

# Elements

An International Magazine of Mineralogy, Geochemistry, and Petrology

February 2006  
Volume 2, Number 1

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## User Research Facilities in the Earth Sciences

User Facilities around the World

X-ray, Neutron, and Mass Spectrometry Techniques

Scientific Advances Made Possible by User Facilities

Accessing User Facilities

New Opportunities at Emerging Facilities

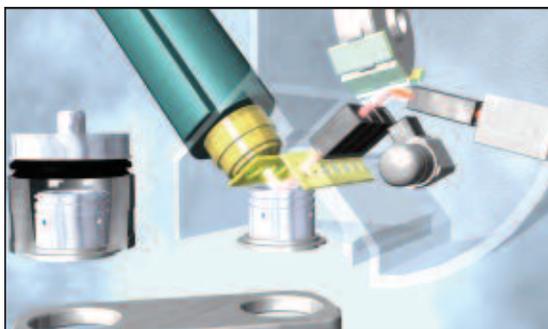
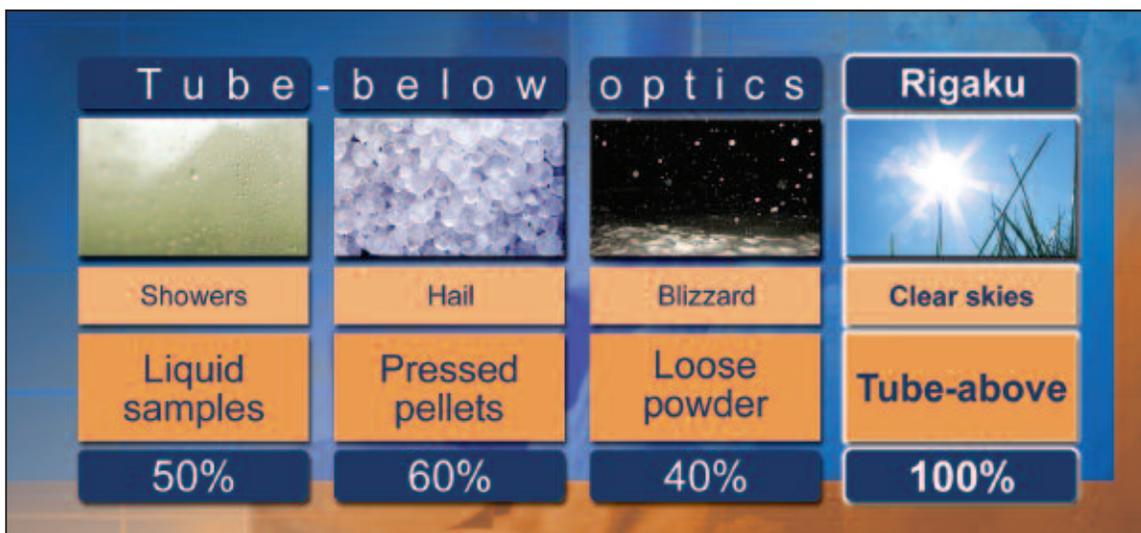


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# Elements

An International Magazine of Mineralogy, Geochemistry, and Petrology



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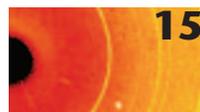
## User Research Facilities in the Earth Sciences

Stephen R. Sutton, Guest Editor



## User Facilities around the World

Gordon E. Brown Jr., Stephen R. Sutton, and Georges Calas



## Synchrotron Radiation, Neutron, and Mass Spectrometry Techniques at User Facilities

Stephen R. Sutton, Marc W. Caffee, and Martin T. Dove



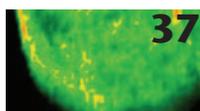
## Scientific Advances Made Possible by User Facilities

Gordon E. Brown Jr., Georges Calas, and Russell J. Hemley



## Accessing User Facilities and Making your Research Experience Successful

Richard J. Reeder and Antonio Lanzirotti



## New Opportunities at Emerging Facilities

John B. Parise and Gordon E. Brown Jr.

### Departments

<b>Editorial</b> . . . . .	<b>3</b>
<b>From the Editors</b> . . . . .	<b>4</b>
<b>Triple Point</b> . . . . .	<b>5</b>
<b>Meet the Authors</b> . . . . .	<b>6</b>
<b>Travelogue</b> . . . . .	<b>36</b>
<b>Mineral Matters</b> . . . . .	<b>43</b>
<b>Society News</b>	
Société Française de Minéralogie et de Cristallographie	44
European Association for Geochemistry . . . . .	46
Mineralogical Society of Great Britain and Ireland . . . . .	48
The Clay Minerals Society . . . . .	50
International Association of Geochemistry . . . . .	52
Mineralogical Society of America . . . . .	54
Geochemical Society . . . . .	56
Mineralogical Association of Canada . . . . .	58
International Mineralogical Association . . . . .	60
European Mineralogical Union . . . . .	61
<b>Conference News</b> . . . . .	<b>53</b>
<b>Calendar</b> . . . . .	<b>62</b>
<b>Parting Shot</b> . . . . .	<b>63</b>
<b>Advertisers in this Issue</b> . . . . .	<b>64</b>





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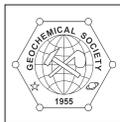
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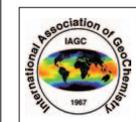
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# The Political Misuse of Science

In August of 2005, US President George W. Bush effectively endorsed teaching intelligent design (ID) alongside evolution in high school biology classes. ID holds that certain

features of the universe and of living things are best explained by an "intelligent cause" rather than a physical process such as natural selection or molecular reactions. Less than three months later, the Kansas State Board of Education in the American Midwest approved new high school science standards that cast doubt on the theory of evolution, opening the door for teaching ID. To do so, the Kansas school board also approved a redefinition of science, stating that science is no longer limited to the search for natural explanations of phenomena.

Scientists are generally highly respected by society at large. In public opinion polls that I have seen in the last few years, the public trusts scientists for being unbiased even more than they do judges. Scientists are viewed as well-trained practitioners of astute observation and calculation, framed without bias. Sure, the system is not perfect. Some examples of scientific fraud, perpetrated by misguided scientists for personal gains, are well known. The good news is that these incidents are extremely rare considering the enormous numbers of scientific endeavors that occur each day in labs and field studies around the world, conducted by hundreds of thousands of scientists. Therefore, society's view of scientists is somewhat predictable. One of the long-term benefits of this is that science is relatively well funded, especially considering that it is often competing for funding with pressing societal needs.

With the backdrop of the Kansas situation, the public's inherent trust of scientists, and the often generous financial support of fundamental scientific endeavors (e.g. see the costs of user facilities described in this issue), a dangerous trend involving the misuse of science, for political and ideological gain, has been developing. This trend is now the target of numerous investigative reports (many extensive) in the print, radio, and television media. The evidence is clear, and the conclusions from it inescapable. A growing number of politicians, especially in the United States, wielding tremendous power and influence, are denying, distorting, or otherwise misusing scientific findings and reports that they find inconvenient or contradictory towards their

programmed political or ideological agenda. And it goes well beyond the selling of ID as science to an unsuspecting American public.

Given the overall and overwhelming trust of science and scientists, it was hard at first to notice this storm as it was gathering. Was the suppression of a White House Office of Science report on the detrimental effects of acid rain during the Reagan years just a blip on the radar screen? Not many people noticed at the time, at least compared to how many people are noticing now. At issue: the political misuse of science now seems to have hit alarming levels, at least in the United States. Among many examples, perhaps the one most indicative of the seriousness of this trend is the misrepresentation and blatant misuse of the 2001 report from the US National Academy of Sciences (NAS) in its unequivocal endorsement of the 2001 United Nations' Intergovernmental Panel on Climate Change (IPCC) findings. Historically, this IPCC report may stand as the long-term scientific land-

A growing number of politicians . . . are misusing scientific findings and reports that they find inconvenient or contradictory towards their . . . ideological agenda

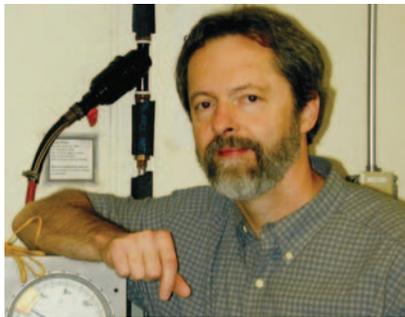
mark work on the influence of humans on average global temperature rise and ultimately, human-driven global climate change. Yet the Bush administration has continuously softened the language of the IPCC and NAS reports. In one celebrated case that came to light in the summer of 2005, the New York Times reported that Mr. Philip Cooney, the Chief of Staff for the White House

Council on Environmental Quality, diluted scientific wording in a key 2003 US Environmental Protection Agency report that clearly made the connection between greenhouse gas emissions and global climate. Mr. Cooney is a lawyer with no scientific training.

The late pre-eminent anthropologist Joseph Campbell celebrated the spiritual awakening of the earliest peoples, and tried to find unity in the religions of today, while at the same time recognizing the ancient to modern influence of science and technology on belief systems. The late Pope John Paul II, a human and religious icon revered around the world, accepted the modern theory of evolution. Within their own personal callings, these men spent brilliant lifetimes spinning new understanding into their web of the world and beyond. Neither would ever have dreamed of distorting, suppressing, or misusing legitimate, consensus-based scientific research. Those who would do otherwise, to promote personal, political, or ideological agendas, must be exposed and put aside.

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## INTRODUCING BRUCE WATSON



At the end of 2005, I finished my term as editor for *Elements*. Editors serve staggered three-year terms, so that a new editor is appointed each year. By this means, we intend that *Elements* remain a vital and current voice for the wide variety of topics that make up our disciplines.

With this in mind, I am very pleased to introduce my

replacement, **Bruce Watson**. Bruce is currently an Institute Professor of Science at Rensselaer Polytechnic Institute. He is a past president of the Mineralogical Society of America, a member of the National Academy of Science, and a recent recipient of the Goldschmidt Medal of the Geochemical Society. His research addresses the many processes affecting the behavior of the chemical elements in the Earth.

A native of New Hampshire, he attended Williams College (where his interest in geology was kindled) and later transferred to the University of New Hampshire, where he received a BA in geology in 1972. After a summer field season with the US Geological Survey, he entered graduate school at MIT with the intention of becoming a volcanologist. The lure of geochemistry at MIT in the 1970s was strong, however, and Bruce was particularly drawn to experimental approaches. He received his PhD in geochemistry from MIT in 1976.

Over a 30-year career, Bruce has pursued such research topics as mineral–melt partitioning, diffusion (in melts, crystals, and fluids), textural aspects of partially molten and fluid-bearing rocks, and kinetic disequilibria in materials as diverse as iron meteorites and marine carbonates. In parallel with this “process-oriented” theme, he has maintained a long-term interest in accessory minerals as hosts for geochemically interesting trace elements and isotopes and has contributed papers on such topics as solubilities and dissolution rates, lattice diffusion of radiogenic isotopes, and inclusion–host relationships. Zircon is his hands-down favorite mineral: over the past 27 years, he has published about 20 papers addressing the survivability, (diffusive) retentivity, and crystallization behavior of this remarkable mineral, which serves as the crustal geochemist’s primary window into the Earth’s distant past.

Bruce’s past editorial service includes two assignments with *Geochimica et Cosmochimica Acta* (associate editor, 1985–1988; editorial board member, 1991–1995), and he has acted as editor of *Chemical Geology* (1991–1995), editor for petrology and geochemistry of *Neues Jahrbuch für Mineralogie* (1988–1995), and editorial board member for *Geofluids* (2003–present).

Bruce has a deep appreciation for the central role of the mineral sciences and geochemistry in the broader sphere of Earth and environmental sciences, and he brings this perspective to *Elements*. Welcome to the team.

**Rod Ewing**

## BIENVENUE À LA SOCIÉTÉ FRANÇAISE DE MINÉRALOGIE ET DE CRISTALLOGRAPHIE (SFMC)

With this issue we warmly welcome one of the world’s oldest mineralogical organizations, the Société Française de Minéralogie et de Cristallographie, to the group of participating societies listed in each issue of *Elements*. Although the founding organizations behind *Elements* are from countries where English is the main language, it has always been our hope that organizations that normally use other languages would join the consortium. The arrival of France is therefore especially significant, and we hope that national societies in other non-English-speaking countries will follow their lead. It is perhaps appropriate that France has been first to make this decision, because our managing editor, graphic designer, and printer are all based in Québec, where English is most certainly not the main language. We can thank French flair for the professional style and quality of *Elements*. Welcome aboard!

## THE AESE AWARDS

We mentioned these awards in the last issue of *Elements*. We share excerpts from the letter Meg Smath, chair of the Association of Earth Science Editors’ Awards Committee, sent Rod Ewing.

I am pleased to inform you that we have conferred upon you our Award for Outstanding Editorial or Publishing Contributions. The reason you were nominated was your creation and editing of *Elements*. That simple sentence does not do justice to the tremendous effort you undertook, first in convincing all the different societies to share the dream with you, and then in making it happen. What you have achieved is a truly outstanding publication. In fact, AESE was so impressed by *Elements* that we named it one of the winners of our Outstanding Publication Award for 2005. This is the first time we have given this award to a journal; all previous winners have been monographs.

We realize of course that *Elements* did not come about from your efforts alone, but ... you are “certainly the person who began it ... and ... most certainly carefully [oversaw] its infancy....”

AESE does not give out its Award for Outstanding Editorial or Publishing Contributions every year, and not without careful deliberation. You join a select group of distinguished Earth scientists and writers: Julia Jackson (2002), John McPhee (1995), Gerald Friedman (1993), Allison (Pete) Palmer (1991), William H. Freeman Jr. (1985), Walter Sullivan (1983), Wendell Cochran (1982), Robert Bates (1981), Brian Skinner (1979), Philip Abelson (1976), Marie Siegrist (1974), Edwin Eckel (1973).

## ABOUT THIS ISSUE

We continually try to identify timely, front-row topics to bring to you in each issue of *Elements*. This issue of *Elements* is a bit different, in that it centers around the tools that many of us use to perform our science. Some of these tools are relatively inexpensive, and some are valued at (literally) billions of dollars. But whatever the cost or the function, the tools described here have one critical aspect in common. They are all shared, and as such are available to the scientific community at large. These shared facilities, or “user facilities” as we call them, are of unimaginable benefit. Without them, such instruments and facilities would be available only to a select few, or more likely, not at all. User facilities, big and small, have changed the face of how we do our science.

We would like to thank Dr. Nicholas Woodward of the US Department of Energy for sponsoring a user-facility workshop in 2004, from where the idea for this issue of *Elements* ultimately came, and Dr. Stephen Sutton of the University of Chicago and Argonne National Laboratory, for bringing the idea of this issue for *Elements* to reality.

## THANKS

As we start the new year, we would like to extend our most heartfelt thanks to all who have helped make *Elements* happen, issue after issue, in our launch year: guest editors, authors, contributors, copy editors, graphic artist, and all those who work behind the scenes. Working with Rod on this project has been a highlight and an inspiration for all of us (we will have more to say about this in the June issue, in which we will formally thank him). Even though he is officially “retired” from the magazine, he will continue to carry his duty until the June issue, for which he is principal editor.

Best wishes to all of you for 2006.

**Michael F. Hochella Jr., Ian Parsons, Bruce Watson,  
and Pierrette Tremblay**

Check our website [www.elementsmagazine.org](http://www.elementsmagazine.org)

Did you know that a PDF file of every issue of *Elements* is posted on our website, with a one-issue delay (for example, a PDF file of this issue will be posted by the time you receive your printed copy of issue 2).

