cameron, one of these exceptional members, by presenting him its Gold Medal. This medal – for outstanding scientific achievement in exploration geochemistry – is the highest honour that the Association can bestow; receiving it is a reflection of Eion's distinguished career as an explorationist, innovator, educator and organiser. He was a founding member of the Association of Exploration Geochemists (AEG, now AAG), which dates his involvement with the Association because it recently celebrated its 40th birthday.

I would like to take this opportunity to welcome Patrice de Caritat to his new role as AAG's *Elements* coordinator (since Volume 7, Number 2) and to thank David Lentz for his previous contributions and commitment to this position.

Paul Morris (paul.morris@dmp.wa.gov.au), AAG President
Geological Survey of Western Australia

RECENT ARTICLES PUBLISHED IN *EXPLORE*

In this new segment, articles recently published in the AAG newsletter, *EXPLORE*, will be highlighted. Articles in *EXPLORE* can be downloaded for free from the Association's website: (www.appliedgeochemists.org).

- Fardin Mousivand, Ebrahim Rastad, Jan M. Peter and Michael Solomon (2011) Age, tectonic setting, lithogeochemistry and hydrothermal alteration of volcanogenic massive sulfide mineralization in the Chahgaz region, south Sanandaj-Sirjan zone of Iran. EXPLORE 150 (March 2011)
- Wendy A. Spirito and Stephen W. Adcock (2010) Canadian geochemical data on the web. EXPLORE 149 (December 2010)
- Robert G. Garrett (2010) How many samples are enough? EXPLORE 149 (December 2010)
- Clifford R. Stanley (2010) How many samples are enough? EXPLORE 148 (September 2010)
- Dennis Martin Schlatter, Uffe Larsen, Bo Møller Stensgaard & Guy Buller 2010. Digital field data capture: the Geological Survey of Denmark and Greenland experiences in Greenland. EXPLORE 147 (June 2010)
- Ryan R.P. Noble, David J. Gray, Ian D.M. Robertson & Nathan Reid 2010. Hydrogeochemistry for mineral exploration in Western Australia (I): Methods and equipment. EXPLORE 146 (March 2010)

AAG COUNCILLORS 2011–2012

The Association welcomes the involvement of several new councillors for the 2011–2012 term: Patrice de Caritat, John Carranza, Matt Leybourne, Romy Matthies, Cliff Stanley and Erick Weiland. Short bios for some of them appear below, and the March 2011 issue of EXPLORE (volume 150) provides details on all (www.appliedgeochemists.org).

Patrice de Caritat has a PhD in sedimentary geochemistry and has practised in water and regolith geochemistry for two decades in Canada, northern Europe and Australia. His interests are in mineral exploration and the impacts of industry on the environment. He is currently project leader at Geoscience Australia for the National Geochemical Survey of Australia, which has just released a quasi-continental geochemical atlas and an underpinning dataset.

John Carranza was a geologist in the Mines and Geosciences Bureau (Philippines) from 1983 to 2001. His work there on exploration geochemistry led to recognition of a previously unknown mineralised area in a Quaternary volcanic terrane. He received the 1998 Research Award from ITC (International Institute for Geo-Information Science & Earth Observation, The Netherlands). In 2001–2003, he was a researcher at ITC on mineral resource management. Since 2003, he has been an assistant professor at ITC, which became in 2010 a faculty of Twente University. John's research involves exploration geochemistry, mineral prospectivity mapping and geological/mineral remote sensing. He has published more than 50 papers in international peer-reviewed geoscience journals and more than 40 papers in international conference proceedings. He has written and published a book entitled *Geochemical Anomaly and Mineral Prospectivity Mapping in GIS*.

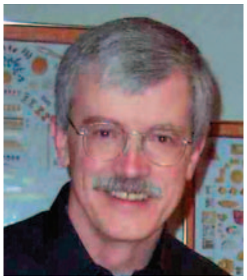
Romy Matthies is a German biogeochemist who holds a PhD from Newcastle University, UK. Her main research interests are on mine drainage generation, prediction, passive remediation and impact assessment. She recently had to terminate her JSPS-funded postdoctoral research at Tohoku University, Japan, due to the disruptions caused by the recent magnitude 9.0 earthquake. With her future hosts at Waterloo University (Prof. Blowes) and Newcastle University (Dr. Jarvis), she is currently rescheduling the commencement of her Marie Curie fellowship to investigate the fractionation processes of non-traditional isotopes.

Erick Weiland has been an active member of AAG since 1978 and has served on past Councils, on the Executive and on various committees. In addition to his recent election to Council, he chairs the AAG Education Committee. He is also the professional geologist's representative on the Arizona Board of Technical Registration. Erick has worked in or with the mining, water resource, and environmental industries in 14 countries since 1973. He received a BS in geological engineering and an MS in geochemistry from the Colorado School of Mines. Erick is an expert in the application of geochemistry in mining, water resource, engineering and environmental projects. Erick applies his skills and experience to assisting clients through his position as Principal Geochemistry Specialist at ARCADIS–US, Inc., in Tucson, Arizona.

Mineralogical Society of America

www.minsocam.org

PRESIDENT'S LETTER

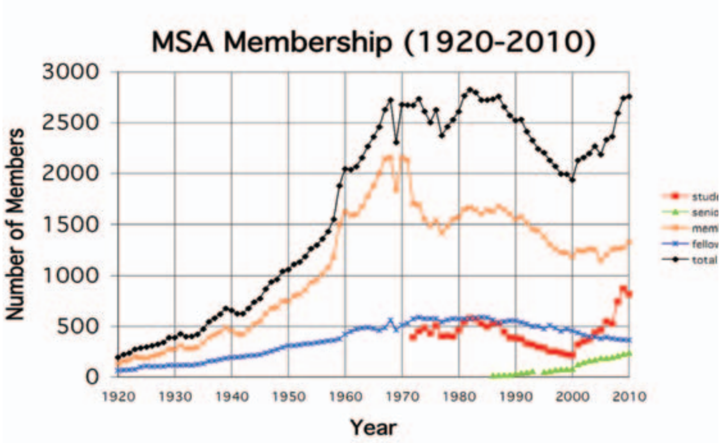


David Bish

I have just returned from a couple of trips to scientific meetings that gave me a glimpse of the health and breadth of what I broadly term "mineralogy." Not surprisingly, I have seen that mineralogy is alive and well in other countries and in other disciplines. A visit to the Australian X-ray Analytical Association's triennial meeting in Sydney revealed many exciting new developments in the area of X-ray analysis of solids, including mining and industrial applications. The weeklong meeting had talks on a range of topics, from in situ field measurements in mining and archeological settings to detailed structural studies of minerals using synchrotron and neutron sources. Researchers are doing some impressive field studies and very rapid online industrial measurements, and many of the new developments in Australia are being driven by the industrial and mining sector. Of probably broader interest to the MSA membership was the large amount of exciting "mineralogy" evident at the recent Lunar and Planetary Science Conference in The Woodlands, Texas. The meeting consisted of a week of multiple oral and poster sessions focusing on, among other things, the mineralogy and petrology of the Moon, Venus, Mercury, Mars, meteorites, asteroids, comets, and even the icy planets and their moons (apologies if I left out your favorite topic). It was a marvelous and stimulating smorgasbord, broad enough to capture any geoscientist's attention!

MSA Council has been thinking again about the makeup of our membership. For a number of years MSA has had an ad hoc membership committee with a variety of responsibilities, and its members have done numerous good things over the years. Most recently, Sorena Sorensen focused on attracting and involving student members. For the first time, we will invite an MSA student member to the spring Council meeting in Chantilly, Virginia. The figure below shows some interesting trends in membership from 1920 to 2010. The numbers of student members (dues $10/year) and senior members (dues $0) have increased sharply since 2000, and we had 816 student members in 2010. The combined numbers of fellows and members, essentially the economic base of our society, have remained approximately constant during the last 10 years. We are actually beginning to see a decrease in the total number of fellows because the number elected each year has been limited to 0.5% of the total membership for about the past eight years. As you can see from the figure, the rise in total membership from 2000 to 2010 was due almost entirely to new student members.

MSA does a lot to encourage students, and student membership is a tremendous bargain at only $10/year. Most of you probably do not know that MSA spends approximately $65 in goods and services for each member, regardless of category, so every student membership is highly subsidized. Students can apply for the Mineralogy/Petrology and the Kraus Crystallographic research grants. MSA also gave 24 American Mineralogist Undergraduate (AMU) Awards in 2010, each of which includes free student membership and the choice of one of our monographs or RIMG volumes. The AMU Awards program (www.minsocam.org/MSA/Awards/UnderGrad_Award.html) is not only tremendous for the student awardees, it is also an excellent membership benefit wherein faculty at any educational institution can recognize their top students in mineralogy. Many of our members donate through our different giving options, and it is their generosity that makes it possible for MSA to provide such substantial student support in these different areas. I am very grateful to everyone for their support of these programs.



Because of these trends in membership, I have recently appointed a new membership committee with a broadened charge. I have asked the committee to evaluate ways to ensure that MSA continues to provide good value to its members and to examine (if possible) why past members let their memberships lapse. The committee will also consider ways in which we can encourage more student members to "graduate" to full membership when they are no longer students. If you have ideas pertaining to membership issues, please let me know, or contact the committee chair, Penny King (penking@unm.edu).

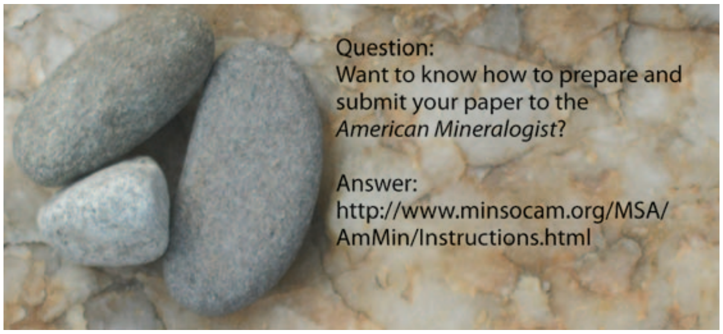
I hope to see some of you at this summer's Goldschmidt 2011 Conference in Prague, where we will present the Dana Medal to Ross Angel. Finally, don't forget to submit your abstract for this fall's GSA meeting in Minneapolis (deadline is July 26). There, MSA will sponsor a number of sessions and will present the Roebling Medal to Juhn G. Liou and the MSA Award to Motohiko Murakami. We'll also cosponsor the popular cocktail hour with the Geochemical Society and the GSA's Mineralogy, Geochemistry, Petrology, and Volcanology (MGPV) Division.

Best wishes for a pleasant and hopefully relaxing summer.

Dave Bish (bish@indiana.edu)
President, MSA

☑ VOTE

2011 MSA ELECTIONS



Question:
Want to know how to prepare and submit your paper to the *American Mineralogist*?

Answer:
http://www.minsocam.org/MSA/AmMin/Instructions.html

IN MEMORIAM

Richard C. Mielenz – Life Fellow, 1946
Fred W. Farwell – Life Member, 1947
Udo Harms – Member, 1991

NOTES FROM CHANTILLY

■ Balloting for the 2011 election of MSA officers and councilors is underway. The slate of candidates for the 2011 MSA Council election is as follows – president: Michael F. Hochella Jr.; vice president: John M. Hughes and Theodore C. Labotka; secretary: Henry L. Barwood and Andrea Koziol; councilors (two to be selected): Christine M. Clark, Adam J. R. Kent, Kimberly T. Tait, and Allan H. Treiman. Darrell Henry continues in office as treasurer. Continuing councilors are Wendy A. Bohrson, Sumit Chakraborty, Pamela C. Burnley, and Guy L. Hovis.

MSA members should have received voting instructions at their current e-mail addresses. Those who do not wish to vote online can request a paper ballot from the MSA business office. As always, the voting deadline is August 1.

■ The MSA had a booth at the Tucson Gem and Mineral Show, Tucson, AZ, 10–13 February 2011, where Jolyon Ralph was presented the 2011 Distinguished Public Service Medal by Bob Downs. Van King was the citationist. The presentation is on YouTube (www.youtube.com/watch?v=oXKwZGSgub0). The Dana Medal will be presented at the Goldschmidt Conference in Prague, Czech Republic, 14–19 August 2011, to Ross John Angel, and there will be a special session in his honor ("Structure, Elasticity and Thermodynamics of Minerals"). MSA will have a booth at the GSA meeting, in Minneapolis, Minnesota, USA, on 9–12 October 2011. During that week MSA will also hold its Awards Lunch, MSA Presidential Address, Joint Reception among MSA, GS, and the new GSA MGPV (Mineralogy, Geochemistry, Petrology, and Volcanology) Division, Annual Business Meeting, Council Meeting, and breakfasts for the past presidents and associate editors. Do not forget the lectures by the Roebling Medalist, Juhn G. Liou, and the MSA Award recipient, Motohiko Murakami. More information will be available through the MSA website.

J. Alex Speer, MSA Executive Director
jaspeer@minsocam.org

50- AND 25-YEAR MSA MEMBERS

The following individuals will reach 50 or 25 years of continuous membership in the Mineralogical Society of America during 2011. Their long support of the Society is appreciated and is recognized by this list and by 25- or 50-year pins, which will have been mailed in early January. If you should be on this list and are not, or have not received your pin, please contact the MSA business office.

50-Year Members

Manuel N. Bass
Peter Bayliss
Richard A. Beach
Peter M. Bell
Arthur H. Brownlow
Richard Vincent Dietrich
Bernard Erlin
Neil E. Foreman
James F. Hays
Edward Allan Jobbins
Blair F. Jones
Cornelis Klein
Donald Langmuir
Bernard E. Leake
Fiorenzo Mazzi
George R. McCormick
Emilio MutisDuplat
George H. Myer
Mervyn S. Paterson
Donald R. Peacor
Robert W. Rex
J. Douglas Scott
Daniel M. Sweeny
Alan R. Woolley

25-Year Members

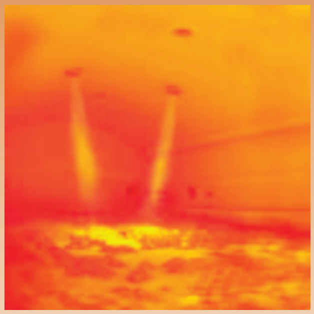
Alan J. Anderson
Richard J. Arculus
Jillian F. Banfield
Sandra M. Barr
L. A. Boatner
John F. W. Bowles
Pamela C. Burnley
Dante L. Canil
George E. Christidis
Philippe D'Arco
Patricia M. Dove
Kathy Ehrig
John M. Fox
Timothy W. Grover
Mickey E. Gunter
Richard D. Hagni
Alain R. D. Hanson
Daniel E. Harlov
Christoph A. Heinrich
Robert E. Jenkins II
Peter B. Kelemen
Andrea Koziol
Antonio Lanzirotti
Ching-Hua Lo
Calvin F. Miller
William G. Minarik
Ritsuro Miyawaki
Masaaki Ohmasa
Giulio Armando Ottonello
J. Michael Palin
Philip M. Piccoli
Lanny R. Ream
Simon A. T. Redfern
Pierre Stephane Salerno
Sheila Seaman
Ulrich F. Soffler
Frank J. Spera Esq.
Allen L. Stork
Tres Thoenen
Marek T. Tokarz
Seiichiro Uehara
Donna L. Whitney

Mineralogical Society of America and Geochemical Society

SHORT COURSE ANNOUNCEMENTS

Sulfur in Silicate Magmas and Melts and Its Importance for Natural and Technical Processes

AUGUST 21–23, 2011 (AFTER GOLDSCHMIDT 2011)
GOSLAR, GERMANY
CONVENORS: Harald Behrens, University of Hannover, and Jim Webster, American Museum of Natural History



The course will cover advances in analytical protocols for sulfur determination in rocks, minerals, and glasses; experimental, spectroscopic and thermodynamic constraints on the speciation, solubility, and diffusion of sulfur in melts; sulfur stable isotope systematics; partitioning of sulfur between fluid, melts, and minerals; the importance of sulfur in preparing, coloring, and melting industrial glasses; volcanic degassing and fining of glass melts; sulfur and magmatic ore deposits; sulfur in solar systems; and others. There will be a poster session for students on August 21 and two workshops:

(1) "The Volcanological Kitchen" (hydrothermal experiments and methods), on August 20 in Hannover, Germany, and

(2) a "Glass-Making and Glass Properties" session on August 24 in Clausthal, Germany.

More information and registration: **www.minsocam.org**

AMERICAN MINERALOGIST UNDERGRADUATE AWARDS FOR OUTSTANDING STUDENTS

The Society welcomes the following exceptional students to the program's honor roll and wishes to thank the sponsors for enabling the Mineralogical Society of America to join in recognizing them. MSA's American Mineralogist Undergraduate (AMU) Award is for students who have shown an outstanding interest and ability in mineralogy, petrology, crystallography, or geochemistry. Each student is presented a certificate at an awards ceremony at his or her university or college and receives an MSA student membership, which includes a subscription to *Elements* and a Reviews in Mineralogy or Monograph volume chosen by the sponsor, student, or both.

Past AMU awardees are listed on the MSA website, as well as instructions on how MSA members can nominate their students for the award.

Nicholas Brown
University of Victoria
*Prof. Dante Canil**

Wendy Anne Cockshell
University of Hawai'i-Manoa
*Dr. Julia Hammer**

Megan D'Errico
Trinity University
*Dr. Diane Smith**

Kent Griffith
Indiana University
*Prof. David Bish**

Thang N. Ha
University of Oklahoma
*Dr. David London**

Thomas Gregory Herbst
Missouri University of Science & Technology
*Dr. John Hogan**

Jamie A. Kendall
Bryn Mawr College
*Dr. Lynne Elkins**

Uyen Thi Thanh Nguyen
University of Oklahoma
*Dr. David London**

David O. Oakley
Williams College
*Prof. Reinhard Wobus**

Yanadet Sripanich
University of Texas at Austin
*Dr. Elizabeth Catlos**

Shelly Jean Wernette
University of Oklahoma
*Dr. David London**

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* Sponsor

Meteoritical Society

http://meteoriticalsociety.org


FIRST ANNOUNCEMENT

HASSAN II CASABLANCA UNIVERSITY
FACULTY OF SCIENCE
In partnership with
ARAB UNION FOR ASTRONOMY AND SPACE
SCIENCES AUASS

ORGANIZES THE SECOND

ARAB IMPACT CRATERING
AND ASTROGEOLOGY CONFERENCE (AICAC II)

CASABLANCA MOROCCO
14th to 20th November 2011

Contact: H. CHENNAOUI AOUDJEHANE
Hassan II University Casablanca.
Faculty of Sciences
h.chennaoui@fsac.ac.ma chennaoui_h@yahoo.fr

ARAB IMPACT CRATERING AND ASTROGEOLOGY CONFERENCE

In November 2009 the Meteoritical Society sponsored the first Arab Impact Cratering and Astrogeology Conference (AICAC), which took place in Amman, Jordan, and brought together scientists and students from a number of Arab countries and from Europe and the Americas. AICAC II is currently scheduled to take place in November 2011 at the Hassan II University in Casablanca, Morocco. Please take note of the dates and the information given on the conference website, www.fsac.ac.ma/aicaii/index.html. Current developments in the Middle East and North Africa will be reviewed in July, with a view to deciding on the final go-ahead for this conference, in good time before the annual meeting of the Meteoritical Society in early August.

METEORITE NOMENCLATURE COMMITTEE

Report from the Chair, Chris Herd

The Meteorite Nomenclature Committee (NomCom), established in 1973 by the Meteoritical Society, governs the naming of meteorites and disseminates information on all new meteorites through the *Meteoritical Bulletin* and the Meteorite Database (www.lpi.usra.edu/meteor/metbull.php). NomCom assesses dense collection areas and develops the formal process for meteorite nomenclature. The Committee reviews names and classifications for several hundred new meteorites from around the world each year. Since the last report, 603 meteorites (354 of which are non-Antarctic) have been approved for *Meteoritical Bulletin* 99 (forthcoming).

After nearly 4 years of service, Michael Weisberg is retiring as editor of the *Meteoritical Bulletin*. The committee is very thankful for his dedicated service. As of April 1, 2011, we welcome **Laurence Garvie** (lgarvie@asu.edu) as the new editor. Other membership changes were made at the start of the year; a list of current NomCom members and their roles can be found at www.meteoriticalsociety.org/bulletin/TermExpirations2011.htm.

Part of the approval process for new meteorites is the designation of a repository for type specimens. Type specimen repositories play an important role in preserving material for scientific research and in curation of that material over the long term. In order to keep our contact information up to date and to gather information on best practices for curation, we are in the process of circulating an online survey to curators. We expect that the outcome of this process will benefit repositories and the scientific community alike. On a related note, a small change has been made to the minimum mass in our guidelines (§7.1f): we now recommend (but do not require) that larger type specimens be provided when the total mass of a meteorite is greater than 400 g. The complete, up-to-date guidelines can be found at www.meteoriticalsociety.org/bulletin/nc-guidelines.htm.

Please do not hesitate to contact me (herd@ualberta.ca) with questions or concerns about NomCom and especially with suggestions for improvement. As always, essential information on meteorite nomenclature, instructions, and the template for reporting new meteorites may be found on our home page, http://meteoriticalsociety.org/simple_template.cfm?code=pub_bulletin.

From the Outgoing NomCom Secretary, Michael Weisberg

It has been a pleasure serving as editor of the *Meteoritical Bulletin* for the past three years, but the editorship is also a formidable task. NomCom is one of the most active and important committees serving the meteoritic and planetary science community. The editor, an *ex officio* member of the Meteorite Nomenclature Committee, manages the meteorite review and voting process, edits meteorite submissions, and is the central point of contact for submission of all new non-Antarctic meteorites. The editor is also responsible for publishing the *Meteoritical Bulletin* twice each year. As editor I was lucky to have support from the current chair, Chris Herd, past chairs Jutta Zipfel and Kevin Righter, and database editor Jeff Grossman. The meteorite database developed and managed by Jeff has become an invaluable tool for conducting NomCom business and a major resource for researching meteorite names, classification, and dense collection areas.

GREENWICH EXHIBIT

From now until the end of August, the Royal Observatory's Impact Season is focussing on asteroids, comets, meteorites and the craters they produce throughout the Solar System. A brand new exhibition, "Impact: Collisions and Catastrophes," is accompanied by a programme of public events, including talks and lectures by scientists, meteorite-handling sessions, and specially produced planetarium shows. For more information, see the Impact website: www.nmm.ac.uk/visit/exhibitions/on-display/impact/.


Artist's impression of a large fireball over London

Mineralogical Society of Poland

www.ptmin.agh.edu.pl

GEOCHEMICAL CONFERENCE: "CONTEMPORARY PROBLEMS IN GEOCHEMISTRY," IN KIELCE, POLAND

Conference attendees standing on the staircase of the Institute of Chemistry building; the authors of this note are in the foreground.

The "Contemporary Problems in Geochemistry" Conference, organized by the Geochemical Group of the Mineralogical Society of Poland and Jan Kochanowski University, was held in Kielce on 27–30 September 2010. This biennial meeting was cosponsored by Nikon Microscopic Polska Precoptic Co. and Leica Kawa Ska Sp. z.o.o.

The official opening was conducted by the chairman of the Geochemical Group, Zdzisław Migaszewski, the vice-president of Jan Kochanowski University in Kielce, Wiesław Caban, and the president of the Mineralogical Society of Poland, Ryszard Kryza. The leading theme at the conference was environmental geochemistry; however, many participants presented the results of their studies in isotope geochemistry, applied geochemistry, and geochemical modeling. Four keynote speakers presented very interesting talks on a broad range of topics: "Biogeochemistry of Trace Elements – Environmental Issues" (Alina Kabata-Pendias, Institute of Soil Science and Plant Cultivation in Puławy), "Recent Geochemical Investigations at the U.S. Geological Survey" (Paul J. Lamothe, USGS), "Selected Geochemical Investigations of the U.S. Geological Survey in Alaska" (James G. Crock, USGS), and "Current Issues in Establishing the Geochemical Background of Trace Elements" (Agnieszka Gałuszka, Jan Kochanowski University). The discussions were very fruitful, encouraging scientific cooperation and the taking up of new scientific challenges, all in a friendly atmosphere.

The meeting also included a walking tour of Kielce entitled "Geodiversity and Geologic Heritage Protection in Kielce." The conference was followed by two field excursions: (1) "Biogeochemical and Hydrogeochemical Studies in Świętokrzyski (Holy Cross Mts.) National Park," and (2) "Influence of Pyrite Mineralization on the Generation of Acid Mine Drainage in the Wiśniówka Mining Area near Kielce." The latter trip ended in an abandoned Eifelian dolomite quarry (Zachełmie), in which tracks of the oldest amphibians have recently been found.