## FUTURE DIRECTIONS IN GEOCHEMISTRY AND MINERALOGY: A VIEW FROM THE NATIONAL SCIENCE FOUNDATION

Margaret S. Leinen



*Dr. Margaret S. Leinen heads the Directorate for Geosciences at the National Science Foundation in the United States. She is a past president of the Oceanography Society, and prior to her appointment at NSF, she served as Dean of the Graduate School of Oceanography and Vice Provost for Marine and Environmental Programs at the University of Rhode Island. Her research focuses on the history of biogenic sedimentation in the oceans and its relationship to global biogeochemical cycles. As Dr. Leinen is the top administrator of the NSF Directorate that funds many of our readers, we asked her to offer some insights into the state of geochemical research. She kindly consented.*

I've never had the nerve to refer to myself as a geochemist or mineralogist in spite of using geochemistry and mineralogy extensively in my own research. Rather, I am an admirer of the three fields that come together in *Elements*. I have been especially delighted by the new journal because it so successfully reaches beyond the individual and group scholarship represented in *Geochimica et Cosmochimica Acta* to the excitement that happens when geoscientists bring multiple fields of expertise to bear on important problems and scientific questions. Looking at the past year it is clear that others are important partners in your excitement—biology, nanotechnology, geophysics, to name but a few.

Reading the pages of the first four issues of *Elements* is an exhilarating tour of new directions in mineralogy, geochemistry, and petrology. The articles make clear that the pace of innovation and evolution in the fields has accelerated in the last decade: new paradigms are elbowing out many old rules. For example, research demonstrates that the physical properties of minerals and their reactivity change with size because surface energy is no longer small relative to the total phase energy in nanoparticles. Over the past decade the interactions between geological and biological processes have emerged clearly. We have moved from a point of view that emphasized physical and chemical Earth processes to one that recognizes that nearly all processes we study are touched by the biology that is such a unique characteristic of our planet in the solar system. These changes in mineralogy, geochemistry, and petrology mirror rapid changes in geoscience as a whole.

I would like to highlight four major changes in the way we study geosciences that are affecting most of the fields funded by the National Science Foundation. I think they will have a profound effect on your three fields as well...

First, geoscientists have proposed and have received the first funding for observations that allow us to look at processes operating at very large spatial scales and decadal time scales. The EarthScope project is the largest and most complex geological experiment that has ever been

undertaken by the US. This continent-scale experiment looks at the structure and dynamics of North America using seismology and geodetic technology (to study stress and deformation); it also examines fault mechanisms by direct measurement from a drill hole across the San Andreas Fault ([www.earthscope.org](http://www.earthscope.org)). This rich landscape of continent-scale dynamics will lay the groundwork for new understanding of large-scale geochemical cycling and the interactions among mineralogy, geochemistry, petrology, deep structure, and dynamics.

Building on this foundation of capability for large-scale Earth observations, the ocean science community has proposed an ocean observatory initiative (OOI) that would use electro-fiber optic cables to connect ocean instruments to each other and to shore. OOI will provide the first sustained capability to observe the interior of the ocean and its seafloor ([www.orionprogram.org](http://www.orionprogram.org)). The hydrologic science community has joined with the engineering community to propose a series of hydrological observatories that will allow scientists to observe entire watersheds and incorporate study of engineered components of those systems. These new large-scale observing systems will provide extraordinary context for individual investigator research. In fact, such observing systems hold the promise of providing the observational and process-oriented framework that will allow studies of much smaller-scale phenomena and processes to be extrapolated to larger scales. Such scaling has been a formidable challenge in the past.

Reconciling laboratory experiments with the more complex real environment has also been a major challenge. A second major trend, related to the observatories, is the development of in situ sensors that can be remotely controlled from the laboratory over wired and wireless networks (e.g. [www.cens.ucla.edu](http://www.cens.ucla.edu)). The potential of such instruments to provide high-quality environmental characterization provides the opportunity to study small-scale materials and processes in the field as a bridge to lab experiments, further enhancing the scalability of studies done at the microscale or even the nanoscale.

Geoscientists are some of the most demanding consumers of high-performance computing. About 40% of the NSF-funded computing in excess of 1 Teraflop processing speed is done by geoscientists. Your future demands have been reflected in a call for geoscience computing at the petascale ([http://www.geo-prose.com/projects/pdfs/petascale\\_broch.pdf](http://www.geo-prose.com/projects/pdfs/petascale_broch.pdf)). This capability will be critical for representing and translating the complexity of geosystems to models that simulate environments we cannot recreate (Earth's interior, past environments), for achieving a simulation of processes based on first principles (e.g. complex multi-element chemical reactions on surfaces), and for integrating dense in situ observation into holistic representations of the environment to unveil large-scale phenomena.

Finally, encouraging efforts to develop greater inter-operability between large data sets is a major priority for the NSF and the community. The opportunity to link one's own observations with a rich mix of other relevant observations promises to allow geoscientists to draw more extensive and/or more interdisciplinary conclusions about their own work and its relation to other fields.

These important developments represent new tools, which are as important as new instruments. I believe that these tools, combined with the creative genius of this community, will ensure that the next decade will be as exciting as the past one has been.

**I would like to highlight four major changes in the way we study geosciences that are affecting most of the fields funded by the National Science Foundation. I think they will have a profound effect on your three fields as well...**

# Meet the Authors

focused on geoscience applications of accelerator mass spectrometry (AMS). In 2001 he accepted a position at Purdue University and is the director of the NSF-funded PRIME Lab, an interdisciplinary AMS laboratory.



**Gordon E. Brown Jr.** is Kirby Professor in the School of Earth Sciences at Stanford University and is also professor and chair of the Stanford Synchrotron Radiation Laboratory Faculty at the Stanford

Linear Accelerator Center. In addition, Brown serves as director of the Stanford Environmental Molecular Science Institute. Current research by Brown and his students involves molecular-scale studies of environmental contaminants in both natural and synthetic systems, including those containing microorganisms. Brown and his students use a variety of synchrotron radiation techniques, coupled with other experimental and theoretical methods, to study the chemical and biological processes that sequester and/or transform contaminant species, particularly at mineral–aqueous solution interfaces. Brown has been a user of synchrotron radiation facilities since 1977 and has served on the science advisory committees of a number of synchrotron radiation sources.



**Georges Calas** is professor of mineralogy at the Université Paris VI and deputy director of the Institute of Mineralogy, Universités Paris VI & VII, CNRS, and Institut de Physique du Globe de Paris.

His research interests concern the control of the physical and chemical properties of minerals, glasses, and melts by molecular-scale processes and how this relates to problems in Earth and environmental sciences and materials science. He has been using synchrotron radiation since the early 1980s, and his group is also involved in neutron scattering in glasses and melts. A former member of the Scientific Advisory Committee of ESRF and of the Scientific Council of LURE, he has also participated in a scientific review panel at APS.



**Marc Caffee** is a professor of physics at Purdue University. He received his PhD in 1986 from Washington University. His studies were on the use of neon isotopic and nuclear track records

found in gas-rich meteorites as gauges of early solar activity. During a postdoctoral fellowship at Lawrence Livermore National Laboratory, he investigated the noble gas inventory and degassing history of Earth's mantle using Xe in mantle emanations. Later, at LLNL he



**Martin Dove** is professor of computational mineral physics in the Department of Earth Sciences, University of Cambridge, and director of the National Institute for Environmental Science based in Cambridge.

His research work is primarily concerned with understanding the behavior of minerals at the molecular scale, and involves the use of neutron scattering coupled with computer simulations. Martin initially studied physics at Birmingham University (BSc and PhD). He held postdoctoral positions in physics (Edinburgh) and theoretical chemistry (Cambridge) before joining the Department of Earth Sciences in Cambridge.



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**Antonio (Tony) Lanzirotti** received his PhD in geochemistry from Stony Brook University in 1995 and is currently with the Consortium for Advanced Radiation Sources (CARS) at the

University of Chicago. He is the beamline scientist for the X26A hard X-ray microprobe at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. He recently served as chair of the NSLS Users' Executive Committee, an organization broadly concerned with representing the interests of the NSLS users and with helping to promote and encourage research at the NSLS. His research interests include development of state-of-the-art X-ray microbeam techniques for the in situ trace element analysis of Earth and environmental samples.

These include studies in microbeam X-ray absorption spectroscopy, fluorescence analysis, computed microtomography, and diffraction microcrystallography.



**John B. Parise** holds joint appointments in geosciences and chemistry at Stony Brook University. He received his PhD from the James Cook University, Australia, in 1980. His

research interests include mineralogy and synthetic solid-state chemistry, with emphasis on the characterization of atomic structure as a function of pressure, temperature, and composition using scattering techniques. Parise's group makes extensive use of intense neutron and X-ray sources at national and international facilities. Along with colleagues at the Geophysical Laboratory and the Oak Ridge National Laboratory (ORNL), he is involved with the construction of the next generation of high-pressure beamlines at the Spallation Neutron Source at ORNL.



**Richard J. Reeder** is professor of geochemistry at Stony Brook University. He received his PhD from the University of California at Berkeley in 1980. His research interests include

fundamental processes that operate at mineral–water interfaces, the chemical behavior of contaminants in environmental systems, and phase transitions in minerals. Reeder's research group has made extensive use of synchrotron-based techniques for studies of metal partitioning into carbonate and phosphate minerals. He is a former editor of *American Mineralogist* and is currently director of the Center for Environmental Molecular Science located jointly at Stony Brook University and Brookhaven National Laboratory on Long Island.



**Stephen R. Sutton**, senior scientist at the University of Chicago, received BS (physics) and PhD (Earth and planetary sciences) degrees from Washington University (St. Louis, USA). He has

been involved in synchrotron radiation research for 20 years, currently as co-project leader for the GeoSoilEnviroCARS beamlines (Sector 13) at the Advanced Photon Source (Argonne National Laboratory, USA) and spokesperson for beamline X26A at the National Synchrotron Light Source (Brookhaven National Laboratory, USA). His research is focused on X-ray fluorescence microprobe development and applications in the Earth, planetary, and environmental sciences, including studies of extraterrestrial materials.

# User Research Facilities in the Earth Sciences

Stephen R. Sutton,<sup>1</sup> Guest Editor

Aerial views of the 800 m circumference European Synchrotron Radiation Facility (ESRF) in Grenoble, France. PHOTO COURTESY ESRF

**The past several decades have seen an explosion in the availability of state-of-the-art research facilities, facilities that have been specifically constructed and operated for use by the general scientific community. Earth scientists have recognized the power of these methods for frontier research and are taking advantage of them in increasing numbers. “User-friendliness” is the key that makes these shared instruments very effective components in our arsenal of collaborative and interdisciplinary research tools.**

KEYWORDS: user facilities, research resources, synchrotron radiation

Electrons stream through a narrow vacuum tube at near the speed of light, encountering more than one thousand precisely tuned magnetic fields that alter their trajectories and cause them to emit X-rays. After traveling a one-kilometre course, the electrons miraculously return to within micrometres of their starting point, and then repeat the harrowing journey...nearly a million times a second! As the X-rays race from the electron path, a carefully positioned experiment room receives them. In this radiation-proof room, a nanogram mineral specimen, heated by an infrared laser beam, sits trapped within a high-pressure device held by an elaborate positioning instrument. The X-rays slam into the crystal and reflect off its lattice planes, producing a diffraction pattern collected by a two-dimensional detector. Outside the room, a team of students and scientists eagerly watch a computer monitor as the emerging pattern reveals the inner structure of the mineral under the extreme conditions, and they begin to contemplate how our view of the Earth's interior will be changed by the new results. Simultaneously, fifty other scientific teams around the “ring” are conducting experiments in biology, materials science, chemistry, and physics, as well as in Earth, planetary and environmental sciences.

The preceding describes just one of the exciting, advanced analytical facilities—a synchrotron X-ray source—that are available to members of the Earth science community. These so-called “user facilities” have emerged over the past couple of decades and have been specifically constructed to serve the research needs of the scientific community, including Earth scientists. Their impact has been great, allowing thousands of cutting-edge experiments to be conducted each year by scientists and students around the world. At US Department of Energy (DOE) user facilities alone, nearly 10,000 individuals in all fields of science conducted experiments in 2004, and ~80% used synchrotron radiation facilities. The advanced technology available at these facilities has opened up completely new areas of geoscience endeavor. For the first time, scientists have been

able to study the properties of candidate mantle and core materials at relevant temperature and pressure, visualize the interactions of immiscible fluids in soil columns, determine the speciation of trace contaminants in heterogeneous sediments, and examine the reactions that take place at mineral-water interfaces, for example.

These facilities represent an extremely effective use of research resources. Essentially, resources are pooled to develop and operate advanced instrumentation for shared use by the entire scientific community. As a result, expenditures to install multiple units at multiple sites are minimized. Another significant benefit is the cross-fertilization of ideas that occurs when scientists from different disciplines interact at the shared facilities.

Are Earth scientists using these shared facilities? The answer is a resounding yes! And, their utilization is increasing. For example, statistics compiled by the US DOE show that at its four synchrotron facilities, the number of users associated with the “Geosciences and Ecology” scientific discipline approximately doubled over the five-year period from 1999 to 2004. The 2004 users accounted for nearly 10% of the total users.

In this issue, we provide an overview of user facilities, what they are, what they can be used for, how they can be accessed, and what the future holds. Regretfully, it is impossible to be comprehensive in the space available, and some valuable facilities and methods have undoubtedly not received the attention they deserve. This issue includes references to additional information, including web addresses for some facilities and informational clearinghouses. The authors include Earth scientists involved in facility development and management, as well as individuals who are primarily users of facilities. The seeds for these articles were planted during a DOE-sponsored workshop, facilitated by Dr. Nicholas Woodward (DOE Geosciences Research Program Director) and held in May 2004, entitled “Geosciences User Facilities – Enhancing Instrumentation Access.” The workshop was organized by Prof. Richard Reeder (Stony Brook University), Prof. Marc Caffee (Purdue University), and me, and many of the authors of these articles were workshop participants.

As described in the article by Gordon Brown Jr. (Stanford University), Georges Calas (Universités de Paris) and me, user facilities have come into operation over the past ~30 years, and the number around the world is substantial and growing, particularly in the US and Europe. These facilities range in size from laboratories managed by large research teams to single instruments managed by individuals. In

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**FIGURE 1** Aerial view of the Advanced Light Source at Lawrence Berkeley National Laboratory overlooking San Francisco Bay in California, USA. PHOTO COURTESY OF THE ADVANCED LIGHT SOURCE

some cases, a facility is focused on a particular type of excitation source; examples are synchrotron radiation accelerators and neutron sources at national or international laboratories (FIG. 1). In other cases, a facility is a collection of varied analytical instruments focused on a particular area of science; an example is an analytical center at a university. In addition, there are single instrument facilities, such as university-based accelerator mass spectrometers or ion microprobes.

Marc Caffee (Purdue University), Martin Dove (University of Cambridge) and I explore the analytical techniques available at synchrotron radiation, neutron, and mass spectrometry user facilities. Each approach offers a unique window into the composition, structure, and history of Earth materials, the processes that produce them, and the processes they control. These analytical methods are highly complementary and foster multidisciplinary research by scientific teams whose members have complementary expertise.

The research conducted at these facilities has impact in disciplines across the Earth sciences, including geochemistry, mineralogy, mineral physics, molecular environmental science, and petrology. Examples of these forefront studies are summarized in the article by Gordon Brown Jr., Georges Calas, and Russell Hemley (Carnegie Institution of Washington). The large, multi-user facilities make possible research that cannot be conducted at individual investigator laboratories.

Although the analytical foci of these facilities are diverse, as described by Richard Reeder (Stony Brook University) and Antonio Lanzirotti (University of Chicago), all have a common mission—to ensure that these analytical instruments are accessible by investigators with innovative research ideas. This mission drives the facilities to work hard to make access and utilization “user-friendly.” Assistance provided includes easy-to-use websites for proposing experiments, straightforward computer programs for manipulating the apparatus and collecting data, and even convenient and comfortable living quarters and amenities. User-friendliness is the key to the effectiveness of a facility.

One of the remarkable changes that has taken place at user facilities is the improvement in effectiveness. In the not-too-distant past, conducting research at one of these facilities required a major commitment in time to become an expert in all aspects of the work, including instrument development itself. The time between project initiation and

publication could be long. But today the instrumentation is largely in place, experienced practitioners are available to assist novice experimenters (FIG. 2), and the time to publication is short. In most cases, a proposed experiment can receive instrument access in less than a few months, and the experimenter can complete a typical few-day experimental session with on-the-spot interpreted results. It is no longer necessary to be an expert in a particular technique to make effective use of it.