It is difficult to summarize a three-day conference in just one sentence, but if we tried, it would read like this: "Contemporary geochemistry requires from the scientists a multidisciplinary approach and the use of various techniques; in return, it provides great challenges, gives satisfaction, and brings major benefit to the public."

Zdzisław M. Migaszewski and **Agnieszka Gałuszka**
Conference Organizers, Jan Kochanowski University of Kielce

Field trip participants posing in the Zachełmie quarry

17th MEETING OF THE PETROLOGY GROUP OF THE MINERALOGICAL SOCIETY OF POLAND: "LAMPROPHYRES AND RELATED MAFIC HYPABYSSAL ROCKS: CURRENT PETROLOGICAL ISSUES"

The annual meeting took place in the Kłodzko region of the Sudetes (southwest Poland), at the northeast margin of the Bohemian Massif, on 14–17 October 2010. The Mineralogical Society of Poland coorganized the meeting, together with the Institute of Geological Sciences of the University of Wrocław and the Jagiellonian University, Kraków, and the Polish Geological Institute–National Research Institute. Sixty scientists and students from Poland, the Czech Republic, Germany, and other countries attended the meeting and presented 24 talks and 33 posters. The presentations spanned various disciplines in basic and applied mineralogy and petrology. A special session addressed the leading theme of the conference, "Lamprophyres and related mafic hypabyssal rocks: Current petrological issues." Lamprophyres constitute a "special" group in the classification of igneous rocks and, though minor in volume, attract much attention from specialists in various Earth science disciplines. This is due to, for example, their mineralogical and geochemical peculiarities, their derivation from subduction-modified or contaminated mantle sources, and the possible links between lamprophyric magmatism and ore mineralization, e.g. Au. The lamprophyre session included 11 talks and 7 posters, with four keynote addresses by Vojtech Janousek (Praha), Lukas Krmicek (Brno), Dejan Prelevic (Mainz), and Thomas Seifert (Freiberg). The Sudetes, where crystalline-basement rocks of the eastern part of the European Variscides are well exposed, are one of the larger lamprophyre provinces in Europe. This provided an excellent learning opportunity for participants in the field trip on the last day of the meeting, which focused on differentiation and emplacement processes in lamprophyres.

Field trip participants on the way to a minette outcrop

During the meeting, several prizes were awarded: to Elena Vasyukova (Novosibirsk) for the best talk (on the lamprophyres of Altai); to Kouakou Yao (Paris) and coauthors, for the best poster (on albitized granitoids in the Sudetes); and to Krzysztof Szopa (Sosnowiec) and Krzysztof Nejbert (Warszawa) and coauthors, for their excellent posters. Other events during the meeting included displays of optical equipment, a barbecue, and a trip to nearby Bear Cave, the most beautiful cave in the region. More information on the conference, a postconference photo gallery, and a list of publications can be found at www.ing.uni.wroc.pl/~lamprophyres2010/index.htm.

Marek Awdankiewicz and **Ryszard Kryza**
Conference organizers, University of Wrocław

European Association of Geochemistry

www.eag.eu.com

FROM THE PRESIDENT

Bernard Bourdon

The Goldschmidt meeting in Prague promises to be one of the year's highlights in the field of geochemistry. Prague is one of the most stunning historical cities in Eastern Europe and will thus have lots to offer delegates. Like Davos in 2009, the open call for sessions was extremely successful and has resulted in the addition of many new and timely sessions to the initial program. With more than 70,000 hotel beds in Prague, all conference delegates should easily find accommodation.

This year, the Goldschmidt abstracts will be published in *Mineralogical Magazine* and will be freely accessible online by the time of the conference at the following website: http://gsminmag.highwire.org/.

As the tragic events in Japan and their environmental consequences unfold, our community should become even more aware of the societal responsibility that we bear. Few other scientific communities are better prepared to tackle some of the environmental challenges that the Japanese government is now facing. Geochemists have the duty to help find solutions to current and future issues. It is also our responsibility to make our own governments aware that the science we do has the potential for developing creative solutions to modern energy, climate, resource and environment problems.

Bernard Bourdon
EAG President

European Association of Geochemistry
and Geochemical Society

21st Annual

Goldschmidt Conference

Prague | Czech Republic | August 14-19, 20 11

Société Française de Minéralogie et de Cristallographie

www.sfmc-fr.org

MEETINGS

Geo-Raman 10 – First Announcement

The tenth Geo-Raman meeting, dedicated to the applications of Raman spectroscopy in the Earth sciences, will be held in Nancy on 11–13 June 2012. An associated international school will be held just after the meeting, on June 14–16. The meeting and school will be sponsored by the European Mineralogical Union and the SFMC. More details will be given in the next issue of *Elements*. Please visit the website www.geoRaman10.uhp-nancy.fr.

Serpentine Days

After the success of the Serpentine Days meeting in Grenoble in 2007, a new edition is being organized for 1–4 April 2012. The conference will take place in Porquerolles, a very hospitable island in the south of France. The meeting will be sponsored by the SFMC. More details will be provided in the next issue of *Elements*. Further information will soon be available on the SFMC website: www.sfmc-fr.org/.

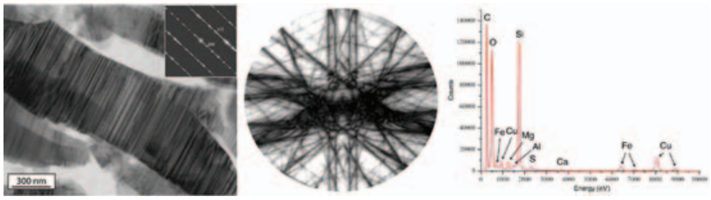
M. Andreani, A. L. Auzende and **A. Delacour**
Organizing Committee

TEM in Mineralogy 2011: 10–14 October 2011 Joint SFMC–DMG Graduate and PhD Course

DMG
Deutsche
Mineralogische
Gesellschaft

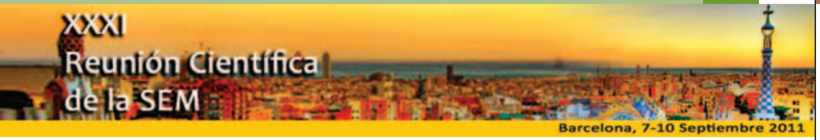
SFMC

The first German–French school on the theme "Transmission Electron Microscopy in Mineralogy," organized by the DMG and SFMC, will be held at the University of Lille in October 2011. The main aspects of TEM techniques (conventional and high-resolution imaging, diffraction, spectroscopy and chemical analysis) will be covered by the course, which will feature practical sessions, simulations and worked examples. Short instructional sessions will add theoretical support to the experiments, analysis and interpretation. The number of participants is limited to 12. The school will interest graduate students, postdocs and researchers. An examination for ECTS credit points will be held at the end of the school. Inscription fee: 300 euros. For more information and registration, go to http://umet.univ-lille1.fr/Animation/MinTem.php/.



Sociedad Española de Mineralogía

www.ehu.es/sem



31st MEETING OF THE SPANISH MINERALOGICAL SOCIETY

The 31st Annual Meeting of the Spanish Mineralogical Society (SEM) will take place in Barcelona from September 7 to 10, 2011. It will be organized in collaboration with the University of Barcelona, the Autonomous University of Barcelona, the Catalonia Polytechnic, and the Institute of Environmental Assessment and Water Research of the Spanish Research Council.

On September 7, a workshop entitled "Nanoparticles in the Environment" will be held. Six lectures given by international specialists will present basic knowledge about the impact of nanoparticles in natural systems, from research methodology to toxicological matters. Lecturers will be Renata Behra (EAWAG), Laurent Charlet (University of Grenoble), Gabriel Cuello (ILL), Antonietta Gatti (University of Bologna), Victor Puntes (Institut Catala de Nanotecnologia), and Xavier Querol (IDAEA-CSIC).

The scientific sessions (oral and poster) will be held on September 8 and 9. They are open to all research in mineralogy, petrology, and geochemistry. Specific topics include atmospheric particulates, biomineralization, clays and clay minerals, low-grade metamorphism, mineral deposits, acid mine waters, conservation of heritage, and CO_2 geologic storage. We aim to promote discussion of ideas and new collaborations, especially among young researchers.

A geotourist field trip to the Cardona salt diapir will be offered on September 10. The meeting is open to the international community. Contributions can be presented in Spanish or English.

For current information: http://www.ehu.es/sem/.

STUDENT TRAVEL GRANTS

Two travel grants financed by the SEM are available to provide partial financial support to help doctoral students attend the International School "Minerals & Biosphere," which will be held in Campiglia Marittima (Italy) on 27–30 September 2011. All student members of the SEM are eligible for these grants. Applications must be sent to SEM Vice-President Fernando Nieto (nieto@ugr.es).

NEW MEMBERS JOIN THE EXECUTIVE COUNCIL

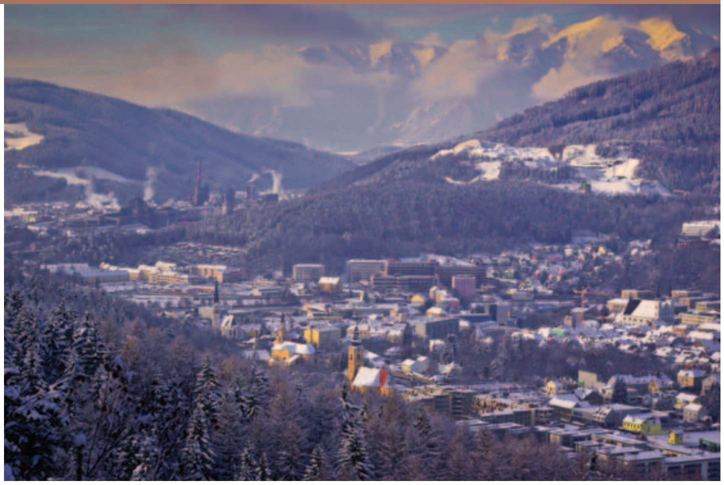
A new president, a new treasurer, and five councilors were recently elected to serve the usual four-year term on the Executive Council. These persons are Carlos Ayora (CSIC, Barcelona, new president, and introduced in a previous issue); Pilar Mata (IGME, Madrid, new treasurer); and Patricia Acero (University of Zaragoza), José Manuel Astilleros (University Complutense Madrid), Isabel Carretero (University of Sevilla), Mercedes Fuertes (University of Oviedo), and José Miguel Herrero (University of Basque Country) (new councilors).

THANK YOU JORDI!

We close our Society news with a sincere expression of gratitude to Jordi Delgado (Civil Engineering School, A Coruña University), who recently completed his service to the SEM as *Elements* news editor. His dedication and expertise are greatly appreciated.

International Association of Geoanalysts

http://geoanalyst.org



Winter view of the Austrian Alps of Styria and the city of Leoben, showing the 16th century city centre (foreground and right), the modern city centre (middle) and traditional mining and industrial activities, which made this one of the wealthiest areas in central Europe during the Middle Ages

ANNOUNCEMENT! LOCATION OF GEOANALYSIS 2015

At its latest meeting in London, the IAG's Governing Council unanimously supported the bid from the Montanuniversität Leoben, Austria, to host the Geoanalysis 2015 conference, which will be the 9th meeting in the Geoanalysis conference series. Leoben was recognized as an excellent venue for Geoanalysis 2015, due to its long mining tradition and to the excellent infrastructure available through the university, with its century-long focus on mining and environmental engineering. The selection of Leoben will bring Geoanalysis back to one of the IAG's core regions, after being held in Beijing, China (2006), Drakensberg, South Africa (2009) and Búzios, Brazil (2012). The 2015 event will be the fourth time that the triennial conference has been held in Europe. Located 175 km southwest of Vienna, in the high mountains of the Austrian state of Styria, Leoben is easily reached by train, requiring only two hours travel from Vienna International Airport and one hour from Graz International Airport. The chairperson of the 2015 Organizing Committee will be Prof. Thomas Meisel of the General and Analytical Chemistry Department of the Montanuniversität. Preliminary information about 2015 has already been posted at www.geoanalyst.org/geoanalysist_conference.html.

GEOANALYSIS 2012

The Geoanalysis 2012 conference website www.ige.unicamp.br/geoanalysis2012/ is being continually updated… check it out!