Advances in user facilities are ongoing, in terms of both advanced technologies and new facilities, and these enhancements are summarized in the article by John Parise (Stony Brook University) and Gordon Brown Jr. Analytical instruments, such as detectors, are continually being improved, and innovations are quickly incorporated into user facilities. In addition, new large research facilities are being constructed, extending the capabilities of existing methods, making new methods feasible for the first time, and spearheading the creation of new scientific disciplines.



**FIGURE 2** User facilities provide a congenial environment for collaborative research. Graduate student Amy Lazicki (UC-Davis) and staff scientists William Evans (center) and Hyunchoe Cynn from the Lawrence Livermore National Laboratory collect X-ray diffraction patterns with the diamond anvil cell at GSECARS/APS. PHOTO COURTESY GSECARS—UNIVERSITY OF CHICAGO

The main “take home” message in this issue is that it is now easier than ever to conduct experiments at a user facility, and there is ample assistance through the entire process to maximize the effectiveness and convenience of any research project. Facilities now have easy-to-navigate, web-based “front doors” with clear information on how to apply for access. The access proposal process is uncomplicated and can be accomplished quickly. Experienced individuals are available to assist in experiment design, data collection, and data interpretation. There is no better time than now to get involved in research at a user facility.

## ACKNOWLEDGMENTS

I would like to thank the authors of the articles in this issue for their superb efforts in putting this issue together. Editors Michael Hochella and Pierrette Tremblay were indispensable in bringing these articles to life. Special thanks also to Nicholas Woodward (US DOE – Geosciences Research Program Manager) and David Lambert (US NSF – Earth Sciences – Instrumentation and Facilities Program Manager) for their encouragement.

# User Facilities around the World

Gordon E. Brown Jr.,<sup>1,2</sup> Stephen R. Sutton,<sup>3</sup> and Georges Calas<sup>4</sup>



View of the Swiss Light Source. PHOTO COURTESY SWISS LIGHT SOURCE/PSI

**N**ational and international communities of scientists from a variety of disciplines have been successful in convincing a growing number of countries to construct major user facilities that collectively serve these communities. These user facilities make possible experimental studies that cannot be done in individual investigator laboratories. In addition, they have created a new style of research, in which scientists working in shared facilities conduct studies that benefit from a merging of ideas and techniques from different disciplines. Earth science users of these facilities are growing in number and are benefiting greatly from the multidisciplinary interactions such facilities stimulate and from the unique experimental capabilities they provide.

KEYWORDS: synchrotron X-rays, neutron scattering, electron beam microcharacterization, nanoscience research

## INTRODUCTION

During the past 20 to 30 years, a large number of national scientific user facilities have been developed in North America, Europe, and elsewhere. These user facilities differ in scale, complexity, construction cost, operations cost, and size of user base relative to the typical analytical facilities that most Earth scientists use in university and government laboratories. Included among these facilities are synchrotron light sources, pulsed beam (spallation) and continuous (nuclear reactor) neutron sources, accelerator-based mass spectrometers, electron beam microcharacterization facilities, and nanoscience centers. In this article, we provide a brief overview of the facilities that are available, focusing on those in North America and Europe.

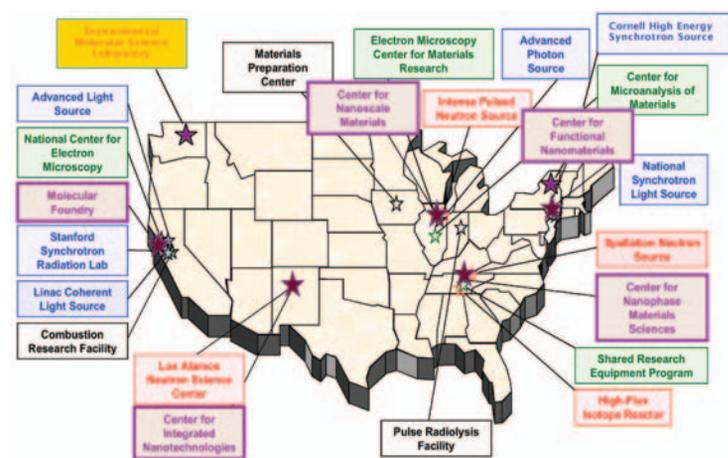
## MAJOR SCIENTIFIC USER FACILITIES AROUND THE WORLD

Most of the national scientific user facilities in the US are supported by the Office of Science of the Department of Energy (DOE), and descriptions of them can be found at [www.science.doe.gov/bes/BESfacilities.htm](http://www.science.doe.gov/bes/BESfacilities.htm). The locations of many of these facilities are shown in FIGURE 1. In addition, a booklet entitled *Scientific Research Facilities* prepared

by the DOE Office of Science can be downloaded at [www.science.doe.gov/bes/srf.pdf](http://www.science.doe.gov/bes/srf.pdf). A number of widely distributed national user facilities also exist in Europe (FIG. 2). TABLE 1 summarizes these facilities, as well as the two major synchrotron facilities in Japan. It also lists a number of the US and European supercomputer centers where computer time is potentially available to Earth scientists on a peer-reviewed proposal basis.

At present, there are 58 synchrotron light sources in 29 countries, including seven in the US and twelve in Japan (the following URLs list these synchrotron light sources and their characteristics: [www.chess.cornell.edu/chess/syncfclt.htm](http://www.chess.cornell.edu/chess/syncfclt.htm); [www.lightsources.org](http://www.lightsources.org)). US light sources and the European Synchrotron Radiation Facility (ESRF) served about 8000 users and 5000 users, respectively, in 2004.

Facilities in Asia have been at the forefront of instrumentation development. For example, the Photon Factory (KEK) in Tsukuba, Japan, a second-generation synchrotron light



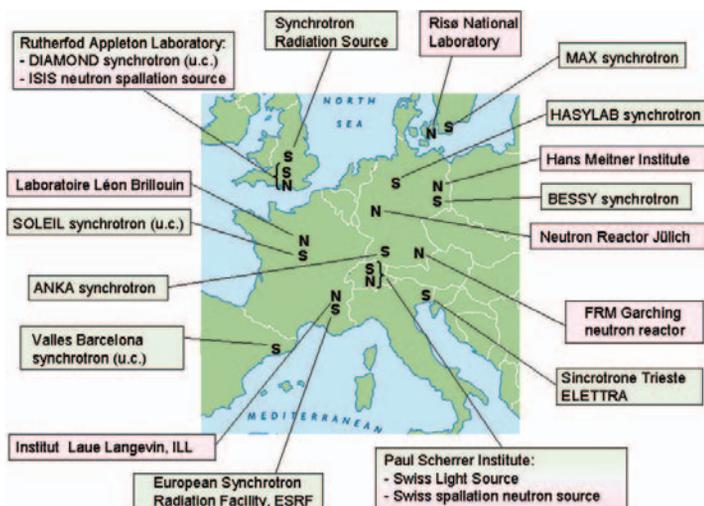
**FIGURE 1** Locations of US scientific user facilities supported by DOE, Office of Basic Energy Sciences. The different color codes used in the labels represent different classes of user facilities (e.g. blue represents synchrotron radiation sources), and the facility labels that are hatched (e.g. Linac Coherent Light Source) represent user facilities that are currently under construction. Figure courtesy of Dr. Patricia Dehmer, Office of Basic Energy Sciences, DOE. Also shown are several other national user facilities supported by other US agencies, including CHSS (NSF) and EMSL (DOE-OBER). A more complete listing of US national user facilities, including mass spectrometry facilities and supercomputer centers, can be found in Table 1.

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**FIGURE 2** Locations of major synchrotron radiation (S) and neutron (N) user facilities in Europe. Under construction (u.c.)

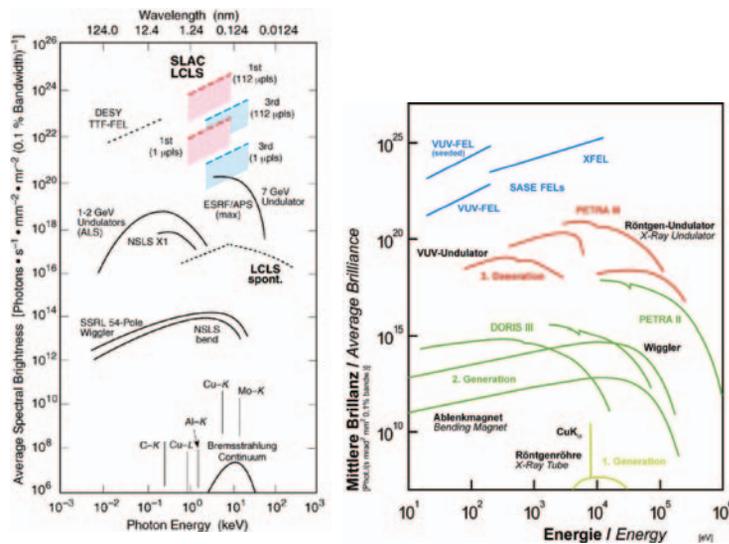
source, has been a productive user facility since 1982. The world's largest third-generation synchrotron source is Spring-8 in Japan, a facility that has been in operation since 1997. The Beijing (China) Synchrotron Radiation Facility has been supporting users since 1991.

In addition, many new synchrotron facilities are under construction or just beginning operations around the world. These include the Canadian Light Source (Saskatchewan), the Australian Synchrotron (Melbourne), Diamond (Didcot, Oxfordshire, UK), and SOLEIL (Gif-sur-Yvette, France).

In most countries, Earth science users are not charged for access to most major research facilities. Access is typically granted on the basis of peer-reviewed proposals (see Reeder and Lanzirrotti 2006). Support of research facilities is variable around the world. In the US, the DOE ([www.doe.gov](http://www.doe.gov)) is the steward for X-ray and neutron facilities used by Earth scientists (Astheimer et al. 2000) and by scientists from other disciplines. Substantial support for US Earth science research facilities is also provided by the NSF ([www.nsf.gov](http://www.nsf.gov)), primarily through its Instrumentation and Facilities Program ([www.nsf.gov/geo/ear/if/facil.jsp](http://www.nsf.gov/geo/ear/if/facil.jsp)). In Europe, research facilities are largely supported by governing bodies in the country of the home institution, but collaborative funding is becoming more widespread, as exemplified by the ESRF ([www.esrf.fr](http://www.esrf.fr)). Support for one of Canada's newest user facilities, the Canadian Light Source ([www.lightsource.ca](http://www.lightsource.ca)), also derives from a partnership approach, in which funding comes from federal, provincial, municipal, industrial, and academic sources.

## CLASSES OF USER FACILITIES

User facilities range from large, multi-instrument laboratories (only parts of which are needed by any user) operated by large management and research teams, to facilities with multiple instruments operated by several investigators, and single instruments managed by individual researchers. An example of a *large, multi-instrument laboratory* is the Environmental Molecular Science Laboratory (EMSL) at Pacific Northwest National Laboratory (PNNL) ([www.emsl.pnl.gov](http://www.emsl.pnl.gov)). EMSL is composed of six specialized facilities containing advanced and one-of-a-kind experimental and compu-



**FIGURE 3** Average spectral brightness/brilliance versus photon energy for selected synchrotron light sources in the US (left) and Germany (right) compared with conventional sealed-tube and rotating anode laboratory X-ray sources. Left figure courtesy of Prof. Herman Winick, SSRL; Right figure is from the following URL: [http://tesla-new.desy.de/content/relatedprojects/index\\_eng.html](http://tesla-new.desy.de/content/relatedprojects/index_eng.html)

tational resources for scientists engaged in fundamental research at the interface of physical, chemical, and biological processes.

At a somewhat smaller scale, *beamlines* are available at government-operated synchrotron radiation facilities and neutron sources. In some cases, these beamlines are dedicated to Earth sciences research (e.g. GeoSoilEnviroCARS Sector 13 at the Advanced Photon Source (APS) – [www.gsecars.org](http://www.gsecars.org)); however, more typically a fraction of a beamline's scientific program is devoted to this mission. These beamlines often have multiple instruments sharing the experimental time.

*Research centers* are typically sited at academic institutions and normally house a variety of instruments organized around a particular type of technique or scientific theme. Examples include centers focused on accelerator mass spectrometry, on electron beam characterization, and on secondary ion mass spectrometry.

Finally, *individual instruments* are typically sited at universities; some fraction of their experimental time is made available to outside users. These instruments include electron microprobes/microscopes, X-ray diffractometers, X-ray photoelectron spectrometers, secondary ion mass spectrometers (SIMS), nano-SIMS, tomography equipment, magnetometers, and computational facilities.

## WHAT IS A SYNCHROTRON LIGHT SOURCE?

Synchrotron light sources are the most widely used user facilities, and thus it is useful here to briefly describe their characteristics. A synchrotron light source consists of an electron or positron source coupled to a particle accelerator. Charged particles are accelerated and then injected into storage rings where they are further accelerated up to relativistic speeds and to energies ranging from 500 MeV to 8 GeV, depending on ring size. As bend magnets steer the charged particles around the storage ring, energy is lost in the form of synchrotron radiation. The energy of this radiation spans the range from far infrared (0.001 keV or 1240 nm) to hard X-rays (100 keV or 0.0124 nm) and is

extremely intense, highly focused, and highly polarized relative to the X-rays produced by a sealed-tube or rotating anode X-ray generator (Winick 1987). As shown in FIGURE 3, the average brightness of synchrotron light produced by bend magnets, or by special multipole magnetic devices called wigglers or undulators, is six to twelve orders of magnitude greater than that from conventional laboratory X-ray sources. Beamlines are built tangential to the electron or positron orbit of the storage ring and capture the radiation emitted from a bend magnet, wiggler or undulator (FIG. 4). Experimental stations (beamstations) at the end of these beamlines can be configured in many ways to conduct scattering, spectroscopy, or imaging experiments using this extremely bright light. Such light sources make new classes of experiments possible for the first time. Also they greatly enhance the sensitivity of conventional types of studies using IR, UV-visible, and X-ray radiation, and they increase experimental throughput enormously. A number of examples of synchrotron radiation research on Earth and environmental materials are given in Brown et al. (2006).

The cost of a synchrotron light source ranges from less than 100 million to greater than one billion US dollars, depending on its size and complexity. For example, the Advanced Photon Source located at Argonne National Laboratory is a 7 GeV storage ring that produces extremely bright hard X-rays. This source, commissioned in 1996, cost about 1 billion US dollars including the cost of most experimental stations and beamlines (SEE FIG. 4).

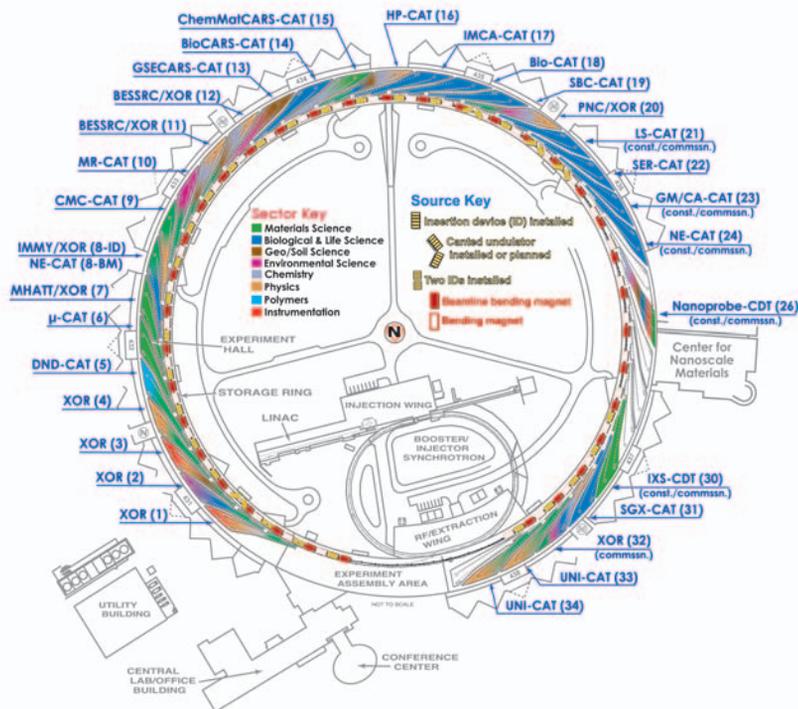
The seven US synchrotron light sources currently have approximately 215 beamstations ranging in energy from hard X-ray to soft X-ray/vacuum ultraviolet and far infrared. Among these beamstations, approximately 80 are currently being used by Earth and environmental scientists to various extents, and about 10% of the total beam time at these facilities is used by these two communities (Brown et al. 2004). In Europe, about 275 synchrotron radiation beamstations are available, and a similar proportion of beamstations are used by Earth and environmental science users.