Italian Society of Mineralogy and Petrology

www.socminpet.it

SIMP PRIZES FOR PHD STUDENTS IN 2010

SILVIO FERRERO

FOR "ANATECTIC MELT IN A METAPELITIC SYSTEM: A FLUID AND MELT INCLUSION STUDY"

The characterization of anatexis in metapelites is fundamental to understanding the geochemical differentiation of the continental crust. Natural anatectic melts were investigated in khondalites (Kerala Khondalite Belt, India) and granulitic enclaves (El Hoyazo, Spain) using a novel approach based on the study of melt and fluid inclusions in peritectic garnets. Anatectic melt inclusions in khondalites contain a peraluminous and ultrapotassic melt with ~1–2 wt% water, while a peraluminous, undersaturated melt was trapped along with a water-rich fluid in the El Hoyazo enclaves. The results show that we can now analyze crustal melt composition rather than assume it, thereby obtaining reliable petrological and geochemical information on anatexis from nano- to microscale objects.

GIUSEPPE MICCICHÉ

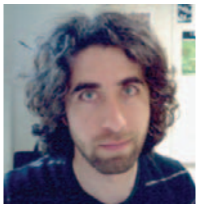
FOR "ATOMISTIC SIMULATION OF LAYERED SILICATES IN THE MUSCOVITE–CELADONITE SYSTEM"

Ab initio (DFT) and cluster expansion methods were used to calculate the variations of the lattice energy between ordered and disordered structures of very large supercells along the muscovite–celadonite solid solution join. Thermodynamic models for muscovite, phengite and celadonite were developed and, through Monte Carlo simulations, the entropy and free energy were calculated. The atomistic NMR spectra obtained are in very good agreement with spectral data from experiments. Our results suggest that the Al/Si distribution appears to be a good indicator of the temperature. Moreover, our model for muscovite appears to be quantitative and, therefore, can be used as a one-mineral geothermometer.

EUGENIO NICOTRA

FOR "GENESIS AND DIFFERENTIATION OF ANCIENT MT. ETNA MAGMAS (ELLITTICO VOLCANO, 40–15 KA): A MULTIDISCIPLINARY APPROACH FROM GEOLOGY TO MELT INCLUSIONS"

The study of the volcanological features of an ancient eruptive center at Mt. Etna may allow the understanding of the present-day magmatic system. A multidisciplinary study of the Ellittico volcano, embracing geology, whole rock geochemistry (major and trace elements; Sr–Nd–Pb–O isotopes), petrography and olivine-hosted melt inclusions was performed. Results shed light on: (1) the origin of these magmas from metasomatized, recycled, oceanic lithosphere; (2) the geometry of the feeder system and differentiation processes in the Ellittico volcano; and (3) the development of halogen-rich magmas due to the influx of volatiles into the feeder system.



LUCA VALENTINI

FOR "GEOCHEMICAL AND NUMERICAL MODELLING OF THE INTERACTION BETWEEN CARBONATITE AND SILICATE MAGMAS"

Carbonatites are exotic igneous rocks with significant economic importance due to their enrichment in rare minerals. Although carbonatite magmas may occur in spatial and temporal association with silicate magmas, their modes of interaction remain unclear. The combined geochemical and numerical models reported in this thesis attempt to clarify the dynamics of carbonatite–silicate magmatic pairs; the results show that textural interpretation may lead to equivocal conclusions. Even in the miscible regime, small-scale emulsions may form as a result of gradient stresses known as Korteweg stresses. The strong rheological contrast, from which Korteweg stress originates, strongly hinders mechanical mixing of carbonatite and silicate magmas.

The First **European Mineralogical Conference** will be held at the Goethe-University in Frankfurt, Germany, **2-6 September 2012**.

planet earth
from core to surface
emc2012
2 - 6 September
european mineralogical
conference · frankfurt / main
germany

The contributing societies presently are:

DMG	**Deutsche Mineralogische Gesellschaft**
MinSoc	**Mineralogical Society of Great Britain & Ireland**
ÖMG	**Österreichische Mineralogische Gesellschaft**
PTMin	**Mineralogical Society of Poland**
SEM	**Sociedad Española de Mineralogía**
SFMC	**Société Française de Minéralogie et de Cristallographie**
SIMP	**Societa' Italiana di Mineralogia e Petrologia**
SSMP	**Swiss Society of Mineralogy and Petrology**

Suggested themes for the meeting are as follows: Mantle petrology and geochemistry; Magmatism; Metamorphism; Applied mineralogy; Clay mineralogy; Mineral physics; Planetary materials; Mineral deposits and raw materials; Low T geochemistry; Geochronology; Geobiochemistry; Advanced analytical techniques; Archaeometry, care and preservation; Open session.
The meeting will provide the frame for the individual societies' award and lecture scheme, for the IMA business meeting, and the IMA medal presentation. The scientific committee will consist of one representative of each society.

The local organizing committee: Gerhard Brey, Heidi Höfer, Sabine Seitz

AN INTRODUCTION TO A LIFE IN SCIENCE

The quest for understanding some aspect of the natural world is what gets a lot of us bounding out of bed in the morning. Many of us love the "aha" moments when we've come a step closer to explaining our planet, field area, rocks or minerals, or when we figure out what is going wrong with our experimental or analytical set-up. Like the arts, science can be a satisfying, creative process as we strive to explain our findings in writing, diagrams and presentations. Solving geologic problems commonly requires long years of training and, unlike many of the sciences, a need to understand both the "big picture" (e.g. plate tectonics) and the "small picture" (atoms in minerals). Some days, we power through our work – solving problems left, right and centre – and other days, we muddle through – perhaps even taking a few steps backwards. In the midst of all of the "science to be done" and ever-growing "in boxes," it can be challenging to step back and look at where we are, where we plan to go, or how we fit into the global geosciences community.

This new *Elements* column – A Life in Science – is dedicated to supporting the career aspirations and progress of geoscientists, from students through retired professionals. It will focus on ways to make your life easier and to establish a satisfying career in the geosciences. For example, upcoming topics may include early-career issues, writing, laboratory science, science outside academia, teaching, industry–university collaborations, communication strategies, science around the world, science after retirement, work–life balance, and issues for minorities.

WHY SHOULD WE THINK ABOUT OUR LIVES IN SCIENCE NOW?

The Geological Workforce Is Changing or Has Changed

Since I was in high school, we've been hearing that "the old guys are going to retire," with the implication that many more jobs will become available in the geosciences. In some countries, this turnover is in progress. For example, some Canadian geoscience departments have experienced a ~50% turnover in the last ten years. In the USA, the American Geological Institute (AGI) has found that the supply of newly trained geoscientists falls short of the geoscience workforce demand and replacement needs (Gonzales et al. 2009). Their surveys indicate that the number of working geoscientists in USA academia, federal agencies, and industry reaches a peak between 51 and 60 years of age (Fig. 1). In contrast, the percentage of geoscientists between 31 and 35 years of age is very low.

These major shifts in geoscience demographics mean that most workplaces, including those in the geosciences, will undergo considerable change in the next 15 years. Succession planning has become one of the more critical workplace issues. Such transformation of our workplaces means that increasingly we will need to embrace change, career development, and mentoring (both giving and receiving).

Career Aspirations Change at Different Educational Levels

It should not be a surprise that geoscientists at different educational levels have different career aspirations and different views of geoscience careers. Indeed, one of the goals of an advanced degree is to develop new academics, while lower-level degrees have broader goals. In 2006, the AGI and the American Geophysical Union surveyed current and recently graduated undergraduate and graduate students' attitudes to work (Gonzales et al. 2009). Although this survey may not represent current conditions, it gives a general idea of career aspirations among US students and recent graduates. Unsurprisingly, their study showed that US undergraduate students have a wide range of career aspirations, with interests in employment across a spectrum of geoscience fields. The highest citations were given for government, the environment, mining, petroleum and academia (Fig. 2). Master's students in US geoscience programs showed interest in a range of careers, with highly positive attitudes towards careers in academia and government, and positive attitudes towards industry. PhD students had more limited positive attitudes to different careers, with 81% interested in academia, significant interest in government and less interest in industry (Fig. 2). Small variations in attitude were observed with time beyond their degrees (Gonzales et al. 2009; their Figs. 3.1-3.3), which is consistent with the idea that student career aspirations are unrelated to faculty members' perception of employment and the finding that faculty gave very high ratings to most geoscience career options (Fig. 2).

An interesting aspect of the AGI survey results is that although master's students ranked industry careers lower than other areas, half of them obtained work in industry: 21% in the oil and gas industry, 20% in the environment industry and 9% in other industries. The remaining master's students found work in academia (24%), government (22%) and other areas (4%). In contrast, employment rates for US PhD graduates in the survey were 67% in academia (including postdoctoral fellowships), 18% in government and 11% in industry. Clearly, employment is related to job openings, and perhaps employment will change as "the old guys retire" (Fig. 1).

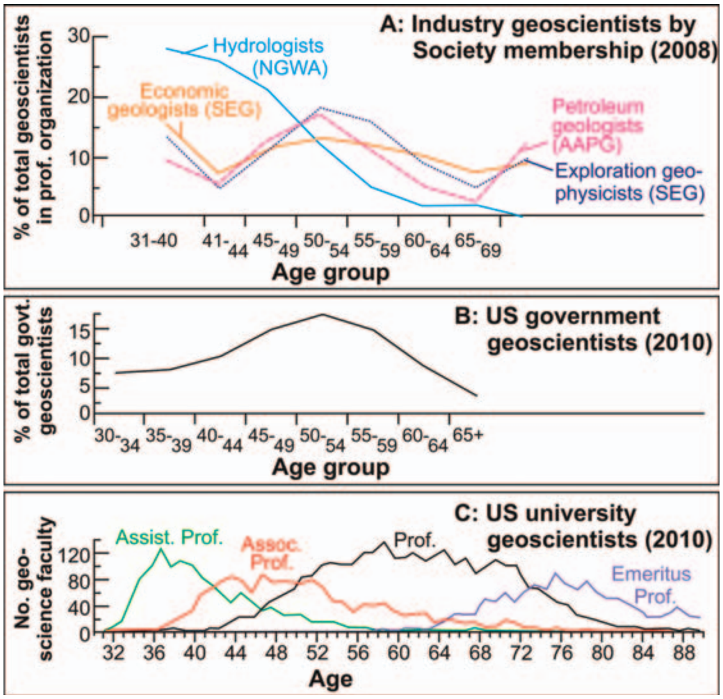


Figure 1 (**A**) Demographics of geoscientists in different professional associations from the AGI Geoscience Workforce Program; data provided by the Society of Exploration Geophysicists (SEG), American Association of Petroleum Geologists (AAPG), Society of Economic Geologists (SEG), and the National Ground Water Association (NGWA) (adapted from Gonzales et al. 2009) (**B**) Demographics of US government geoscientists (adapted from Gonzales 2011) (**C**) Demographics of US university geoscientists by rank (adapted from Gonzales 2011)

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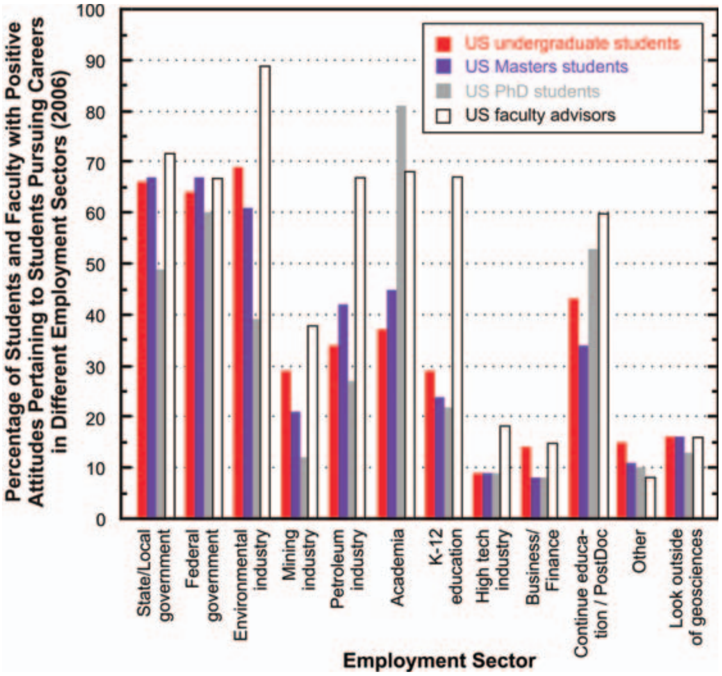

Figure 2 Percentage of students and faculty advisors with positive attitudes about students pursuing careers in different employment sectors. Source of data: Gonzales et al. 2009

Career Aspirations Change as a Function of Education Experiences and Career–Life Issues

While the AGI survey was centred on geoscientists, another survey focused on PhD students and postdoctoral scholars in sciences in the University of California (UC) system (Goulden et al. 2009). The latter study garnered substantial press coverage when it showed that both PhD students and postdoctoral scholars had a high initial interest in professorships but that their interest decreased during their training. The reason most highly reported for this change in focus for the PhD students was negative experiences in graduate school. In addition, women PhD students in science cited career–life issues as having a 44% influence on their decision, compared to 20% for men. Career–life issues include considerations related to children, other life interests, the time-consuming nature of professional activities, and geographical location preferences.

The UC postdoctoral fellows showed a similar shift in career aspirations away from professorships with research emphasis. For women, career–life issues were the most important reason for shifting their career goal, whereas men were statistically more likely than women to cite career advancement and monetary-compensation concerns. In sum, these changes in career aspirations provide insight into recruitment and retention, not only for universities, but also for government and industry employers who are interested in personnel who have been trained in critical thought in a PhD program.

Impetus for Thinking about Our Lives in Science

As described above, major demographic changes are ongoing or expected in geoscience workplaces over the next 15 years. For some of us, these changes mean retirement, while others may be left with a different work environment and possibly rapid learning curves as more senior geoscientists retire. These demographic changes, as well as changes in the global economy and increased resource management needs (e.g. in developing nations), also mean that geoscience career opportunities will continue to change. At the same time, each of us has different life experiences that influence our career trajectories. Experiences during our education – and how we respond to them – may have a strong influence on our career choices (Goulden et al. 2009). Finally, career–life issues and career advancement opportunities may influence our early-career choices (Goulden et al. 2009). We hope to address some of these topics in future A Life in Science columns.

AN EXTENSION OF A LIFE IN SCIENCE

Although A Life in Science will be reviewed by several geoscientists before it is published, it is likely to be written with some cultural bias – our attitudes are strongly influenced by where we live. Each country has its own economic basis and social structure, which influence our "lives in science" by providing different opportunities and career–life issues. In addition, there is no defined right or wrong way to approach one's career – what works for one person may not work for another. To address these matters, readers are invited to comment on this column on *Elements'* brand new Facebook page (www.fecebook.com/elements-magazine). Please visit and give us your opinions so that we can better address your needs!

ACKNOWLEDGMENTS

David Lescinsky, Whitney McCutcheon, Pierrette Tremblay, Thomas Clark, and Cornelius Klein are thanked for comments on this article.

Penny King (penking@unm.edu)*
University of New Mexico

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* Dr. Penny King is a mid-career geochemist who has lived on three continents. She is currently a senior research scientist at the Institute of Meteoritics of the University of New Mexico. She is coordinating the new A Life in Science column investigating career–life issues.

FUTURE CHALLENGES IN THE MINERAL SCIENCES

"We aim to identify 100 mineralogical questions that, if answered, would have the greatest impact on resolving current and future challenges in the Earth, planetary and environmental sciences."

Defining the major future research challenges in the mineral sciences provides a real opportunity to demonstrate the critical importance of our discipline to a wide audience of academics, funders, politicians and the public. The exercise will reveal not only the healthy nature of the mineral sciences and how they can be used strategically, but also how the mineral sciences are an essential contributor to human prosperity. Such exercises have been undertaken by other disciplines, and they have proved very successful in demonstrating the international nature, range and relevance of those disciplines to the academic community and society in general. Such exercises can help influence the future research agenda and enable scientists to engage with funding bodies to agree on funding priorities. In the current climate of funding scarcity, coupled with the ever-increasing demand to demonstrate the societal "impact" of our research, it is essential that we raise the profile of mineralogical research and demonstrate how it will contribute to solving key Earth science problems, both fundamental and applied. This initiative will allow us to talk with authority when dealing with the funders of our research, especially government agencies and industry, and convey the importance of what we do (and why they should pay us to do it!).

An example of a successful approach, which has proved extremely effective for the conservation–biology community, is the publication of community-led papers defining the "One Hundred Questions of Importance" in a given field of research (Sutherland et al. 2009). In this particular exercise, the international community identified 100 scientific questions which, if answered, would have the greatest impact on conservation practice and policy. Representatives from international organizations, regional sections and working groups of the Society for Conservation Biology, and academics from all continents except Antarctica compiled 2291 questions of relevance to the conservation of biological diversity worldwide. The questions were gathered from individuals through workshops, e-mail requests and discussions. Voting by e-mail to establish a shortlist of questions, followed by a 2-day workshop, was used to derive the final list of 100 questions. Inevitably several of the questions developed clear themes. A previous exercise (Sutherland et al. 2006) was very widely read, thus revealing considerable interest in this approach; it was the most downloaded paper ever from any British ecological society journal and was the third-most downloaded paper from Blackwell Publishing's 850 journals in 2006. A more recent "100 questions" exercise in agriculture (Pretty et al. 2010) is already the most downloaded paper from the publisher's website – generating several thousand downloads in the first month – and the paper is informing discussions in Brussels and at the UN rapporteur on food.

The international mineralogical community is invited to participate in a similar exercise for the mineral sciences. This exercise seeks to identify 100 mineralogical questions which, if answered, would have the greatest impact on resolving the Earth, planetary and environmental science challenges that we will face over the coming decades. The challenges confronting Earth scientists are relatively well defined (e.g. climate change, energy security, resource sustainability, environment protection, waste management, geological hazards, etc.). What is less well appreciated (by funding bodies at least) is that many of these challenges have a key mineralogical component and that they require the unique knowledge, insight and expertise of mineral scientists in order to overcome them. By identifying these issues explicitly and by framing them in terms of well-defined, answerable scientific questions, we will significantly raise the profile of the mineral sciences, emphasizing their importance not only to funding agencies and policy makers but to the public at large. This is a chance for the mineral science community to define what it stands for and re-establish the discipline's central importance within the wider scientific community.

The success of the exercise relies on the participation and support of all areas of the international mineralogical community. I believe that this initiative is best led by mineralogical societies/associations and international bodies, with input from any relevant individuals or bodies in universities, public research institutions, funding organizations, industry, policy makers and entrepreneurs. The mineralogical societies have a unique opportunity to mobilise the mineralogical community globally and provide an authoritative, unbiased and balanced assessment of what the key mineralogical challenges are.

PROPOSAL

Participants

The success of such an exercise relies on wide participation from all sections of the community, including (a) national and international academic societies and (b) industry, combined with more holistic input from (c) national and international funding bodies and (d) government agencies/policy makers.

Individuals, groups and societies/associations will be asked to solicit question submissions from their memberships, solicit questions from industry and other relevant bodies, participate in a workshop to compile the final list of 100 questions and participate in writing the final published paper.

Submission of Questions

Submission of questions will be managed through a central website and will be open to any group or individual wishing to participate. The web-based submission form will consist of the following sections:

- a text box for the question itself, limited to 50 words
- a text box for brief explanatory notes
- an optional box for the name and affiliation of the submitter or group
- a box to indicate the country of residence of the person submitting the question
- a box to indicate whether the question comes from somebody in academia, industry, government or other
- a tick box confirming the submitter's permission for their question to be used in discussions and/or to be published
- a tick box to confirm the submitter's willingness to have his/her name and affiliation identified in the supplementary material

The submission period will last until 30 November 2011.

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Shortlisting of Questions

After web submission has closed, a list of all submissions will be circulated to representatives of the participating organizations. Questions will be grouped and rephrased as there will be inevitable overlap. The prioritization process will be as inclusive as possible. The resulting list of priority questions will be circulated to all national representatives/societies. These will be taken forward to the final workshop.

Workshop

A two-day workshop (planned for early–mid 2012), will be attended by representatives of the participating bodies and will determine the final list of 100 questions. The shortlisted questions will be subdivided into key areas. Groups of representatives will be asked to consider one or more of the key areas, according to their expertise, with the aim of eliminating, modifying and combining questions to create a democratically agreed-on final list. Finally all representatives will be asked to agree on the final set of 100 questions that will form the basis of the final publication.

Publication

The list of questions will be published in *Mineralogical Magazine* as an open access paper so that all participating bodies will be free to post the paper on their websites and all individuals will be able to download the paper free of charge. The paper will be organized into sections according to the key priority areas identified during the shortlisting process. Each section will be accompanied by an introductory text. All representatives of participating bodies will be named as authors on the paper. A document containing a list of all submitted questions will be made available as supplementary material, along with the names and affiliations of those who opt to submit such information.

Supporters

The following have endorsed the '100 questions' initiative:

- C. AYORA IBÁÑEZ, President,
  Sociedad Española de Mineralogía
- D. BISH, President,
  Mineralogical Society of America
- N. COOK, President,
  International Association for the Geology of Ore Deposits
- J. DE YOREO, President,
  Materials Research Society
- Y. GU, President,
  International Council for Applied Mineralogy
- R. KRYZA, President,
  Mineralogical Society of Poland
- S. MUKASA, President,
  Geochemical Society
- R. OBERTI, President,
  European Mineralogical Union
- S. POLI, President,
  Società Italiana di Mineralogia e Petrologia
- P. SCHROEDER, President,
  Clay Minerals Society
- E. TILLMANNS, President,
  International Mineralogical Association
- M. WIEDENBECK,
  International Association of Geoanalysts

Promotion of the Exercise

Once the final list is published, it is hoped that the representatives of participating bodies, and others, will use it as an opportunity to promote mineralogical research through press releases and other public-engagement activities, as well as in discussions with policy makers and funding bodies.

For more information about the exercise and how to participate, or to register your interest in becoming a representative, please visit our website (www.100-questions.org). The anticipated go-live date for the submissions website is 30 June 2011.

Richard Harrison
University of Cambridge

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Sutherland WJ and 43 coauthors (2009) One hundred questions of importance to the conservation of global biological diversity. Conservation Biology 23: 557-567, doi: 10.1111/j.1523-1739.2009.01212.x

GEOCHEMISTRY OF EUROPEAN BOTTLED WATER[1]

Geochemistry of European Bottled Water is based on the analytical data from 1785 samples of bottled water bought in European supermarkets in 2008. The samples represent 1189 different brands from 1247 wells at 884 locations. The samples were acquired as a result of a unique effort by the editors, Clemens Reimann and Manfred Birke, and a large number of colleagues from 38 countries in Europe. The declared purpose of the effort was to inform the public about the wide range of solute concentrations and the variability of other parameters pertaining to commercially available bottled water.

Chapter 1 provides an in-depth explanation of the motivation and the objectives of the research. Chapter 2 explains some aspects of the hydrochemistry of groundwater. Chapter 3, "Background Information," very briefly describes the geology, tectonic setting, past and active volcanism, distribution of precipitation, and soil types of Europe. The book does not present details on the geology or the hydrogeological background of a given sample of bottled water. This would clearly be a colossal enterprise, beyond the scope of the book.

Chapter 4 explains the analytical and handling procedures, including sampling, sample preparation, and the elaborate quality control of the analytical data. All samples were analyzed at the laboratory of the Federal Institute for Geosciences and Natural Resources (BGR) in Berlin, Germany. The laboratory analyzed 72 individual parameters for each sample using state-of-the-art analytical procedures. Repeated analysis of international standards assured analytical quality.

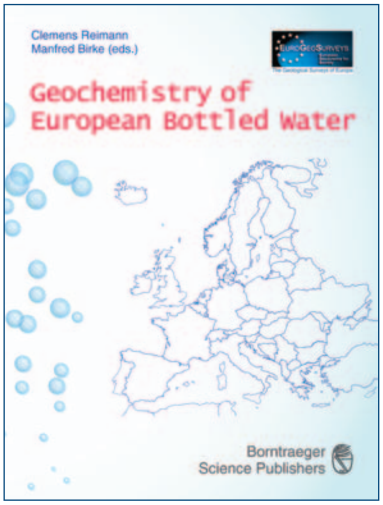
The concentration data for nine solutes are compared with the corresponding parameters printed on the bottle labels. For the calcium, magnesium, iron, sodium, sulfate, and fluoride contents, basically no outliers were identified on the appropriate diagrams. However, (too) many analyses showed large discrepancies for bicarbonate and dissolved silica. Some duplicate samples were acquired after some months and analyzed under the same conditions as the first set. Some parameters showed interesting and surprisingly large differences at some locations.

A strong alkalinity–pH correlation can be observed when comparing CO_2-bearing with noncarbonated water in glass bottles. Water in plastic containers shows a large scatter, and values are displaced to higher pH. Sorption and desorption related to the material of the bottles were clearly demonstrated. For example, in long-term experiments, cobalt increased in the water stored in blue-colored glass bottles and in soft-PET bottles.

Chapters 5 and 6 present additional new data from European drinking water (tap water), surface waters, and Norwegian groundwater, and compare these data with the data from the analyzed bottled water. The usefulness of these chapters is not evident to me, and the probability diagrams are difficult to read.