## NEUTRON SCATTERING FACILITIES

Neutron scattering centers represent another major type of national user facility that has had a significant impact on Earth sciences research. As shown in Table 1, there are four major neutron scattering facilities in the US and Canada and six in Europe. As pointed out by Sutton et al. (2006), neutron scattering is much more sensitive to light elements, including hydrogen, than X-ray scattering, and it is also sensitive to different isotopes of the same element. The latter characteristic allows neutron scattering experiments on isotopically substituted materials that focus on the structural role of a particular element where a relatively low-abundance isotope scatters more strongly than the naturally abundant isotope of that element. Examples of the types of research carried out at these facilities include neutron scattering on isotopically substituted silicate glasses (Cormier et al. 2001), magnetic ordering in wüstite at high pressure (Ding et al. 2005), and neutron scattering studies of hydrogen in novel clathrate hydrates (Lokshin et al. 2004).

A major disadvantage of neutron scattering relative to X-ray scattering is that large samples are required in neutron scattering because of the relatively low neutron scattering power of nuclei and the low neutron fluxes of existing neutron sources. This situation will change dramatically with

## THE ADVANCED PHOTON SOURCE Sector Allocations & Disciplines Source Configuration



**FIGURE 4** Distribution of beamlines at the Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois, US. The various Collaborative Access Team (CAT) designations are shown for each sector. FIGURE FROM [WWW.APS.ANL.GOV/ABOUT/RESEARCH\\_TEAMS/BEAMLINE\\_WEB-SITES.HTM](http://WWW.APS.ANL.GOV/ABOUT/RESEARCH_TEAMS/BEAMLINE_WEB-SITES.HTM)

the completion of the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in the United States, which will provide neutron fluxes that are 100 to 1000 times more intense than the highest flux neutron source currently existing (the ISIS pulsed neutron source at Rutherford Appleton Laboratory in the United Kingdom). This improvement will permit the use of much smaller samples, which will reduce difficulties in dealing with samples that are compositionally inhomogeneous on the millimeter scale. It will also reduce data collection times and sample throughput substantially. In addition, significant developments in high-pressure neutron diffraction have taken place recently. New opportunities are arising from the construction of the SNS, where a beamline dedicated to high-pressure neutron scattering will be built (see Parise and Brown 2006).

## MASS SPECTROMETRY FACILITIES

Mass spectrometry laboratories are available as user facilities, and these include primarily ion microprobe and accelerator mass spectrometry (AMS) instruments. These facilities make it possible for members of the Earth science community to obtain isotopic measurements for studies of the geochronology of the early Earth, cosmochemistry, erosion rates, mantle dynamics, meteorite chronology, and radiocarbon dating, for example. Ion microprobes at least partially supported by the US National Science Foundation Instrumentation and Facilities Program (NSF-IF; [www.nsf.gov/geo/ear/if/facil.jsp](http://www.nsf.gov/geo/ear/if/facil.jsp)) include the Northeast National Ion Microprobe Facility at Woods Hole Oceanographic Institution (Massachusetts) and the National Ion Microprobe Facility at the University of California–Los Angeles. In Europe, examples of national ion microprobe facilities

include (1) the UK Ion Microprobe Facility, which is located in the Department of Geology and Geophysics, University of Edinburgh, Scotland; (2) the Nordic Ion Microprobe Facility, located at the Swedish Museum of Natural History, Stockholm, Sweden; and (3) the National Ion Microprobe Facility, located at the Centre de Recherches Pétrographiques et Géochimiques, Nancy, France. AMS facilities partially supported by NSF-IF include the Purdue Rare Isotope Measurement Laboratory at Purdue University (Indiana) and the Arizona AMS Laboratory at the University of Arizona. In Europe, more than 15 AMS facilities are currently integrated in a network sponsored by the European Science Foundation ([www.stats.gla.ac.uk/iaams/](http://www.stats.gla.ac.uk/iaams/)).

## SUPERCOMPUTER CENTERS

Over the past 25 years, a number of supercomputer centers have been established at US multipurpose national laboratories by the US Department of Energy (see Table 1). Major Earth, atmospheric, and ocean science problems are being addressed using these supercomputers, including climate modeling, atmospheric chemistry simulations, ocean circulation models, simulation of the early universe, inversion of seismic data to generate 3-D tomographic images of Earth's interior, reactive transport modeling of contaminants in groundwater aquifers, and molecular environmental science problems, including molecular-scale simulations of mineral-water interfaces. A recent National Academy of Sciences report (Graham et al. 2005) presenting a comprehensive overview of supercomputing in the US and abroad can be obtained at [http://books.nap.edu/html/up\\_to\\_speed/notice.html](http://books.nap.edu/html/up_to_speed/notice.html). A similar overview describing supercomputing facilities in European countries has been produced by the Academic Research Computing Advanced Facilities Discussion Group Europe (ARCADE: [www.arcade-eu.info/index.html](http://www.arcade-eu.info/index.html)). Several of the more recent US supercomputers have blazing speed and enormous storage capacities. For example, the 3328-processor IBM BlueGene/L - eServer Blue Gene Solution 65536 supercomputer at the National Energy Research Scientific Computing Center (NERSC), located at Lawrence Livermore National Laboratory, is currently the most powerful computer on Earth, according to the TOP500 List of

Supercomputers ([www.top500.org/lists/2005/06/](http://www.top500.org/lists/2005/06/)); it operates at a maximum speed of 136.8 Teraflops. In addition, Yokohama, Japan, is the site of the Earth Simulator Center, which is built around a NEC Vector SX6 supercomputer that runs at 35.8 Teraflops (currently the fourth-fastest computer on Earth). The purpose of this center is to make quantitative predictions and assessments of variations in the atmosphere, oceans, and solid Earth; to forecast natural disasters and environmental problems; and to conduct simulations relevant to industry, bioscience, and energy. Access to US supercomputers, such as the HP Cluster Platform 6000 rx2600 Itanium2 at PNNL, which runs at a speed of 8.6 Teraflops (currently the 30<sup>th</sup>-fastest computer on Earth), is available to the scientific community on a peer-reviewed proposal basis. Once approved, investigators can access this supercomputer remotely.

## CONCLUDING REMARKS

The impact of user facilities, both experimental and computational, around the world is growing, and these facilities are causing a revolution in the way science is conducted. As an example of the changes such facilities have created over the past 30 years, a modern third-generation synchrotron light source and fast-readout CCD detector make it possible to collect a complete set of X-ray intensity data from a typical large unit cell protein crystal in several minutes. In contrast, one of us (GEB) spent at least five weeks collecting diffraction data on five olivine single crystals with small unit cells in the late 1960s as part of his PhD work. This enormous change in experimental capability is now being felt in many different fields of science, including the Earth sciences.

## ACKNOWLEDGMENTS

We are grateful to the governments of the countries that have funded the construction of user facilities and that continue to fund their operation costs. Such facilities are funded in large part by the Office of Science, Department of Energy in the US, by the Ministry of Research in France, and by national scientific funding agencies in other countries (see TABLE 1 footnotes).

**TABLE 1** NORTH AMERICAN, EUROPEAN, AND JAPANESE NATIONAL SCIENTIFIC USER FACILITIES

User Facility	Location	Main Sponsor	Currently Available Techniques and/or Research Topics	Year of First Operation
<b>US and Canadian Synchrotron Light Sources</b>				
National Synchrotron Light Source I (X-Ray) (2.8 GeV – 2 <sup>nd</sup> generation)	Brookhaven National Lab (BNL), Upton, NY	DOE-BES (1)	Spectroscopy, scattering, microscopy, tomography	1982
National Synchrotron Light Source II (VUV) (0.8 GeV – 2 <sup>nd</sup> generation)	BNL	DOE-BES	Spectroscopy, scattering, microscopy, tomography, IR, photoemission	1982
Stanford Synchrotron Radiation Laboratory (SSRL) (3 GeV – 3 <sup>rd</sup> generation)	Stanford Linear Accelerator Center (SLAC), Stanford, CA	DOE-BES	Spectroscopy, scattering, tomography, photoemission	1974 (SPEAR2) 2004 (SPEAR3)
Advanced Light Source (ALS) (1.5–1.9 GeV – 3 <sup>rd</sup> generation)	Lawrence Berkeley National Lab (LBNL), Berkeley, CA	DOE-BES	Spectroscopy, scattering, microscopy, tomography, IR, photoemission	1993
Advanced Photon Source (APS) (7 GeV – 3 <sup>rd</sup> generation)	Argonne National Lab (ANL), Argonne, IL	DOE-BES	Spectroscopy, scattering, microscopy, tomography	1996
Cornell High Energy Synchrotron Source (CHESS) (5.5 GeV – 2 <sup>nd</sup> generation)	Ithaca, NY	NSF (2)	Spectroscopy, scattering	1979
Synchrotron Radiation Center (SRC) (0.8–1 GeV – 2 <sup>nd</sup> generation)	Stoughton, WI	NSF	Spectroscopy, scattering, microscopy, photoemission, lithography	1987
Center for Advanced Microstructures and Devices (CAMD) (1.5 GeV – 2 <sup>nd</sup> generation)	Baton Rouge, LA	State of LA	Lithography, spectroscopy, microscopy	1990
Canadian Light Source (CLS) (2.9 GeV – 3 <sup>rd</sup> generation)	University of Saskatchewan, Canada	Canadian Consortium (3)	Spectroscopy, scattering, microscopy, IR scattering	2004
<b>European and Japanese Synchrotron Light Sources</b>				
European Synchrotron Radiation Facility (ESRF) (6.0 GeV – 3 <sup>rd</sup> generation)	Grenoble, France	European Consortium (4)	Spectroscopy, scattering, microscopy, tomography	1994
Synchrotron Radiation Source (SRS) (2 GeV – 2 <sup>nd</sup> generation)	Daresbury Laboratory, Warrington, UK	CCLRC (5)	Spectroscopy, scattering	1980

User Facility	Location	Main Sponsor	Currently Available Techniques and/or Research Topics	Year of First Operation
<b>European and Japanese Synchrotron Light Sources (cont'd)</b>				
Hamburger Synchrotronstrahlungslabor HASYLAB (4.5 & 12 GeV – 2 <sup>nd</sup> generation)	Deutsche Elektronen-Synchrotron (DESY), Hamburg, Germany	BMBF (6)	Spectroscopy, scattering, microscopy	1993 (DORIS III) (PETRA II)
Berliner Elektronenspeicherring-Gesellschaft für Synchrotron Strahlung (BESSY) (1.7–1.9 GeV – 3 <sup>rd</sup> generation)	BESSY, Berlin-Adlershof, Germany	BMBF	Spectroscopy, scattering, microscopy	1979 (BESSY I) 1998 (BESSY II)
Swiss Light Source (SLS) (2.4 GeV – 3 <sup>rd</sup> generation)	Paul Scherrer Institut, Villigen, Switzerland	Swiss Government (7)	Spectroscopy, scattering	2001
Sincrotrone Trieste (ELETTRA) (2.2–2.4 GeV – 3 <sup>rd</sup> generation)	Trieste, Italy	Italian Consortium (8)	Spectroscopy, scattering	1978
Angströmquelle Karlsruhe (ANKA) (2.5 GeV – 3 <sup>rd</sup> generation)	Forschungszentrum Karlsruhe, Germany	German Consortium (9)	Spectroscopy, scattering, microscopy	2000
MAX II (1.5 GeV – 3 <sup>rd</sup> generation)	Lund University, Sweden	Vk (10), Lund University	Spectroscopy, scattering	1996
Source Optimisée de Lumière d'Énergie Intermédiaire du LURE (SOLEIL) (2.75 GeV – 3 <sup>rd</sup> generation)	Saint-Aubin, Gif-sur-Yvette, France	French Consortium (11)	Spectroscopy, scattering, microscopy	To be commissioned in 2006
DIAMOND (3 GeV – 3 <sup>rd</sup> generation)	Rutherford Appleton Laboratory, Didcot, UK	CCLRC (12) and Wellcome Trust	Spectroscopy, scattering, microscopy	To be commissioned in 2007
Photon Factory (KEK) (2.5 GeV – 2 <sup>nd</sup> generation)	Tsukuba, Japan	Japanese Government	Spectroscopy, scattering, microscopy	1982
Spring-8 (JASRI) (8 GeV – 3 <sup>rd</sup> generation)	Nishi Harima, Japan	Japanese Government	Spectroscopy, scattering	1997
<b>US and Canadian High-Flux Neutron Sources</b>				
High-Flux Isotope Reactor (HFIR)	Oak Ridge National Lab (ORNL), Oak Ridge, TN	DOE-BES	Neutron scattering	1966
Intense Pulsed Neutron Source (IPNS)	ANL	DOE-BES	Neutron scattering	1981
Manual Lujan Jr Neutron Scattering Center (Lujan Center)	Los Alamos National Lab (LANL), Los Alamos, NM	DOE-BES	Neutron scattering	1985
Spallation Neutron Source (SNS)	ORNL	DOE-BES	Neutron scattering	Under construction
Canadian Neutron Beam Centre (CNBC)	Chalk River, Ontario, Canada	NRC (13)	Neutron scattering	1950
<b>European High-Flux Neutron Sources</b>				
Institut Laue Langevin (ILL) High Flux Reactor	Grenoble, France	European Consortium (14)	Neutron scattering	1967
ISIS Pulsed Neutron Source	Rutherford Appleton Laboratory, Didcot, UK	CCLRC	Neutron scattering	1985
Laboratoire Léon Brillouin (LLB) Neutron Reactor	Centre d'études nucléaires, Saclay, France	CEA, CNRS	Neutron scattering	1981
Swiss Spallation Neutron Source (SINQ)	Paul Scherrer Institut, Villigen, Switzerland	ETH (7)	Neutron scattering	Under construction
FRM Garching Neutron Reactor	TU Munich in Garching, Germany	BMBF	Neutron scattering	2004 (FRM II)
FRJ-2 Research Reactor	FZJ, Jülich, Germany	BMBF	Neutron scattering	1962
Berlin Neutron Scattering Center (BENSC)	Hans Meitner Institute, Wannsee, Germany	BMBF and Land Berlin	Neutron scattering	1993
<b>US Electron Beam Microcharacterization Centers</b>				
Center for Microanalysis of Materials	University of Illinois, Urbana-Champaign, Urbana-Champaign, IL	DOE-BES	Electron microscopy, surface microanalysis, diffraction, backscattering	NA
Electron Microscopy Center for Materials Research (EMCMR)	ANL	DOE-BES	High-resolution TEM	1981
National Center for Electron Microscopy (NCEM)	LBNL	DOE-BES	High-resolution electron-optical microcharacterization	1983
Shared Research Equipment (SHaRE) Program	ORNL	DOE-BES	Electron beam microcharacterization	NA
<b>Examples of US and European Mass Spectrometry Facilities</b>				
Arizona AMS Laboratory	University of Arizona, Tucson, AZ	NSF	Radiocarbon dating and studies involving other cosmogenic isotopes	1981
Purdue Rare Isotope Measurement Laboratory (PRIME)	Purdue University, West Lafayette, IN	NSF	Radiocarbon dating, exposure dating, erosion rates, meteorite chronology	1989
Northeast National Ion Microprobe Facility (NENIMF)	Woods Hole Oceanographic Institution, Woods Hole, MA	NSF	Solar/presolar processes, early Earth evolution, mantle dynamics	1996
National Ion Microprobe Facility	University of California – Los Angeles, CA	NSF	Geochronology, cosmochemistry	1996
Ion Microprobe Facility	University of Edinburgh, Scotland	NERC	Geochronology, climatology, early Earth evolution, volcanology	1987
National Ion Microprobe Facility	Centre de Recherches Pétrographiques et Géochimiques, Nancy, France	CNRS	Geochronology, cosmochemistry, erosion rates	2001
Nordic Geological Ion Microprobe Facility (NORDSIM)	Swedish Museum of Natural History, Stockholm, Sweden	European Consortium (15)	Geochronology, petrology	2001
<b>US Nanoscale Science Research Centers</b>				
Molecular Foundry	LBNL	DOE-BES	STM, AFM, TEM, mass spectrometers, NMR, e-beam lithography	Under construction
Center for Nanophase Materials Science (CNMS)	ORNL	DOE-BES	Synthesis, characterization, theory, modeling, simulation design	Under construction
Center for Integrated Nanotechnologies (CINT)	LANL and Sandia National Lab (SNL)	DOE-BES	Nanophotonics, nano-electronics, nanomechanics	Under construction

User Facility	Location	Main Sponsor	Currently Available Techniques and/or Research Topics	Year of First Operation
<b>US Nanoscale Science Research Centers (cont'd)</b>				
Center for Functional Nanomaterials (CFN)	BNL	DOE-BES	Fabrication and study of nanoscale materials	Under construction
Center for Nanoscale Materials (CNM)	ANL	DOE-BES	Bio-inorganic interfaces, complex oxides, nanocarbon, nanomagnetism, nanophotonics, nanopatterning, X-ray nanoprobe	Under construction
<b>Other Examples of US and European User Facilities</b>				
William R. Wiley Environmental Molecular Science Laboratory (EMSL)	Pacific Northwest National Laboratory (PNNL)	DOE-BER (16)	Environmental chemistry, surface and interface science, genomic research	1997
Bayerisches Geoinstitut	Universität Bayreuth, Germany	European Union	High-pressure syntheses and experiments, analytical equipment; characterization of material properties	1986
Williamson Research Centre for Molecular Environmental Science	University of Manchester, United Kingdom	NERC (17)	Molecular environmental science	2001
<b>Examples of US, European, and Japanese Supercomputer Centers</b>				
National Energy Research Scientific Computing Center (NERSC)	LLNL	DOE-OS (18)	Climate modeling, materials research, early universe simulations, protein structures	1978
San Diego Supercomputer Center	University of California, San Diego	NSF	Multidisciplinary	1985
Scalable Computing Laboratory	Ames Laboratory, University of Iowa	DOE-ASCR (19)	Multidisciplinary	1989
National Center for Computational Science (NCCS)	ORNL	DOE-OS	Multidisciplinary	1992
Brookhaven Computing Facility (BCF) – Riken BNL Research Center	BNL	RIKEN (20) & DOE	Multidisciplinary	1997
Molecular Science Computing Facility (MSCF)	PNNL (EMSL)	DOE	Molecular environmental science, atmospheric chemistry, systems biology, catalysis, materials science	2003
NASA/Ames Research Center	NASA/Ames Mountain View, CA	NASA	Multidisciplinary	2005
National Leadership Computing Facility (NLCF)	ANL	DOE	Multidisciplinary	2007
Earth Simulator Center	Yokohama, Japan	Japan Agency for Marine-Earth Science and Technology	Atmosphere and ocean sciences, solid Earth	2002
Barcelona Supercomputing Center (BSC)	Universitat Politècnica de Catalunya, Spain	Ministerio de Educación y Ciencia	Earth sciences, biology	2005
Ecole Polytechnique Fédérale de Lausanne	Lausanne, Switzerland	Swiss National Science Foundation	Multidisciplinary	2005

NA Not available

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| <p>(1) US Department of Energy – Basic Energy Sciences (BES)</p> <p>(2) US National Science Foundation (NSF)</p> <p>(3) Alberta Heritage Foundation for Medical Research, Alberta Innovation &amp; Science, Boehringer Ingelheim, Canada Foundation for Innovation, City of Saskatoon, Western Economic Diversification, Ontario Innovation Trust, Saskatchewan Industry and Resources, National Research Council, Natural Resources Canada, SaskPower, University of Alberta, University of Saskatchewan, University of Western Ontario</p> <p>(4) France, Germany, Italy, United Kingdom, Spain, Switzerland, Belgium, Netherlands, Denmark, Finland, Norway, Sweden</p> | <p>(5) Council for the Central Laboratory of the Research Councils (CCLRC), United Kingdom</p> <p>(6) Bundesministerium für Bildung und Forschung (Federal Ministry for Education and Research)</p> <p>(7) Eidgenössische Technische Hochschule (ETH), Zurich</p> <p>(8) AREA Science Park, Regione Friuli Venezia Giulia, National Institute for the Physics of Matter (INFN), Sviluppo Italia, Consiglio Nazionale delle Ricerche (CNR)</p> <p>(9) Angströmquelle Karlsruhe, Land Baden-Württemberg</p> <p>(10) Vetenskapsrådet (Swedish Research Council)</p> <p>(11) Centre National de la Recherche Scientifique (CNRS), Commissariat à l'Énergie Atomique (CEA), France</p> <p>(12) Council for the Central Laboratory of the Research Councils (CCLRC), United Kingdom</p> | <p>(13) National Research Council (NRC), Canada</p> <p>(14) France: CEA and CNRS; Germany: Forschungszentrum Jülich (FZJ); United Kingdom: CCLRC</p> <p>(15) Nordic facility funded jointly by Sweden, Norway, Finland, and Denmark</p> <p>(16) US DOE, Office of Biological and Environmental Research (BER)</p> <p>(17) Natural Environment Research Council (NERC), United Kingdom</p> <p>(18) US DOE, Office of Science (OS)</p> <p>(19) US DOE, Office of Advanced Scientific Computing Research (ASCR)</p> <p>(20) Rikagaku Kenkyusho (RIKEN, The Institute of Physical and Chemical Research) of Japan ■■</p> |
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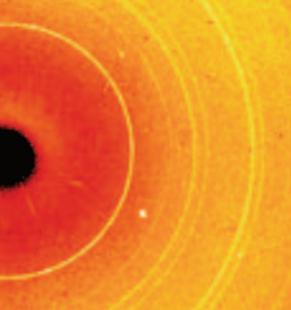
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# Synchrotron Radiation, Neutron, and Mass Spectrometry Techniques at User Facilities

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X-ray diffraction pattern of stishovite (SiO<sub>2</sub>) in a diamond anvil cell at 40 GPa. From Prakapenka et al. (2004), *Journal of Physics and Chemistry of Solids* 65: 1537–1545

**U**ser research facilities around the world offer tremendous opportunities for scientific experimentation by members of the Earth science community. Synchrotron radiation sources, neutron sources, mass spectrometers, and others represent a powerful force in tackling complex scientific problems. In these techniques, Earth materials are bombarded with beams of ions, subatomic particles and/or photons to learn the secrets of their properties and histories. Some of these methods can be applied to nanoscale materials with “desktop” instruments while others require macroscopic samples and utilize large-scale devices residing in multiple buildings; and there is everything in between.

KEYWORDS: Synchrotron radiation, neutrons, mass spectrometry, user facilities, analytical techniques

## INTRODUCTION

Analytical methods available at user facilities are remarkable in their scope, and their capabilities are highly complementary. Some methods require samples to be exquisitely prepared while others can be applied to “as-is” specimens. Some methods involve the coordination of large, multibuilding apparatus while others are carried out in a small room. Although the instruments are highly variable in their make-up, the techniques they offer represent a powerful force in tackling complex scientific problems. From chemical analyses of components in nanogram specimens from the interplanetary medium, to chronological studies of the earliest rocks from the Earth’s crust, to the properties of the mineral phases in the deep Earth, the scientific potential is huge and limited only by the imagination and innovation of Earth scientists.

Here, we highlight some current capabilities to give a flavor of the information that can be obtained at user facilities. Our focus is on techniques using synchrotron radiation, neutrons, and mass spectrometry. Each provides a different yet complementary view into the complex nature and histories of Earth materials and geological processes. Synchrotron radiation is well-suited for experiments that define the arrangement of atoms and their electronic structures. Neutrons can probe the structures and dynamics of light elements. Mass spectrometry yields information on isotopic composition valuable for radiometric dating. Although the

operation of these instruments is complex at the lowest level, they are designed, constructed, and operated with novice users in mind. User-friendly software interfaces and skilled technical assistance are available.

## SYNCHROTRON RADIATION

Synchrotrons generate intense radiation in the infrared to X-ray regime. The unique properties of this radiation (high brilliance, polarization, continuous energy spectrum, temporal structure) allow a wide variety of analytical techniques. The application of these techniques can provide crucial information about the nature of minerals and other Earth materials, including crystalline structure, chemical composition, chemical speciation, surface and interface structure, electronic structure, and porosity (e.g. Fenter et al. 2002). One of the major advantages to using synchrotron light for investigating Earth materials is that the penetrating power of the radiation permits studies in near-natural conditions, for example, in the presence of water. Synchrotron experiments are conducted at a “beamline” consisting of optical equipment to condition the X-ray beam and a shielded experiment room containing a sample manipulator and X-ray detectors (FIG. 1).

Earth materials are often heterogeneous, and X-ray microbeam studies are valuable in unraveling this complexity. Spatial resolutions down to 100 nm are achievable using zone plates, mirrors, and refractive optics. Most X-ray-based methods can be applied with high spatial resolution, including X-ray fluorescence (XRF), X-ray absorption fine structure (XAFS), X-ray diffraction (XRD), and computed microtomography (CMT). By applying these techniques in a nearly simultaneous fashion, it is possible to produce elemental maps with sub-part-per-million sensitivity and determine the speciation and mineralogy at selected locations in the material. An example is a study of Ni- and Zn-contaminated soils from the Morvan region of France, which resulted in a quantitative assessment of the forms of these two elements (Manceau et al. 2003). Toxic and radioactive elements are also amenable to this approach. In a plutonium sorption experiment on Yucca Mountain (Nevada, USA) tuff, Pu was found to be strongly associated with Mn-rich smectite phases and all but absent in the zeolite and iron-oxide grains that dominate the rock (Duff et al. 1999).

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**FIGURE 1** Photograph of the GeoSoilEnviroCARS undulator experimental station at the Advanced Photon Source (Argonne, Illinois, USA) showing the surface and interface diffractometer (left) and X-ray microprobe (back center). COURTESY OF GEOSOLENVIROCARS, UNIVERSITY OF CHICAGO

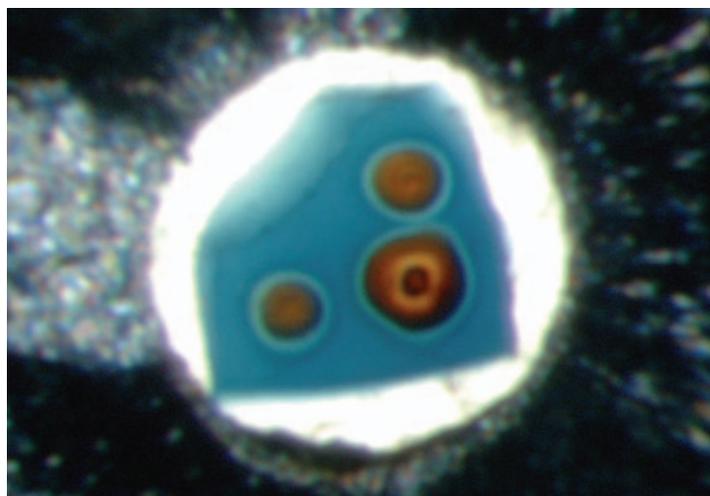
*X-ray absorption fine-structure spectroscopy (XAFS)* provides detailed information regarding the average electronic and molecular energy levels associated with a specific element. This information permits determinations of oxidation state, coordination number, identity of nearest neighbors and bond lengths (e.g. Koningsberger and Prins 1988). Such data are crucial for understanding the structure of complex minerals, geochemical properties of Earth materials, and transport mechanisms for ore-forming metals, for example. Speciation measurements can be obtained for trace elements down to about 10 parts per million and with or without spatial resolution. The XAFS measurement consists of collecting absorption intensity (or some product of the absorption, such as X-ray fluorescence) as the energy of the exciting X-ray beam is scanned with high-energy resolution (<1 eV) through the X-ray absorption edge of the element of interest. The resulting absorption spectra can then be interpreted in terms of the molecular environment of that atom (e.g. Stern and Heald 1983). The method is applicable to virtually all elements in the periodic table, and samples in all forms (liquid, solid, gas) can be analyzed in this way.

XAFS is extremely valuable in low-temperature geochemical studies, such as for establishing the speciation of contaminants in sediments (See Brown et al. 2006). For example, Zachara et al. (2004) showed that toxic hexavalent chromium from Hanford waste tanks was only partially reduced to trivalent chromium in the underlying sediments. It is also possible to determine the speciation of cations in glasses (e.g. Galois and Calas 1993) and in situ melts under controlled oxygen fugacity (Berry et al. 2003).

Synchrotron radiation also permits crystallography experiments in *high-pressure devices*, such as the large-volume press (LVP) and the diamond anvil cell (DAC), both of which can also be heated to high temperature. An advantage of in situ observations is that complications due to quench effects can be avoided. In this way, the extreme conditions deep in the Earth can be simulated, and determinations can be made of equations of state, crystal structures, and phase relations of mantle and core materials, for example. The DAC consists of two gem-quality diamonds with small facets opposed to compress a hole-bearing gasket (the sample chamber). Nanogram quantities of material (powder or single crystal) can be compressed to ~200 GPa and laser heated (FIG. 2) to several thousand degrees (i.e. to

outer core conditions). Pressure determinations are made in situ, using ruby fluorescence or diffraction from included materials of known lattice parameters. Temperature is determined from the color of the sample's incandescence. A recent flurry of DAC research activity has focused on the discovery of a post-perovskite phase transition in  $\text{MgSiO}_3$  near 125 GPa (e.g. Murakami et al. 2004); this discovery is relevant to improving our understanding of the structure and dynamics of the lowermost portion of the mantle (<300 km from the core-mantle boundary).

The LVP is a floor-standing hydraulic ram with external heating and a larger ( $\text{mm}^3$ ) sample chamber than the DAC. Pressure and temperature (<30 GPa, <3000K, i.e. mantle conditions) are determined by load and thermocouple, respectively. For both the DAC and LVP, conventional X-ray diffraction experiments are conducted to characterize the sample under these extreme conditions. A recent advance has been the development of deformation tooling for the LVP that allows samples to be deformed under high P-T conditions with well-controlled strain rates. By analyzing the distortion of the Debye rings in powder diffraction patterns, elastic lattice strain can be determined, which is related to stress through elastic constants (Singh 1993). This approach has been used to determine the pressure and strain dependence of the strength of  $\text{Mg}_2\text{SiO}_4$  ringwoodite (Nishiyama et al. 2005).



**FIGURE 2** Laser-heated hydrous ringwoodite  $[\gamma\text{-(Mg,Fe)}_2\text{SiO}_4]$  single crystal (~100  $\mu\text{m}$ ) at 30 GPa in a diamond anvil cell. A silicate perovskite plus magnesiowüstite assemblage formed at three different temperatures is present within each of the round heated areas. PHOTO COURTESY OF S.D. JACOBSEN (CARNEGIE INSTITUTION OF WASHINGTON) AND J.-F. LIN (LAWRENCE LIVERMORE NATIONAL LABORATORY)

*Microtomography* is the extension to finer spatial resolution of tomographic imaging techniques used in medicine (CAT scanning). By using high-brightness synchrotron radiation beams, spatial resolutions in the  $\mu\text{m}$  range can be achieved at the expense of maximum sample size (typically no sample larger than mm to cm size range). The internal microstructure of valuable or fragile objects can be examined. In addition, element-specific tomography is possible either by collecting transmission tomograms above and below an absorption edge or by using fluorescence techniques. An attractive aspect of microtomography is that virtually no sample preparation is required and essentially any object can be imaged. Microtomographic images can be used to determine the microdistribution of contaminants in plants, locate mineral inclusions in mantle-derived diamonds, visualize the inundation of soils by oil and water, determine

grain-size distributions in volcanic rocks, and observe the morphologies of vapor bubbles in melts (e.g. Rivers et al. 2004).