Chapter 7 presents detailed descriptions and diagrams for 67 analytical parameters in alphabetical order, from "alkalinity" to "zirconium," on two facing pages for each parameter. The chemical properties, occurrence, and use of the substance are portrayed on the left page. The right page shows the distribution of the parameter on a map of Europe using symbols of different size. Other diagrams show the probability of the parameter and curves for the concentration frequency. The table lists the locality with the lowest and the highest concentrations for the parameter and the average value.

This is the most extensive and entertaining part of the book. Here you can find out about your favorite solute. For example, bromine, one of my favorites, shows relatively high concentrations in waters from Eastern Europe. The authors relate the data to the preference of consumers in this area for relatively highly mineralized water. This is consistent with the distribution map for electrical conductivity data (ec-values), which also shows a clear trend for high-ec water in the eastern and northeastern parts of Europe. Because all data can be found on Excel spreadsheets on the attached CD, I quickly prepared Cl/Br mass-ratio histograms, which showed that >75% of all waters have an evaporite signature, very few waters have a direct seawater character, and only <20% have Br-enriched signatures typical of crystalline basement. Interestingly but not surprisingly, more than 50% of the Norwegian groundwater samples have a Cl/Br ratio less than that of seawater. This little exercise was also performed rapidly thanks to the data repository on the CD.



Aluminum is an important but analytically difficult solute. It is often present in the form of colloids and particulates in the water, and measured concentrations can be far above what one would expect for dissolved Al. The median value for Al is given as 1.19 µg/L. This value seems very plausible because computed (PHREEQC) saturation states show undersaturation for common, primary, rock-forming silicates, such as feldspar and mica, present in most of the reservoir rocks, and oversaturation for typical secondary minerals, such as clays.

The median value for dissolved silicon (not SiO_2) is given as 6.5 mg/L. This value corresponds to very mild supersaturation with respect to quartz ($SI_{Qtz} = 0.4$) and saturation for chalcedony ($SI_{Cha} = 0$). This may indeed indicate Si control by a "silica ceiling" (authors), or, more accurately, a "chalcedony ceiling." The reported high-silica waters are oversaturated even with respect to amorphous silica and would tend to become turbid during storage.

Chapter 8 deals with the physiology of the most important parameters, their health effects, and the statutory threshold values. The statutory threshold values in drinking and mineral waters in European countries, the European Union, and the United States are also listed in a comprehensive table in appendix A. Appendix B lists all data used in chapter 7 and the additional water data used in chapters 5 and 6. All these data and new analyses of 579 tap-water samples are stored on the enclosed CD.

The book has been produced with much effort and concern for detail. It provides an excellent overview on the nature of European bottled waters and contains a wealth of information, some of which may be interesting and useful to you. Particularly interesting are the detailed parameter descriptions in chapter 7. Also helpful are the nutritional, physiological, and human toxicological appraisals of the various dissolved substances.

Purchasing the book is strongly recommended for hygienists, hydrogeologists, geochemists, and hydrochemists, and anyone else working in the broad fields of groundwater and mineral water.

Kurt Bucher
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Albertstraße 23b, 79104 Freiburg, Germany

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[1] Reimann C, Birke M (eds) (2010) Geochemistry of European Bottled Water. Borntraeger Science Publishers, Stuttgart, 268 pp, 1 CD, ISBN 978-3-443-01067-6, €78 (http://borntraeger-cramer.com/9783443010676)

NANOSCOPIC APPROACHES IN EARTH AND PLANETARY SCIENCES[2]

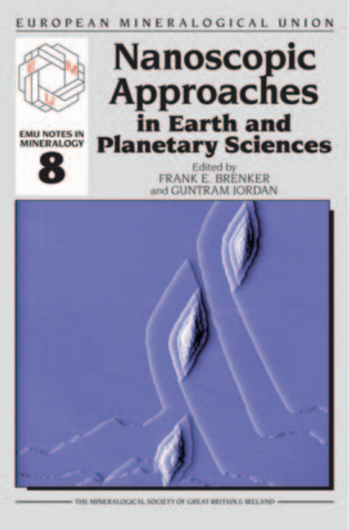
Published by the European Mineralogical Union and the Mineralogical Society of Great Britain and Ireland, this volume follows the 9th EMU School entitled "Nanoscopic Approaches in Earth and Planetary Sciences," held in Munich in 2007. This seems like a long delay before publication of the book, especially since methodological developments usually go fast. However, the content of the book is clearly not outdated. Some chapters even contain bibliographic references published as recently as 2010. As noted in the preface, this book aims to provide a thorough introduction to nanoscale techniques and related results and developments in the Earth and planetary sciences. In my opinion, this goal was achieved. In a book dealing with methodological considerations, it is always difficult to find a balance between technical information and scientific applications. Some of the chapters achieve that balance perfectly, and I definitely recommend their reading to students and colleagues who need to use these techniques or process recently acquired data.

In chapter 1, Wirth gives the basics of focused ion beam (FIB) milling techniques. Considering the wealth of geoscience studies he has accomplished using FIB, he is the perfect author for this chapter. The chapter will be of great interest to those who are about to start using FIB for the preparation of ultrathin samples, getting 3-D textural and/or chemical information at the nanoscale, or performing micromachining. Indeed, in addition to providing basic facts about the instruments and ion–solid interactions, the chapter gives many practical tips that are usually difficult to find in the literature.

Chapter 2 by Brenker, about the nanopetrology of pyroxenes, shows how a TEM study of the nanostructures in pyroxenes can provide useful information on the thermal history of rocks. Chapter 3, by Golla-Schindler and van Aken, is on the use of electron energy loss spectroscopy for nanoscale determination of $Fe^{3+}/\Sigma Fe$ ratios and valence state mapping. It is definitely a must-read for everyone (and they are numerous) who wants to learn how to determine the redox state of Fe with this technique. After providing some details on the technique (scattering geometry, excitation process, shape of the ionization edges, data corrections, etc.), the authors review the different approaches that can be taken and then assess their validity and limits. These reviews read almost like simple recipes, giving you the feeling that you will be able to carry out the operations easily.

Chapter 4 by Lyon and Henkel, on time-of-flight secondary ion mass spectrometry (TOF-SIMS), and chapter 5 by Sinha and Hoppe, on ion microprobe analysis, are complementary and give a detailed overview of ion microprobe measurements. Like chapter 3, these chapters achieve a perfect balance between a detailed commentary on basic principles, ion sources, detectors, and mass analyzers on the one hand and geoscience applications on the other. These are, again in my opinion, must-read chapters.

Chapter 6, by Vincze, Silversmit, Vekemans, Terzano, and Brenker, deals with synchrotron radiation micro- and nanospectroscopy. It is restricted to hard X-ray microprobes that allow performing X-ray fluorescence (XRF) and X-ray absorption spectroscopy (XANES and EXAFS) measurements. After presenting the instrumentation, including the light source, the chapter focuses on the advantage of coupling XRF measurements with Monte Carlo simulations to achieve precise quantitative measurements of elemental concentrations at the trace level in solids. Three-dimensional micro-XRF methods as well as XANES and EXAFS spectroscopic analysis (with a short practical course on how to process EXAFS data) are also presented. One regrets the absence of a chapter on soft X-ray nanospectroscopic analysis (e.g. scanning transmission X-ray microscopy, or STXM), which allows measuring the speciation of light elements such as carbon, nitrogen, and oxygen as well as heavier elements such as the transition elements at the 25 nm scale. This technique is indeed increasingly applied in the geosciences, and it would have complemented nicely chapter 6.



In chapter 7, Pina and Jordan provide an exquisite review of the kinetics and mechanisms of growth and dissolution of mineral surfaces at the nanoscale. The chapter starts with a short section on the principles of the scanning probe microscope and in particular the atomic force microscope (AFM). Then it details applications on the growth of mineral surfaces and explains clearly what we can learn about mineral-growth mechanisms, how such growth is influenced by supersaturation, the different kinetic models, the role of defects, and the influence of organic and inorganic impurities. This is followed by a much shorter but still very interesting section on mineral dissolution.

Finally, chapter 8 by Becker, Reich, and Biswas, on nanoparticle interactions in natural systems, includes results from TEM and STM analysis. The reader interested in nanoparticles may want to read this chapter to understand how atomistic calculations, including at the quantum mechanical and empirical levels, can complement information provided by nanoscale analyses. Noteworthy, one section provides results from atomistic calculations on a calcite biomineralization template by peptides.

If you are interested in EELS, Fe redox state measurements, SIMS, synchrotron-based micro- or nano-XRF, molecular dynamics simulations, nanoparticles, AFM analyses, or mineral dissolution and growth mechanisms, you will definitely be glad to have this book on your shelves for learning and teaching purposes.

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4 Place Jussieu, 75005 Paris, France

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[2] Brenker FE, Jordan G (eds) (2010) Nanoscopic Approaches in Earth and Planetary Sciences. EMU Notes in Mineralogy 8. European Mineralogical Union and the Mineralogical Society of Great Britain & Ireland, 382 pp, ISBN: 978-0-903056-25-0, £40 (£25.50 for individuals)

2011

July 3–7 International Conference on the Biogeochemistry of Trace Elements, Florence, Italy. Details: Dr. Giancarlo Renella, e-mail: giancarlo.renella@unifi.it; website: www.icobte2011.com

July 3–7 5th International FEZA Conference, Innovations in Zeolites and Ordered Porous Solids, Valencia, Spain. E-mail: feza2011@pacifico-meetings.com; web page: www.feza2011.com

July 4–9 Seventh Hutton Symposium on Granites and Related Rocks, Avila, Spain. E-mail: hutton@ugr.es; web page: www.seventh-hutton.org/meeting/Welcome.html

July 10–15 Gordon Research Conference: Catchment Science: Interactions of Hydrology, Biology & Geochemistry, Lewiston, ME, USA. Web page: www.grc.org/programs.aspx?year=2011&program=catchment

July 10–15 Gordon Research Conference: Radiation & Climate, Waterville, ME, USA. Web page: www.grc.org/programs.aspx?year=2011&program=radclimate

July 10–16 11th International Symposium on Antarctic Earth Sciences, Edinburgh, United Kingdom. Web page: www.isaes2011.org.uk

July 10–20 EMU School – Bulk and Surface Structures of Layer Silicates and Oxides: Theoretical Aspects and Applications, Rome, Italy. Web page: www.univie.ac.at/Mineralogie/EMU

July 11–15 Inter/Micro: 62nd Annual Applied Microscopy Conference, Chicago, IL, USA. E-mail: intermicro@mcri.org; web page: www.mcri.org

July 14–22 Asteroids, Comets, Meteors (ACM) meeting, Niigata, Japan. Web page: chiron.mtk.nao.ac.jp/ACM2011

July 17–22 Gordon Research Conference: Thin Film & Crystal Growth Mechanisms, Biddeford, ME, USA. Web page: www.grc.org/programs.aspx?year=2011&program=thinfilm

July 17–22 Gordon Research Conference: Organic Reactions & Processes, Smithfield, RI, USA. Web page: www.grc.org/programs.aspx?year=2011&program=orgreac

July 17–22 Gordon Research Conference: Origins of Solar Systems, South Hadley, MA, USA. Web page: www.grc.org/programs.aspx?year=2011&program=origins

July 20–27 International Union for Quaternary Research (INQUA) XXVIII Congress, Bern, Switzerland. Website: www.inqua.tcd.ie/congress.html

July 24–29 Gordon Research Conference: High Temperature Corrosion, New London, NH, USA. Web page: www.grc.org/programs.aspx?year=2011&program=hightemp

July 24–29 10th International Conference on Mercury as a Global Pollutant, Halifax, Nova Scotia, Canada. Web page: www.mercury2011.org

July 25–29 ASTM Johnson Conference: The On-Going Asbestos Debate, Burlington, VT, USA. Web page: www.astm.org/D22_Johnson.htm

July 31–August 4 The Society for Organic Petrology (TSOP) Annual Meeting, Halifax, Nova Scotia, Canada. Web page: www.tsop.org

August 1–5 10th ICAM International Congress for Applied Mineralogy, Trondheim, Norway. Details: Maarten A.T.M. Broekmans, e-mail: maarten.broekmans@ngu.no; website: www.icam2011.org

August 5–7 Third International Conference on Science in Society, Washington, DC, USA. Web page: http://science-society.com/conference-2011

August 6–9 9th International Eclogite Conference, Teplá Premonstratensian Monastery, Czech Republic. Web page: http://petrol.natur.cuni.cz/eclogites/index.php/ice/2011