Mineral surface reactivity depends on the identity and arrangement of surface functional groups. *Interface scattering*—the angular distribution of X-radiation scattered from highly polished, atomically flat crystals—is one of the few approaches that can be used to determine the arrangement of atoms at truncated surfaces and at mineral–water interfaces. Such studies utilize high-precision diffractometers (Fig. 1) and are valuable in developing a detailed understanding of the chemical reactions at these surfaces and interfaces. In addition, in conjunction with spectroscopic methods, sorption experiments can reveal the bonding behavior of solute species, particularly those of interest from a geochemical transport standpoint. Recent work has focused on reactivity and sorption of hydrated metal oxide surfaces, such as hematite (Trainor et al. 2004) and orthoclase (Fenter et al. 2000). This work demonstrates that the arrangement of atoms at the mineral–water interface can have a dramatic control on reactivity (See Brown et al. 2006).

The discussion above, focusing on high-energy techniques, is far from an exhaustive description of methods used at synchrotron user facilities to investigate Earth materials. In particular, soft X-ray and vacuum ultraviolet (VUV) synchrotron sources offer methods optimal for studies of light elements. For example, scanning transmission microscopy is valuable for high-resolution (sub-50 nm) imaging and light-element speciation mapping (e.g. carbon compounds). Synchrotrons are also attractive sources of infrared radiation allowing Fourier transform infrared (FTIR) analyses with 100-fold intensity enhancement over laboratory sources plus spatially resolved capabilities at the  $\sim 10\ \mu\text{m}$  scale.

## NEUTRON METHODS

Beams of neutrons provide an extremely versatile set of tools for mineral sciences, yet for a number of reasons the mineralogical and Earth sciences communities are a long way from fully exploiting the potential of neutron scattering (Rinaldi 2002; Dove 2002).

The power of neutron scattering arises from two factors: first, neutrons have a mass that is similar to the masses of atoms and second, neutrons interact with matter via short-range interactions with atomic nuclei or via dipolar magnetic interactions with any magnetized ions. The point about the mass of the neutron means that beams of neutrons can be tuned to have wavelengths comparable to typical interatomic spacings while simultaneously having energies that are comparable to the energies of thermal vibrations. Thus neutrons can uniquely give information about both the structure and dynamics of matter, and experiments can be designed to optimize one or the other, or both at the same time.

The second point is important because the interaction between neutrons and atomic nuclei is nucleus specific, which means, for example, that  $\text{Mg}^{2+}$ ,  $\text{Al}^{3+}$ , and  $\text{Si}^{4+}$  have distinctly different neutron scattering cross sections, unlike scattering by X-rays. Thus neutrons are able to provide direct information about  $\text{Mg}^{2+}/\text{Al}^{3+}/\text{Si}^{4+}$  ordering in minerals; for example, Welch and Knight (1999) studied cation ordering of these species in an amphibole. Hydrogen, an important component of many minerals, is a particularly special case. The scattering from the  $^1\text{H}$  nucleus when the spins of the neutron and proton are along the same direction is significantly different from the case where the spin vectors are aligned in opposite directions. On the other hand, the deuterium nucleus,  $^2\text{H}$ , has no spin, and its interaction with neutrons is different again. The significance of

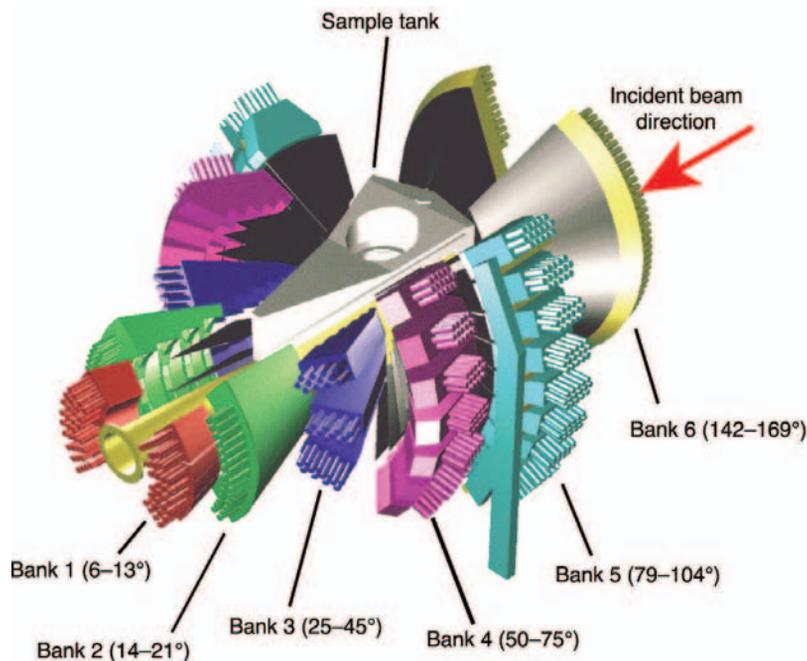


**FIGURE 3** Interior of the ISIS Neutron Facility Experimental Hall (Chilton, UK). COURTESY OF THE COUNCIL FOR THE CENTRAL LABORATORY OF THE RESEARCH COUNCILS (CCLRC)

all this is two-fold: first, neutrons can see hydrogen in diffraction experiments (typically deuterated samples are preferred in such experiments), and second, the strong spin-dependence of the scattering of neutrons from  $^1\text{H}$  means that part of the scattering is sensitive to the positions and dynamics of individual  $^1\text{H}$  atoms (Dove 2002; Bée 1988).

The strength of the interaction between neutrons and matter is usually relatively weak, both for scattering and absorption (there are some notable exceptions that can be exploited). There are two positive consequences. One is that it is possible to develop sample environment equipment, such as high-pressure equipment, without having to worry too much about beam attenuation (Zhao et al. 1999; Le Godec et al. 2001). The other is that a measurement is not dominated by scattering from the surface, as it is in X-ray diffraction. Thus neutrons provide a true probe of bulk properties. The downside of the weak interaction with matter, and the fact that neutrons are not usually produced in copious quantities, is that samples need to be quite large ( $\text{cm}^3$  scale) and experimental stations are built to a larger scale than in other techniques.

Two methods are used to produce beams of neutrons (Winkler 2002). The traditional method exploits the fact that nuclear fission reactors produce neutrons, and designs of reactor cores can be optimized to reflect neutrons into beam tubes leading to experimental stations (e.g. ILL, Grenoble, France). This typically results in a continuous beam of neutrons containing a range of neutron wavelengths. Monochromator crystals are used to select the desired wavelength of the beam incident on the sample. The second method generates beams of neutrons by directing a beam of protons onto a metal target—the so-called “spallation” method in which neutrons are knocked out of the nuclei of the target atoms (e.g. ISIS, Oxfordshire, UK; Fig. 3). The spallation method lends itself to producing pulsed bursts of neutrons, and by measuring the time taken for the neutrons to travel from the target to the detector, it



**FIGURE 4** Schematic representation (left) and photograph (right) of the General Materials (GEM) diffractometer at the ISIS Neutron Facility (Chilton, UK). The instrument is stacked with banks of detectors covering all scattering angles, with the highest resolution obtained with the back-scattering detectors. This instrument is designed for both diffraction and total scattering measurements. COURTESY OF THE COUNCIL FOR THE CENTRAL LABORATORY OF THE RESEARCH COUNCILS (CCLRC)

is possible to determine the wavelength. These two sources often give rise to complementary experiment instrumentation. For example, a powder diffractometer on a reactor source will use a fixed wavelength and will have detectors in a plane covering a wide range of scattering angles, whereas with a spallation source the full range of wavelengths will be used, and detectors will be positioned around the Debye-Scherrer rings for a range of scattering angles.

We will describe two types of instruments, namely diffractometers and spectrometers. Both measure the intensity of the scattered neutron beam as a function of scattering vector  $\mathbf{Q}$  (or  $Q = |\mathbf{Q}|$ ), but the two types of instruments are differentiated by the fact that spectrometers also measure as a function of energy change,  $E$ , at the same time. In many cases  $E$  can be related to the frequency,  $\nu$ , of a quantum of excitation,  $E = h\nu$ .

Diffractometers can be designed to perform traditional measurements for both *powder* and *single-crystal diffraction*, and can be optimized for high resolution or high intensity (Fig. 4). The best high-resolution neutron powder diffractometers give as high a resolution as one could want, with measurements being limited by natural line broadening processes. Diffractometers can also be optimized for measurements with sample environment equipment, including high-pressure apparatus. Of note is the fact that high-pressure work can be performed with spallation sources with measurements taken for scattering angles of  $90^\circ$ , enabling nearly complete elimination of scattering from the equipment (Zhao et al. 1999; Le Godec et al. 2001). It is now also possible to measure sample temperature at simultaneous high pressures and temperatures using *neutron radiography* rather than thermocouples (Le Godec et al. 2001). Examples

of recent applications of diffraction measurements from minerals are given in Dove (2002), Pavese (2002), and Redfern (2002).

Other diffraction methods that are becoming increasingly popular in mineral sciences are techniques focusing on larger-scale structures. These include *small-angle scattering* (e.g. to measure the sizes of precipitates within solid solution), measurements of *texture maps*, and measurements of *strain distributions* within mineral assemblages (Schäfer 2002). Another application that has yet to be used in earnest in mineral sciences is *diffraction or reflection from surfaces*; this application has been greatly used by chemists.

The diffraction measurements described so far focus on measurements of Bragg peaks. Other instruments can be optimized to measure weaker, diffuse scattering. In the case of powder diffraction, measurements of diffuse and Bragg scattering, called “total scattering,” can provide information about pair distribution functions. This is particularly useful for studies of disordered crystalline materials, glasses, and melts, and is a diffraction technique that has a lot of untapped potential for research in mineral sciences (Dove et al. 2002).

Spectrometers are designed to measure the dynamics of atoms within matter. *Dynamical processes* include coherent excitations such as harmonic lattice vibrations (phonons) and spin waves (including sound waves and high-frequency bond-bending vibrations such as the O–H stretching vibration), low-frequency tumbling of water molecules, and even lower frequency diffusion motions. The frequency range spans several orders of magnitude, and spectrometers can be designed for different frequency ranges. The traditional instrument at reactor sources is the “triple-axis spectrometer,” which is designed to measure phonon dispersion curves point by point. This instrument has two monochromator crystals, one to set the incoming wavelength, and the other to reflect neutrons of different wavelengths into a single detector. It thus becomes possible to measure the intensity for specific changes in energy  $E$  and scattering vector  $\mathbf{Q}$ , and by mapping out measurements for a wide range of values of  $\mathbf{Q}$  and  $E$  it is possible to construct a nearly complete picture of the dispersion curves. There is no comparable instrument for spallation sources; instead spectrometers are designed using choppers and banks of detec-

tors, and give measurements for a whole range of  $Q$  and  $E$  values in a single setting. In addition to performing measurements of dispersion curves using single-crystal samples, by using polycrystalline samples and running experiments that will integrate over  $Q$ , it is possible to perform measurements of vibrational density of states. Chaplot et al. (2002) review the application of neutron spectroscopic methods to the study of the dynamic properties of minerals.

As noted above, the spin dependence of the scattering of neutrons from  $^1\text{H}$  means that a strong component of the scattering from hydrogen provides information about individual atoms in a process called “*incoherent scattering*.” This has been exploited in studies of the dynamics of hydrogen-containing molecules in solids and liquids (Bée 1988), and has been used in some early studies of the motions of hydrogen in minerals, including water in cordierite (Winkler 1996).

One mineral for which a range of neutron scattering measurements have been performed is cristobalite. Early high-resolution neutron powder diffraction measurements were used to characterize the disorder in the high-temperature  $\beta$  phase and to facilitate modeling of the thermodynamics of the low-temperature  $\alpha$  phase (Schmahl et al. 1992). It was subsequently proposed that the phase transition would be accompanied by a large change in the low-frequency dynamics, and this was confirmed by neutron spectroscopy measurements (Swainson and Dove 1993). Total scattering studies have been used more recently to provide detailed information about the structure of the disordered  $\beta$  phase (Tucker et al. 2001).

At the time of writing, we are seeing a dramatic increase in neutron scattering research capabilities, which matches the pace of development of facilities such as synchrotron radiation sources. These developments are described by Parise and Brown (2006) in this issue.

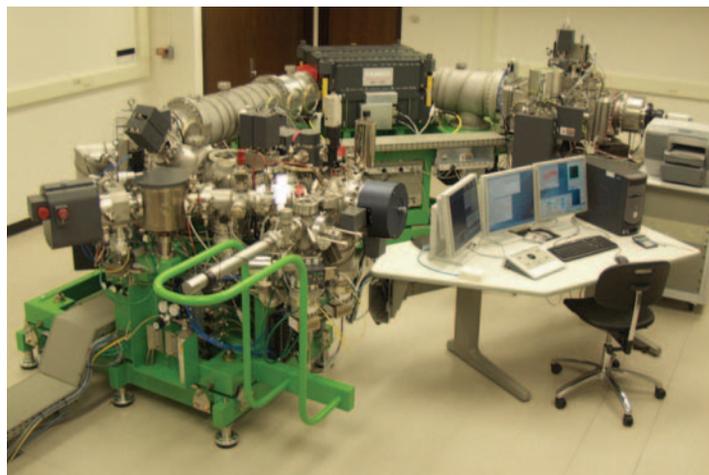
## MASS SPECTROMETRY

Mass spectrometry has become a vital technique for Earth scientists, allowing high sensitivity analyses of elemental abundance and isotopic composition. Such information is valuable in chronological studies over the entire age of our solar system, for example. Mass spectrometers range from relatively simple, bench-top instruments to complex apparatus that require dedicated facilities and are based on sophisticated technologies such as particle accelerators, focused ion beams, and lasers. The physical principle upon which these instruments are based is the mass separation of charged particles as they traverse a magnetic field. Many of these advanced mass spectrometry facilities are open to the scientific community as user facilities.

Most Earth and planetary materials are extremely heterogeneous assemblages. In many instances the constituents are less than a millionth of a meter in size, much smaller than a human hair. Detailed information regarding the evolutionary history of the constituents can only be obtained via a technically challenging, grain-by-grain analysis. The rigorous challenges of spatial resolution coupled with sufficient sensitivity to detect the masses of a few thousand atoms are being met by *secondary ion mass spectrometry (SIMS)*.

SIMS works by sputtering the surface of a grain with a primary beam of ionized cesium or oxygen. As atoms residing near the surface are liberated, some are ionized and collected into a spectrometer with high mass resolution. Virtually the entire periodic table is accessible, with detection limits of 10–100 ppb for many elements and precision of isotope ratios as good as 0.1 per mil. These secondary ions are mass analyzed by a combination of electrostatic and

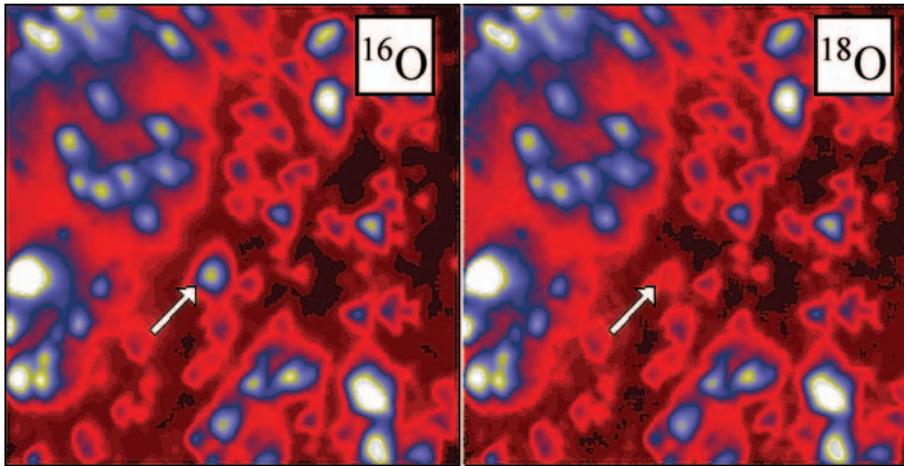
magnetic components. Particle detection is achieved using a combination of electron multipliers, Faraday cups, and imaging detectors, such as microchannel plates. Most of these so-called *ion microprobes* (FIG. 5) have the capability to perform both momentum and energy mass analysis and are commonly available as user facilities. The mass resolving power ( $m/\Delta m$ ) of SIMS instruments covers a large range, is adjustable on individual instruments, and typically extends from  $\sim 1000$  to 50,000 (inverse of the smallest mass fraction that can be measured). Ion microprobe/SIMS instruments are capable of focusing the primary beam to spots as small as 50 nm for in situ analysis of thin sections or grain mounts. In addition to performing elemental and isotopic abundance ratio measurements, many SIMS instruments can also create an image of the microdistribution of isotopic ratios in a sample, effectively creating an isotopic map.



**FIGURE 5** CAMECA IMS-1280 large radius multicollector ion microprobe optimized for analysis of stable isotope ratios at the University of Wisconsin–Madison WiscSIMS Laboratory. PHOTO COURTESY J. VALLEY

An exciting research direction in single-grain mass spectrometry is the search for grains produced prior to the formation of our solar system. These “presolar grains” from meteorites have isotopic compositions distinct from those of typical solar system material, so the precise isotopic abundances can shed light on the type of star that produced them. Presolar silicon carbide grains (e.g. Bernatowicz et al. 2003) range in diameter from 0.1 to 10 microns and have an abundance in meteorites of  $\sim 10$  parts per million. Their distinctive isotopic signatures are large variations in  $^{12}\text{C}/^{13}\text{C}$  and  $^{14}\text{N}/^{15}\text{N}$ , which are comparable to the ranges observed in the atmospheres of carbon-rich giant stars. The discovery of rare presolar silicate grains (e.g. Anders and Zinner 1993) was made possible by the imaging capability of SIMS techniques (FIG. 6). Currently, mass spectrometric methods are being developed for “dating” these grains and using them to characterize the chemical evolution of our galaxy (e.g. Clayton 1997). The extent to which these studies will be successful may well hinge on further advances in mass spectrometric techniques and the availability of these advances to the general scientific community.

The ages of solar system materials are based on a number of isotopic chronometers. These isotopic ratios are determined using a variety of mass spectrometers, including a new generation of instruments collectively referred to as *inductively-coupled plasma mass spectrometers (ICP-MS)*. These instru-



**FIGURE 6** SIMS maps (~30  $\mu\text{m}$  wide) of oxygen isotopic microdistributions ( $^{16}\text{O}$  left;  $^{18}\text{O}$  right) in oxide grains separated from the Tieschitz meteorite. The arrows show the presence of a grain of anomalous (presolar) isotopic composition. PHOTO COURTESY OF L. NITTLER, CARNEGIE INSTITUTION OF WASHINGTON, DEPARTMENT OF TERRESTRIAL MAGNETISM

ments measure isotopes of Cr, Fe, Ca, Sr, Pd, Ag, Mn, Ni, Hf, W, Nd, Sm, U, Cm, Pb, Li, B, Be, Cu, Zn, Hg, Mo, and others. ICP-MS utilizes several sample introduction techniques, including laser ablation and direct introduction of a solution into the ionization region. Laser ablation enables the in situ analysis of isotopic structures of mineral grains. Ionization is achieved by argon plasma at atmospheric pressure. The ions are then introduced into the mass spectrometer through a differentially pumped region. The mass spectrometer itself may consist of magnetic and/or electrostatic sectors followed by one or more detectors. The power of high-resolution ICP-MS is in its ability to distinguish between molecules of very similar masses.

In one example of ICP-MS work, measurements of Pb isotopes in meteoritic Ca-Al-rich inclusions give a chronological reference point of  $4.566 \pm 0.002$  billion years for the first matter condensed in our solar system (Amelin et al. 2002). The measurement of W isotopes by high-resolution ICP-MS, in conjunction with the initial  $^{182}\text{Hf}/^{183}\text{Hf}$ , indicates that core formation in the iron meteorite parent bodies took place within 10 million years of the beginning of the solar system (Kleine et al. 2002). Other isotopic systems indicate that by ~40 million years, Earth itself had differentiated (e.g. Halliday and Lee 1999) and that by 200 million years melts had crystallized in the crust, forming zircons.

These zircons provide a wealth of information regarding the early evolution of Earth. Zircon simultaneously concentrates uranium and excludes lead, so it is a perfect mineral for U-Pb chronometry. Zircon grains are highly resistant to weathering and can survive multiple geologic events. They preserve isotopic records of events occurring over much of Earth history, most notably within several hundred million years after the formation of Earth. Their isotopic records can be deciphered using micro-analytical techniques, in particular SIMS. Measurements of  $\delta^{18}\text{O}$  and trace element compositions can then be used to delineate geologic processes occurring in the early Earth (e.g. Wilde et al. 2001).

Mass spectrometric techniques have also shed considerable light on the collisional processes responsible for the transport of asteroidal objects to Earth by using cosmic ray exposure ages to date the collisional events. Noble gases are useful for determining cosmic-ray exposure ages in mete-

rites, principally  $^3\text{He}$ ,  $^{21}\text{Ne}$ ,  $^{38}\text{Ar}$ ,  $^{81}\text{Kr}$ , and  $^{124,126}\text{Xe}$ . These measurements are performed using *noble gas mass spectrometers*, which typically have a mass resolving power of  $<1000$  and an abundance sensitivity of  $\sim 10^{-6}$ . Radionuclides used to determine cosmic-ray exposure ages, pre-atmospheric sizes, and shielding depths include (with half-lives given in brackets)  $^{10}\text{Be}$  (1.5 Myr),  $^{26}\text{Al}$  (0.705 Myr),  $^{36}\text{Cl}$  (0.301 Myr),  $^{53}\text{Mn}$  (3.5 Myr), and  $^{129}\text{I}$  (16 Myr). The development of *accelerator mass spectrometry (AMS)* increased the detection sensitivity of all these radionuclides by virtue of detecting atoms rather than decay products. The abundance sensitivity is realized by accelerating the ions to  $\geq 1$  MeV. Ions accelerated to this energy can

pass through a thin carbon foil or a stripper gas at the accelerator terminal, effectively disassociating molecular interferences. AMS facilities are commonly made available as user facilities, so that exposure age determinations are available to the general scientific community.

In a variant of this collisional dating method, cosmic-ray exposure ages on terrestrial rocks can be used to date collisional events on Earth. In the case of Meteor Crater in Arizona (USA), the explosive force of the Canyon Diablo iron meteorite excavated rock that, until that time, had been shielded from exposure to cosmic rays. AMS measurements have determined the subsequent accumulation of cosmogenic  $^{14}\text{C}$ ,  $^{10}\text{Be}$ ,  $^{26}\text{Al}$ , and  $^{36}\text{Cl}$ , thereby establishing the age of the crater at ~50,000 years (Nishiizumi et al. 1991; Phillips et al. 1991), consistent with the first absolute dating of the crater using thermoluminescence measurements of impact-heated sedimentary rocks (Sutton 1985).

Thus, mass spectrometry methods have provided pieces to the geologic puzzle stretching in time from before the formation of the solar system 4.566 billion years ago to recent meteorite collisions with Earth. Acquisition of this knowledge would not have been possible without the use of a variety of mass spectrometric techniques, many of which, notably those at AMS and SIMS facilities, have been developed and are operated as user facilities.

## CONCLUDING REMARKS

We are currently in a very productive period for user facility-based research in the Earth sciences. A large number of facilities exist representing a wide spectrum of analytical capabilities. Each technique provides a unique window into the composition, structure, and history of Earth materials, the processes that produce these materials, and the processes they control. Equally significant, sufficient experience in the operation of user facilities has been gained to make them very effective in responding to and meeting the needs of the research community. Many Earth scientists are currently taking advantage of the frontier capabilities offered by user facilities, and their numbers are growing.

## ACKNOWLEDGMENTS

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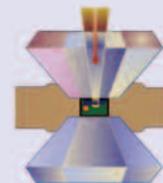
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# Research Opportunities in Experimental Geosciences



Bayerisches Geoinstitut is a research facility dedicated to the investigation of processes in the Earth's interior through experimental and theoretical studies using a multidisciplinary approach. Since its foundation in 1986, Bayerisches Geoinstitut has developed into one of the best equipped and most productive institutes of its type in the world.



## Funding possibilities:

### European User Facility for High-Pressure Research

#### EU "Research Infrastructures: Transnational Access" Programme

Bayerisches Geoinstitut is funded as a EU Research Infrastructure for the purpose of accepting visiting scientists ("users") from institutions in States and Associated States of the EU (with the exception of Germany) to use its experimental and analytical facilities for periods generally between 1 week and 3 months.

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- \* Spectroscopy (Mössbauer; Raman; FTIR; UV-Vis; EELS)
- \* Diamond anvil cells (external & laser heating) for *in situ* studies
- \* Physical property measurements (GHz ultrasonic interferometry; impedance spectroscopy; high-temperature creep; thermal diffusivity)
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- \* Electron microprobe, laser ablation ICP-MS, ICP-AES

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# Scientific Advances Made Possible by User Facilities

Gordon E. Brown Jr.,<sup>1,2</sup> Georges Calas,<sup>3</sup> and Russell J. Hemley<sup>4</sup>

**N**ational scientific user facilities are becoming increasingly available to many different scientific communities in a number of countries. There is a growing use of these facilities by Earth and environmental scientists to study a broad range of materials and processes under realistic P–T and environmental conditions at unprecedented levels of energy and spatial resolution and elemental and isotopic sensitivity. The results of these studies are providing new insights into biogeochemical processes operating at Earth's surface as well as petrological, geochemical, and geophysical processes in Earth's interior. The availability of national user facilities is changing scientific approaches and is leading to multidisciplinary studies that were not possible a decade ago.

KEYWORDS: national scientific user facilities, synchrotron radiation sources, neutron sources, Earth science research.

## INTRODUCTION

Discoveries in most areas of science come from observations at different spatial scales, ranging from astronomical to subatomic, using instrumentation that ranges in complexity from a simple reflecting telescope to a particle accelerator. In the Earth sciences, relevant spatial scales extend from atomic to global, and instrumentation can be as simple as a hand lens and Brunton compass or as complex as a synchrotron light source. The repertoire of available research instruments has expanded greatly during the past 20 to 30 years because of the development of large-scale national user facilities in many countries. These facilities, which include synchrotron light sources, neutron sources, particle accelerators, electron beam microcharacterization facilities, and nanoscale-science research centers, are having a major impact on research on materials of all types. Such facilities are being used to determine the structures, compositional variations, physical properties, and submicron-scale heterogeneities of Earth materials. Experiments are carried out under conditions mimicking those in key geological environments, such as in Earth's deep interior or at the interfaces between mineral particles and aqueous solutions in soils at Earth's surface, where much of the chemistry relevant to the environment occurs. Many of these advanced techniques and cutting-edge technologies are not

generally available in university or individual investigator laboratories, but user facilities make them available to many scientific communities. User facilities also make possible experimental studies that were impossible prior to their existence. This article focuses on the role of national user facilities, particularly synchrotron radiation and neutron sources, in Earth and environmental science research and highlights some of the discoveries such facilities have enabled in these fields over the past decade.

At the atomic scale, 3-D observations require the use of electromagnetic radiation of wavelengths similar to the bond distances between atoms (0.1–0.5 nanometers) in the building blocks (unit cells) of crystals. Short-wavelength radiation, referred to as X-rays (with energies ranging from about 100 eV to greater than 100 keV), was first discovered in 1895 by Wilhelm Conrad Röntgen. Since that time, X-rays and X-ray diffraction (XRD) have revolutionized many areas of science, as demonstrated by the 18 Nobel Prizes in physics, chemistry, and medicine awarded from 1901 through 2005 that are directly linked to the usage of X-rays. XRD has had a profound impact on mineralogy, having been used over the past 90 years to determine the atomic structures of the 4000+ known minerals.

XRD has also had a major impact on our knowledge of the materials that comprise Earth's interior through studies of the stability and phase transformations of minerals at pressures and temperatures representative of Earth's mantle (~0 to 136 GPa and 1200 to 3600K). The high pressures and temperatures can be generated using diamond anvil cells (DAC) and laser heating, respectively, permitting XRD and spectroscopic studies of mineral phases under in situ conditions (Mao and Hemley 1998; Bass et al. 2004). Large volume presses provide access to somewhat lower temperatures and pressures, but the sample volume is larger than in a DAC. High-P–T studies using these devices have revealed phase transformations and changes in mineral densities at pressures and temperatures corresponding to the depths of major discontinuities in seismic wave velocities within the deep Earth.

XRD is not the only means of determining the atomic structure of matter. The elastic scattering of neutrons also provides this type of information, with some advantages and disadvantages. Advantages include the ability to distinguish between atoms with similar atomic numbers or between different isotopes of the same element. Disadvantages include the fact that larger samples are required in neutron

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scattering than in X-ray scattering experiments because the neutron scattering cross-sections of atoms are smaller than X-ray scattering interactions with atoms (see Sutton et al. 2006 for additional details).

In addition to XRD, various types of X-ray spectroscopy are also becoming important research tools of scientists from many disciplines, including Earth and environmental sciences. X-ray absorption fine-structure (XAFS) spectroscopy in particular has become the technique of choice for studies of heavy metal and radionuclide speciation at mineral-water interfaces and for characterization of the chemical forms of environmental pollutants in soils. The only practical way of conducting an XAFS study of environmental pollutants at trace concentration levels (<1000 ppm) is to utilize a synchrotron radiation source—the most common type of national user facility worldwide.

Since synchrotron light sources first became available to general users in 1974, they have had a growing impact on research in the Earth sciences. This research focuses on atomic to micron scales and includes trace element geochemistry, interface and surface geochemistry, mineralogy, mineral physics, and petrology. In addition, the new field of molecular environmental science (MES) has been a major beneficiary of synchrotron light sources because of the need to determine the molecular-level speciation, spatial distribution, and phase association of environmental pollutants at very low concentration levels (low parts per million) and spatial scales of nanometers to microns in highly heterogeneous Earth materials such as soils. Synchrotron light sources have also contributed to the development of a mechanistic understanding of the abiotic and biotic processes that can sequester or release pollutants or transform them into more (or less) toxic forms.

The techniques that synchrotron light sources make available include wide-angle and small-angle elastic X-ray scattering (WAXS and SAXS), anomalous X-ray scattering (AWAXS and ASAXS), surface X-ray scattering, nuclear resonant inelastic X-ray scattering (NRIXS), synchrotron X-ray Raman scattering (XRS), nuclear resonant forward scattering (NRFS, a measure of the Mössbauer effect), synchrotron X-ray fluorescence (SXRF) spectroscopy, X-ray absorption fine-structure (XAFS) spectroscopy, X-ray emission spectroscopy (XES), X-ray photoelectron spectroscopy (XPS), X-ray standing wave (XSW) spectroscopy, infrared (IR) spectroscopy, transmission X-ray microscopy (TXM), scanning transmission X-ray microscopy (STXM), X-ray photoelectron emission microscopy (XPEEM), X-ray tomography, and X-ray fluorescence tomography at both hard and soft X-ray energies. Some of these methods are surface sensitive (e.g. XPS and XPEEM) or can be utilized in a surface-sensitive fashion (e.g. grazing-incidence XAFS or regular XAFS when the element of interest is present only at a surface; crystal truncation rod diffraction). Most of these methods can also be made spatially sensitive by reducing the size of the X-ray beam using focusing mirrors ( $\mu$ SXRF,  $\mu$ XAFS,  $\mu$ XRD,  $\mu$ -X-ray fluorescence tomography) or Fresnel zone plates (TXM, STXM, XPEEM), resulting in spatial resolution down to 25 nm at low X-ray energies (e.g. the carbon *K* edge – 284 eV). Many of these X-ray methods and their scientific applications, particularly those involving focused X-ray beams, would not be possible without the extreme brightness of synchrotron light sources.