August 7–10 Teaching Mineralogy, Petrology and Geochemistry in the 21st Century, Minneapolis, MN, USA. E-mail: mogk@montana.edu; web page: http://serc.carleton.edu/NAGTWorkshops/mpg/workshop2011/index.html

August 7–11 Microscopy and Microanalysis 2011, Nashville, TN, USA. Web page: www.microprobe.org/events/microscopy-microanalysis-2011

August 7–11 European Association of Geochemistry (EAG) Workshop: Tools in Environmental Biogeochemistry – Opportunities and Limitations, Tübingen, Germany. Details: Andreas Kappler, e-mail: andreas.kappler@uni-tuebingen.de; web page: www.eag.eu.com/education/shortcourse/eag-shortcourse2011

August 8–12 74th Annual Meeting of the Meteoritical Society, Greenwich, England. Details: Gretchen Benedix, e-mail: greb@nhm.ac.uk; web page: www.metsoc2011.org

August 8–12 Asia Oceania Geosciences Society (AOGS 2011), Taipei, Taiwan. Web page: www.asiaoceania.org/aogs2011

August 9–11 21st Biennial Conference, European Current Research on Fluid Inclusions (ECROFI XXI), University of Leoben, Austria. E-mail: ecrofiXXI@unileoben.ac.at; website: https://ecrofiXXI.unileoben.ac.at

August 14–19 2011 Goldschmidt Conference, Prague, Czech Republic. E-mail: helpdesk@goldschmidt2011.org; web page: www.goldschmidt2011.org

August 14–19 International Materials Research Congress (IMRC) 2011, Cancun, Mexico. Web page: www.mrs.org/s_mrs/sec.asp?CID=25401&DID

August 21–23 MSA and GS Short Course: Sulfur in Magmas and Melts and Its Importance for Natural and Technical Processes, Goslar, Germany. Details: Harald Behrens and Jim Webster, e-mail: h.behrens@mineralogie.uni-hannover.de or jdw@amnh.org; web page: http://msasulfurinmelts.org

August 21–24 2nd International Workshop on Antimony in the Environment, Jena, Germany. Web page: www1.uni-jena.de/Antimony2011 =291980

August 22–26 EAG Short Course: Process-Oriented Biogeochemical Modeling in Aquifers–Recent Practice and Limitations, Dresden, Germany. Web page: www.eag.eu.com/education/shortcourse/eag-shortcourse2011b

August 22–26 25th International Applied Geochemistry Symposium (IAGS 2011), Rovaniemi, Finland. Web page: www.iags2011.fi

August 22–29 XXII Congress of the International Union of Crystallography, Madrid, Spain. Web page: www.ecanews.org/iucrs.php. and www.iucr2011madrid.es

August 28–September 1 242nd American Chemical Society (ACS) National Meeting & Exposition, Denver, CO, USA. Web page: www.acs.org

August 29–September 2 14th Latin American Geological Congress and the 13th Colombian Geological Congress, Medellín, Colombia. Web page: www.14clg.com

August 30–September 2 3P Arctic Conference: Polar Petroleum Potential, Halifax, Nova Scotia, Canada. Web page: www.3parctic.com

September 4–7 7th European Conference on Mineralogy and Spectroscopy (ECMS 2011), Potsdam, Germany. Details: Prof. Dr. Monika Koch-Mueller, e-mail: mkoch@gfz-potsdam.de; web page: www.physchemgeo.com/ECMS/index.html

September 4–7 FRAGILE EARTH: Geological Processes from Global to Local Scales and Associated Hazards, Munich, Germany. Web page: www.geosociety.org/meetings/2011munich

September 4–10 Comparative Evolution of Past and Present Accretionary Orogens: Central Asia and the Circum-Pacific, Urumqi, Xinjiang Uygur Autonomous Region, China. Web page: www.geosociety.org/penrose/11china.htm

September 7–9 Ore Deposits in an Evolving Earth, London, UK. Website: www.fermor2011.org.uk

September 7–10 SEM 2011, XXXI Scientific Meeting of the SEM (Sociedad Española de Mineralogía), Barcelona, Spain. Web page: http://congress.cimne.upc.es/sem2011/frontal/default.asp

September 12–16 Fifth International Conference on Mars Polar Science and Exploration, Fairbanks, AK, USA. Web page: www.lpi.usra.edu/meetings/polar2011

September 14–17 10th Congress of Italian Zeolite Association, Naples, Italy. Web page: www.aiz2011.unina.it; e-mail: aiz2011@unina.it

September 15–16 Frontiers in Diagenesis: Clay and Carbonate Facies and their Diagenetic Pathways in Reservoir Rocks, Cambridge University, UK. Details: Nick Tosca, Christopher Jeans; web page: www.minersoc.org/pages/groups/cmg/cmg.html

September 19–23 VIII Forum Italiano di Scienze della Terra, Torino, Italy. Web page: www.geoitalia.org/index.php?action=folder_list&folder_id=189

September 19–23 9th International Symposium on Applied Isotope Geochemistry (AIG-9), Tarragona, Spain. Web page: http://congress.cimne.com/AIG-9/frontal/invitation.asp

September 20–24 GEOMED2011 – 4th Hemispheric Conference on Medical Geology, Bari, Italy. Details: Saverio Fiore, e-mail: fiore@imaa.cnr.it; web page: www.geomed2011.it

September 20–24 Joint Meeting of the German Crystallographic Society (DGK), the German Mineralogical Society (DMG) and the Austrian Mineralogical Society (ÖMG), University of Salzburg, Austria. E-mail: salzburg2011@conventus.de; web page: www.salzburg2011.org

September 25–30 The Clay Minerals Society 2011 Annual Meeting, Lake Tahoe, NV, USA. www.clays.org/annual%20meeting/announcement.html

September 26–29 11th Biennial Society for Geology Applied to Mineral Deposits (SGA) Meeting, Antofagasta, Chile. E-mail: sga2011@ucn.cl; web page: www.sga2011.ucn.cl

September 27–30 International GNM-GABeC School on Minerals and Biosphere, Campiglia Marittima (LI), Italy. E-mail: lattanzp@unica.it; web page: www.socminpet.it/minbio2011/index.html

September 30–October 2 103rd meeting of the New England Intercollegiate Geological Conference (NEIGC), Middlebury College, VT, USA. Web page: neigc.org

October 4–8 9th Silicate Melts Workshop, La Petite Pierre, Alsace, France. Details: Don Dingwell, Pascal Richet, and Alan Whittington; e-mail: dingwell@lmu.de, richet@ipgp.fr, whittingtona@missouri.edu; web page: http://web.missouri.edu/~whittingtona/9thSMW

October 9–12 Geological Society of America Annual Meeting, Minneapolis, MN, USA. E-mail: meetings@geosociety.org; web page: www.geosociety.org/meetings/2011

October 14–16 Migmatites: Contemporary Views and Examples – Annual Meeting of the Petrology Group and General Meeting of the Mineralogical Society of Poland, Bukowina, Poland. Web page: www.ptmin.pl

October 16–20 Materials Science & Technology 2011 Conference and Exhibition – MS&T '11 combined with the ACerS 113th Annual Meeting, Columbus, OH, USA. Web page: www.tms.org/Meetings/meetings.asp

October 18–21 12th International Congress on Rock Mechanics (ISRM 2011), Beijing, China. E-mail: secretariat@isrm2011.com; website: www.isrm2011.com

October 24–28 Cathodoluminescence 2011: A MAS Topical Conference, Gaithersburg, MD, USA. E-mail: CL2011@microbeamanalysis.org; website: www.microbeamanalysis.org

November 2–6 MaThCryst Workshop on Mathematical Crystallography, Manila, Phillipines. Web page: www.crystallography.fr/mathcryst/manila2011.php

November 7–9 Workshop on Formation of the First Solids in the Solar System (Solids 2011), Kauai, HI, USA. Web page: www.lpi.usra.edu/meetings/solids2011

November 11–13 **9th Swiss Geoscience Meeting**, ETH Zürich, Switzerland. Web page: http://geoscience-meeting.scnatweb.ch

November 21–24 **Conference on Arsenic in Groundwater in South Asia**, Hanoi, Vietnam. E-mail: vietcetasd53@yahoo.com; web page: http://vietas.er.dtu.dk

November 28–December 2 **MRS (Materials Research Society) Fall Meeting**, Boston, MA, USA. Web page: www.mrs.org/s_mrs/index.asp

December 5–9 **AGU Fall Meeting**, San Francisco, CA, USA. Web page: www.agu.org/meetings

2012

January 22–27 **36th International Conference and Expo on Advanced Ceramics and Composites**, Daytona Beach, FL, USA. Web page: http://ceramics.org/dates-deadlines

February 6–12 **10th International Kimberlite Conference**, Bangalore, India. Website: www.10ikcbangalore.com.

February 20–24 **2012 Ocean Sciences Meeting**, Salt Lake City, UT, USA. Web page: www.agu.org/meetings

March 4–7 **XIV EMPG (Experimental Mineralogy, Petrology and Geochemistry) Meeting**, Kiel, Germany. E-mail: empg2012@min.uni-kiel.de; web page: www.EMPG2012.uni-kiel.de

March 11–15 **The Minerals Metals & Materials Society (TMS) TMS 2012: Linking Science and Technology for Global Solutions**, Orlando, FL, USA. E-mail: mtgserv@tms.org; web page: www.tms.org/meetings/annual-12/AM12home.aspx

March 19–23 **43rd Lunar and Planetary Science Conference (LPSC 2012)**, The Woodlands, TX, USA. Web page: www.lpi.usra.edu/meetings/lpsc2012

March 25–29 **243rd American Chemical Society (ACS) National Meeting & Exposition**, San Diego, CA, USA. Web page: www.acs.org

April 9–13 **MRS Spring Meeting**, San Francisco, CA, USA. Web page: www.mrs.org/s_mrs/index.asp

April 22–25 **AAPG Annual Convention & Exhibition**, Long Beach, CA, USA. Web page: www.aapg.org/meetings

May 28–30 **Geological Association of Canada and Mineralogical Association of Canada Annual Meeting**, St. John's, NL. Web page: www.gac.ca/activities

May 31–June 10 **Erice School: Present and Future Methods for Biomolecular Crystallography**, Erice, Sicily, Italy. Web page: www.crystalerice.org/Erice2012/2012.htm

June 24–29 **Goldschmidt 2012**, Montreal, Canada. E-mail: helpdesk@goldschmidt2012.org; website: www.goldschmidt2012.org

July 9–13 **Inter/Micro: 63rd Annual Applied Microscopy Conference**, Chicago, IL, USA. Web page: www.mcri.org

July 15–19 **International Congress on Ceramics (ICC4)**, Chicago, IL, USA. Web page: http://ceramics.org/4th-international-congress-on-ceramics-icc4

July 28–August 2 **American Crystallographic Association (ACA) Annual Meeting**, Boston, MA, USA. Web page: www.AmerCrystalAssn.org

July 29–August 2 **Microscopy and Microanalysis 2012**. Phoenix, AZ, USA. Web page: www.microprobe.org/events/microscopy-microanalysis-2012

August **ECM-27 – XXVII European Crystallographic Meeting**, Bergen, Norway. Web page: www.lcm3b.uhp-nancy.fr/ecasig5/Activity.php

August 2–10 **34th International Geological Congress**, Brisbane, Australia. E-mail: info@34igc.org; web page: www.34igc.org

August 12–17 **Annual meeting of the Meteoritical Society**, Cairns, Queensland, Australia. Details: Trevor Ireland, e-mail: trevor.ireland@anu.edu.au; web page: www.meteoriticalsociety.org

August 19–23 **244th ACS National Meeting & Exposition**, Philadelphia, PA, USA. Web page: www.acs.org

September 2–6 **EMC2012: Planet Earth – From Core to Surface (joint meeting), Johann Wolfgang Goethe-University**, Frankfurt, Germany. Details: Kevin Murphy; web page: http://emc2012.uni-frankfurt.de

September 17–20 **Geoanalysis 2012**, Búzios, Brazil. Web page: www.ige.unicamp.br/geoanalysis2012

October 7–11 **MS&T'12: Materials Science & Technology Conference and Exhibition**, combined with ACerS 114th Annual Meeting, Pittsburgh, PA, USA. Web page: www.matscitech.org

November 4–7 **Geological Society of America (GSA) Annual Meeting**, Charlotte, NC, USA. Web page: www.geosociety.org/meetings

November 26–30 **MRS Fall Meeting**, Boston, MA, USA. Web page: www.mrs.org/s_mrs/index.asp

2013

April 7–11 **245th American Chemical Society (ACS) National Meeting & Exposition**, New Orleans, LA, USA. Web page: www.acs.org

May 19–22 **AAPG 2013 Annual Convention & Exhibition**, Pittsburgh, PA, USA. Web page: www.aapg.org

May 22–24 **Geological Association of Canada /Mineralogical Association of Canada Annual Meeting**, Winnipeg, Manitoba, Canada. Web page: www.mineralogicalassociation.ca/index.php?p=35

July **IAVCEI General Assembly 2013: Forecasting Volcanic Activity**, Kagoshima, Japan. Details: Masato Iguchi, e-mail: iguchi@svo.dpri.kyoto-u.ac.jp; web page: www.iavcei.org/IAVCEI.htm

August **ECM-28 – XXVIII European Crystallographic Meeting**, Warwick, UK. Details forthcoming

August 4–8 **Microscopy & Microanalysis 2013**, Indianapolis, IN, USA. Web page: www.microprobe.org/events

September 8–12 **246th American Chemical Society National Meeting & Exposition**, Indianapolis, IN, USA. Web page: www.acs.org

October **MS&T'13: Materials Science & Technology Conference and Exhibition**, Montreal, Quebec, Canada. Details forthcoming

October 27–30 **Geological Society of America Annual Meeting**, Denver, CO, USA. E-mail: meetings@geosociety.org; web page: www.geosociety.org/meetings

2014

September 1–5 **21st General Meeting of the International Mineralogical Association (IMA2014)**, Johannesburg, South Africa. E-mail: info@ima2014.co.za; web page: www.ima2014.co.za

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 http://homepages.udayton.edu/~akoziol1/meetings.html). To get meeting information listed, please contact her at Andrea.Koziol@notes.udayton.edu.

STAMP COLLECTING

My dad was a stamp collector; no problem with that, but he never passed the passion on to me. It was a passion for my dad, and like any collecting activity it can become an obsession. Quite frequently I hear the pejorative term "stamp collecting" applied by some of my geological colleagues to the work that goes into the description of new mineral species. I always rankle at the term and consider it ill-informed.

I suppose that the view might be engendered by a lack of understanding of the significance of such an important scientific endeavour. To put it plainly, minerals are the fundamental components of the majority of the many materials studied by geoscientists. Some minerals may be rare (vanishingly so in certain cases), and some certainly may be esoteric. Nevertheless, each has its own geochemical story to tell, if we can only read the record in an appropriate way. Each mineral formed simply because the right geochemical conditions to do so prevailed at the time.

So what? The fact that we do not yet understand the formation mechanism of many of the rarer species (let alone the details concerning the common ones) means only that the appropriate work has not been carried out. It is easy to suggest why it is important to pursue studies of the formation of minerals that are generally unfamiliar to those out of the cognoscenti loop. Such studies are necessary if we want a more sophisticated understanding of the chemical and physical environment in which we live. Applications abound and include, among others, acid mine drainage (AMD) systems and other polluted environments, hydrothermal systems and alteration, dispersion of elements in the regolith, and mineral-processing technologies.

FIGURE 1 Cloncurryite, Great Australia mine, Cloncurry, Queensland, Australia. FOV 1mm. PHOTO: S. HINKLEY, SPECIMEN: V. HOPPE

A couple of arcane examples from my own experience spring to mind. What are we to make of the "mineralogical pH meter" inherent in the mineralogy of AMD systems, and what do the rarer minerals tell us? What use might be made of the "mineralogical redox probe" intrinsic to the formation of nevadaite, $(Cu,\square,Al,V)_6[Al_8(PO_4)_8F_8](OH)_2(H_2O)_{22}$, versus cloncurryite, $Cu_{0.56}(VO)_{0.44}Al_{1.98}Fe_{0.02}(PO_4)_2F(OH){\cdot}5H_2O$, (FIG. 1), and what do the iodine-rich caliche deposits of Chile imply about the chemistry of natural aqueous solutions at the limits of the stability of water? How should we proceed to explore the ambient-temperature aqueous geochemistry of Ti in the natural environment given that secondary anatase is a reasonably common "glue" in windblown materials of the Australian regolith, and in light of a recent discovery of an unprecedented Ti(IV) sulfate, $K_3Ti^{4+}Fe^{3+}(SO_4)_4O\text{-}2H_2O$, (FIG. 2) in an oxidized sulfide ore body? Here is an aspect of geochemistry that has barely been explored.

So, I would say all strength to the elbows of the mineralogists who are, by way of further example, extending our knowledge of rare element substitution in garnet-like minerals in rather exotic skarns, some of which contain no Si ($Ca_3SbSnAl_3O_{12}$, $Ca_3SbZrFe_3O_{12}$)! Hats off too to the mineralogists exploring completely new classes of silicates that resemble intermediates between the amphiboles and the micas (although the ribbons in the structures are composites of silicates and other metallates); here is a whole new field with important ramifications for petrologists. These mineralogists and others are the vanguard telling us that we need to understand much more about what can and cannot be made on planet Earth, and what we need to be working on in laboratories in order to understand what we have to understand. We need to do this if Earth science is to continue to be a relevant, evolving and useful discipline.

FIGURE 2 $K_3Ti^{4+}Fe^{3+}(SO_4)_4O{\cdot}2H_2O$ crystals (about 1.5 mm tall) on coquimbite, $Fe_2(SO_4)_3{\cdot}9H_2O$. PHOTO AND SPECIMEN: A. KAMPF

Maybe my dad was right: I should have collected stamps. But I didn't – I collected minerals, then got over collecting them just for the sake of it. If I had not proceeded thus, I would have missed the very simple question that has sustained my professional career for several decades: "How did this form and why?" The question remains a challenge for mineralogists, geologists, geochemists, chemists, physicists and theoreticians. It may never be answered in all its grandeur, and there remains an enormous amount of research that needs to be done, much of it based on the science of mineralogy. No substitute for scholarship, no more disparaging throwaway lines, bravo to the "stamp collectors"!

Professor Pete Williams
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p.williams@uws.edu.au

LASER ABLATION INSTRUMENT for ICP-MS

RESOlution M-50

RESOlution M-50 193 nm
Excimer Laser Ablation Instrument

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Developed in collaboration
with Dr. Wolfgang Muller

Image from Flatbed Scanner
Image from SEM (BSE)
Single Frames from M-50 Video Display

Developed by
Ashley Norris Geostar Software

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Sample Cell

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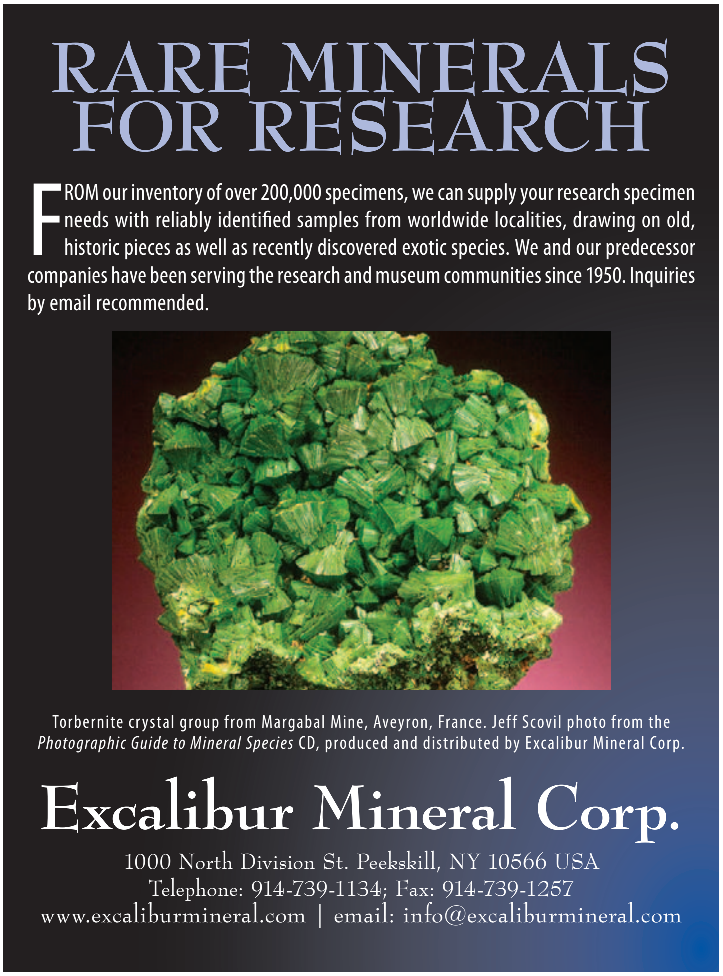

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WHEN THE WELL IS DRY, WE KNOW THE WORTH OF WATER.

BENJAMIN FRANKLIN (1706-1790),
POOR RICHARD'S ALMANAC, 1746

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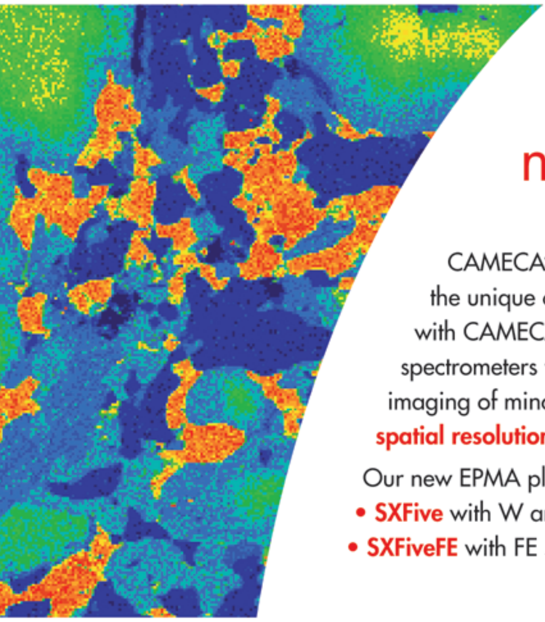


CAMECA SXFiveFE
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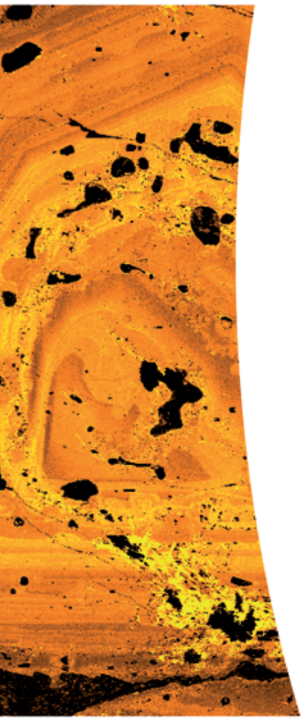

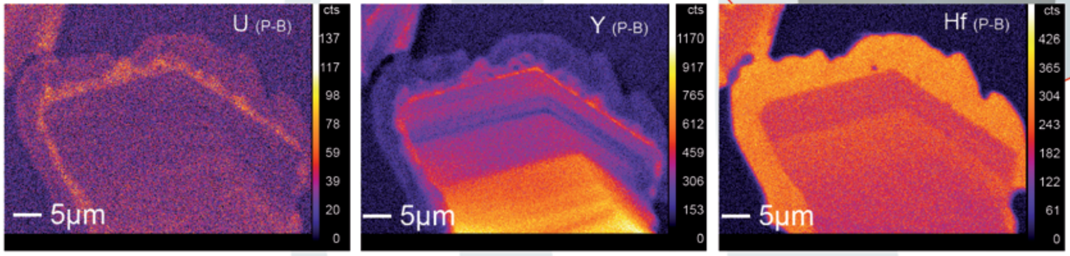
U (P-B)
cts
137
117
98
78
59
39
20
0
5µm
Y (P-B)
cts
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917
765
612
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153
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Hf (P-B)
cts
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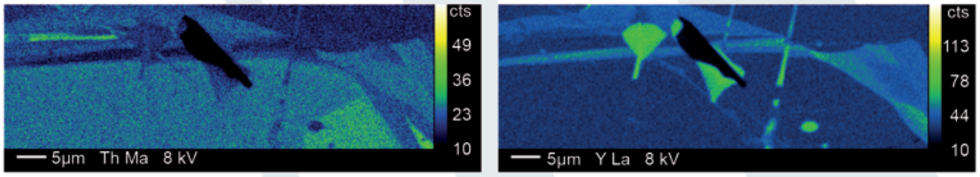
122
61
0
5µm


cts
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36
23
10
5µm Th Ma 8 kV
cts
113
78
44
10
5µm Y La 8 kV