Developments in high-energy synchrotron techniques coupled with new high-pressure techniques allow inelastic scattering and spectroscopic measurements under extreme pressures down to 4 keV, which covers the *K* edges of first-row transition elements and *L* edges of rare-earth elements,

both central to geochemistry. These measurements allow atomic coordination and electronic and magnetic properties to be studied at extreme pressures.

The examples of scientific discoveries presented below are representative of different subdisciplines within the Earth sciences. Most of the examples come from the application of synchrotron radiation and neutron scattering techniques to Earth materials and processes. Additional examples of applications of neutron scattering and analytical methods, such as accelerator-based mass spectrometry, can be found in the article by Sutton et al. (2006) in this issue.

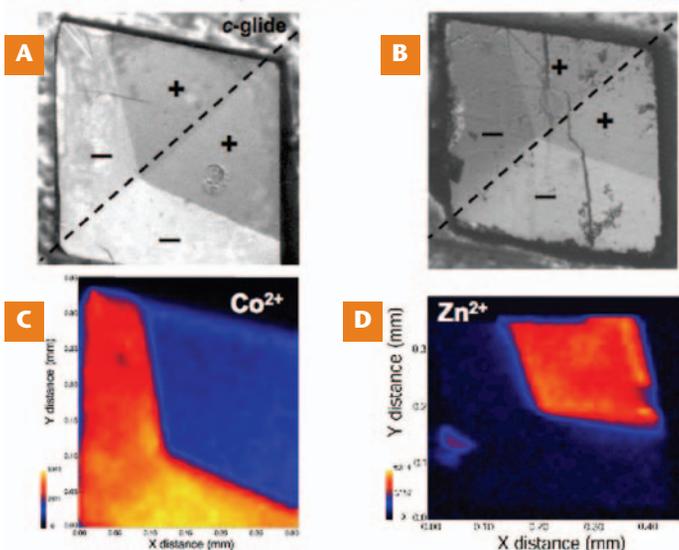
## EARTH AND ENVIRONMENTAL SCIENCE APPLICATIONS OF USER FACILITIES

### *Mineralogy, Petrology, and Trace Element Geochemistry*

Minerals are key components of rocks and provide unique information on their formation conditions. Their minor and trace element and isotope compositions provide important insights into the geochemical cycling of elements and can give us the absolute ages of rocks and the Earth. In addition, minerals are of great importance in modern society because of their many technological and industrial applications. Synchrotron-based methods such as XAFS spectroscopy provide unique information on the location of trace elements in mineral structures, which is key to understanding the controls that minerals exert on element partitioning (Blundy and Wood 2003). This information is also important for understanding charge-compensation processes in minerals and for deriving realistic activity-composition relations. Intersite trace element distributions in minerals can be uniquely provided by XAFS. For example, Quartieri et al. (1999) used XAFS to demonstrate that Nd enters the <sup>VIII</sup>X site in the X<sub>3</sub>Y<sub>2</sub>Si<sub>3</sub>O<sub>12</sub> garnet structure and does not substitute for Al at the <sup>VI</sup>Y site. Most recent XAFS determinations of trace element environments in minerals indicate a high degree of relaxation around substituting elements of different sizes in minerals, such as the substitution of Cu<sup>2+</sup> and Zn<sup>2+</sup> for Ca in calcite (Elzinga and Reeder 2002). The mismatch between the size of the relaxed substituted sites and the lattice site is accommodated by elastic strain. A similar XAFS investigation of substitutional Cr<sup>3+</sup> and Fe<sup>3+</sup> ions in corundum has also confirmed full site relaxation during substitution (Gaudry et al. 2003). The coordination shell relaxes to an arrangement similar to that for Cr in  $\alpha$ -Cr<sub>2</sub>O<sub>3</sub> or for Fe in  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>. This work shows that the red and green colors of ruby and  $\alpha$ -Cr<sub>2</sub>O<sub>3</sub>, respectively, do not originate from different Cr sites but from a modification of the electronic structure.

Petrological applications of synchrotron radiation and neutron scattering methods include XAFS studies of the structural environments of trace elements in silicate melts and glasses and neutron scattering studies of medium-range order in silicate glasses. Silicate melts play a major role in element and heat transfer within the Earth and are responsible for all igneous rocks. In addition, silicate glasses, which are produced by quenching of silicate melts, are used widely as industrial materials and as surrogates for silicate melts in experimental studies. Synchrotron X-ray and neutron scattering methods are unique in their ability to provide information on the structure of amorphous solids and liquids (oxidation states and coordination environments of elements, polymerization of silicate tetrahedra). Oxidation states may now be measured in  $\mu$ m-sized spots, as in glassy inclusions in volcanic minerals (Métrich et al. 2002). X-ray spectroscopic and scattering techniques have been used to determine the local structural environments of trace and major elements as well as the medium-range order in sili-

## Site-selective incorporation of metals at the calcite surface



**FIGURE 1** Differential incorporation of cation (DIC) images of as-grown (10 $\bar{1}$ 4) surfaces of Co<sup>2+</sup>-doped (A) and Zn<sup>2+</sup>-doped (B) calcite crystals. The c-glide plane is vertical and the c-axis points at 45° to the upper right. Polygonal shading patterns reveal two pairs of vicinal surfaces, labeled + and -. They represent regions on the surface having growth steps oriented in different directions. Growth steps in the + vicinals, parallel to [441] and [48 $\bar{1}$ ], are symmetrically equivalent, but are not equivalent to those in the - vicinals. Individual growth steps are not resolved. (C and D) Synchrotron  $\mu$ XRF maps corresponding to crystals in the DIC images. Raw counts are plotted, and light shading indicates highest counts. Corresponding Ca maps are featureless. Co<sup>2+</sup> is preferentially incorporated at steps in the - vicinals, whereas Zn<sup>2+</sup> is preferentially incorporated at steps in the + vicinals. FIGURE COURTESY OF RICH REEDER; AFTER ELZINGA AND REEDER 2002.

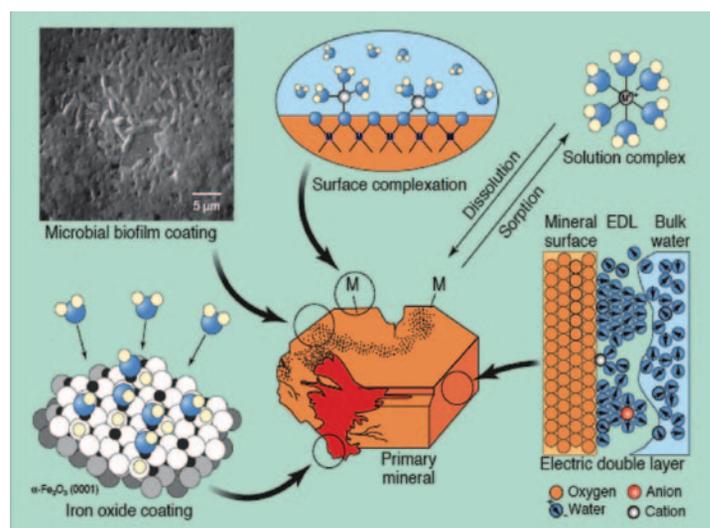
cate glasses and melts (Brown et al. 1995). This work provides unique insights into trace element partitioning and crystal nucleation. For example, XAFS studies of silicate glasses provided the first direct evidence for 5- and 4-coordinated Ni<sup>2+</sup> (Galoisy and Calas 1993) and Fe<sup>2+</sup> (Jackson et al. 2005) and for two-dimensional cation-rich regions extending over 15–20 Å (Cormier et al. 2001). This inhomogeneous distribution of cations in glasses, distinct from precursors of mineral nuclei, may be related to the progressive organization of supercooled liquids as temperature decreases. The use of high-energy X-ray scattering, which is only possible using synchrotron radiation, allows resolution of Si–O and Al–O contributions in aluminosilicate glassy networks, giving an accurate description of Si/Al disorder (Petkov et al. 2000). Structural changes in glasses and melts may be investigated as a function of temperature using in situ X-ray and neutron diffraction and XAFS (Brown et al. 1995). Disorder and thermal expansion of cationic sites occur without discontinuity through the glass transition (Majérus et al. 2004a). Above the glass transition, a relaxation of the silicate network occurs on a medium-range scale (6–7 Å) as a result of a higher cation motional rate relative to the network. Large user facilities have also been used to study processes governing the modification of glass and melt structures at high pressure (polyamorphism). Determination of the structure of high-density glasses requires in situ studies since coordination changes are reversible (Majérus et al. 2004b).

## Interface and Surface Geochemistry

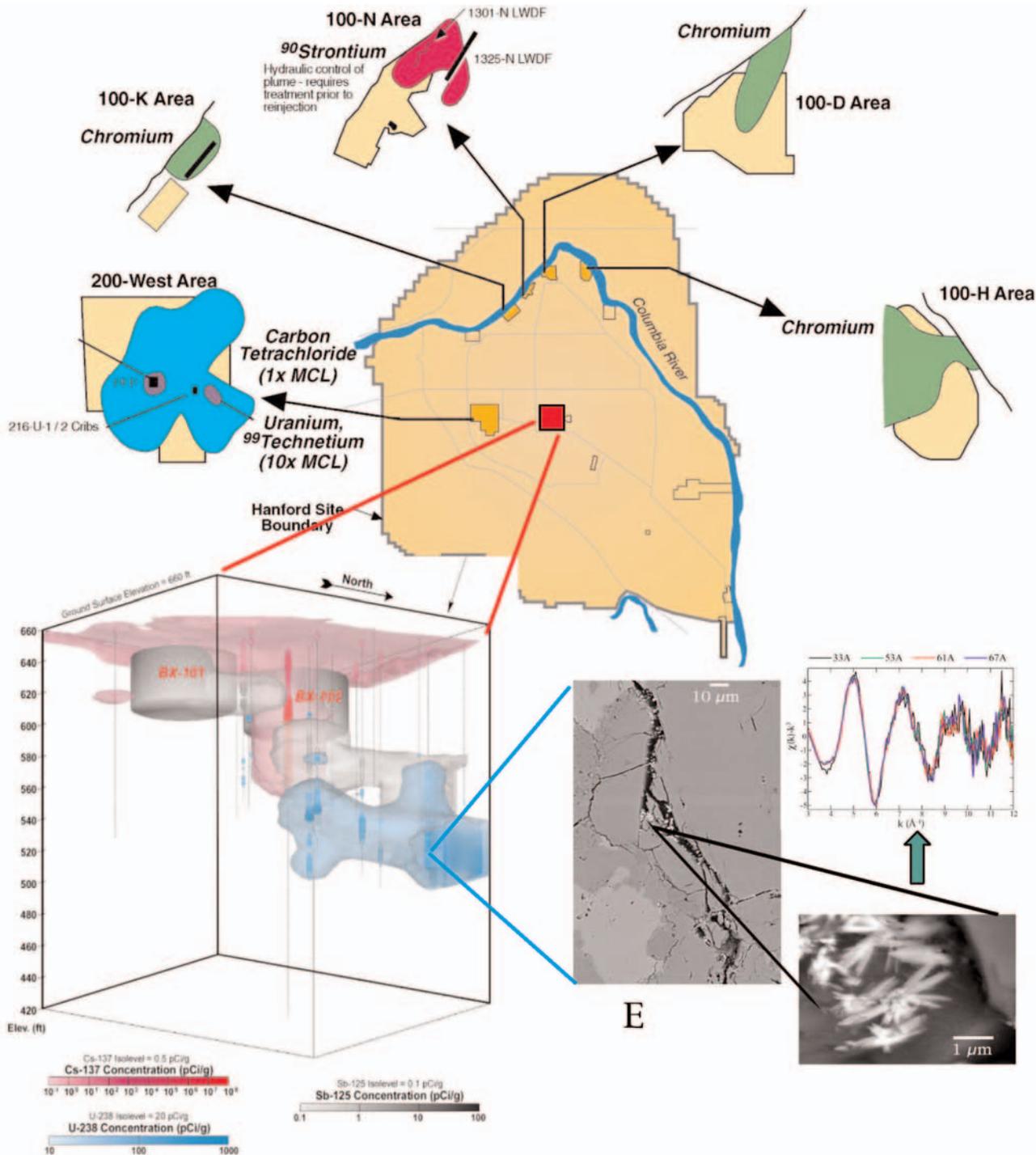
Recognition of the importance of surface chemical reactions in geochemical and environmental contexts (Fig. 2) can be traced back to the pioneering work by early soil chemists on soil–fluid interactions, particularly the paper by J. Thomas Way (1850). More than 150 years later, we

have a better understanding of the sorption and exchange phenomena that account for Way's observation that the filtration of "liquid manure" through a loamy soil resulted in the manure being "deprived of colour and smell." Much of this molecular-level understanding has come from synchrotron radiation studies, particularly XAFS studies of ion sorption reactions at mineral–water interfaces (Brown and Parks 2001). For example, Hayes et al. (1987) used XAFS under in situ conditions to show that aqueous selenate ions (SeO<sub>4</sub><sup>2-</sup>) form dominantly outer-sphere complexes on goethite ( $\alpha$ -FeOOH) surfaces, whereas aqueous selenite ions (SeO<sub>3</sub><sup>2-</sup>) form dominantly bidentate-binuclear inner-sphere complexes on these surfaces. Since this study, hundreds of similar XAFS experiments on many different adsorbed cations and anions have been performed, providing much-needed molecular-level insights into ion sorption processes. An important question raised by these studies is how the structures of mineral surfaces in contact with water differ from simple terminations of the bulk crystal structure, which are typically assumed to accurately represent the structures of wet mineral surfaces (Brown and Sturchio 2002). This question has recently been addressed for the hydrated  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> (0001) (Eng et al. 2000) and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> (0001) (Trainor et al. 2004) surfaces using synchrotron-based surface scattering known as crystal truncation rod (CTR) diffraction. These CTR diffraction studies show that the structures of the hydrated  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> (0001) surfaces are significantly different from each other, which helps explain their differences in reactivity to water (Liu et al. 1998) and aqueous metal ions such as Pb<sup>2+</sup><sub>aq</sub> (Bargar et al. 2004). They also show that these hydrated surfaces are not well represented by simple terminations of the bulk corundum and hematite structures along the (0001) plane. An excellent review of synchrotron-based X-ray scattering studies of these and other mineral surfaces is provided by Fenter and Sturchio (2004). This approach is providing the first detailed molecular-level views of mineral–water interface structures and interfacial water under environmental conditions, and shows that surface hydration layers are a general characteristic of mineral–water and mineral–water vapor interfaces.

X-ray scattering and other synchrotron-based methods, such as scanning transmission X-ray microscopy, are also being used to provide unique insights into the changes in



**FIGURE 2** Example of a complex mineral–water interface, including both iron oxide and microbial biofilm coatings, illustrating some of the molecular-scale processes occurring at these interfaces, including interaction with water, sorption or surface complexation of aqueous metal ions, and dissolution. Also shown is a model of the electrical double layer at the mineral–aqueous solution interface. From BROWN 2001.



**FIGURE 3** (Top) Map (not to scale) of the Hanford Site, Washington State, showing contaminant plumes in the vadose zone beneath various Hanford Tank Farms. (Lower left) 3-D nature of  $^{137}\text{Cs}$ ,  $^{125}\text{Sb}$ , and  $^{238}\text{U}$  plumes beneath Tank BX-102 in the 200-East Area, where 300,000 liters of waste containing 7–8 metric tons of uranium were spilled in 1951. (Lower right) Backscattered electron images of vadose-zone plagioclase grains containing Na-boltwoodite in cracks, and  $\text{U L}_3$ -XAFS spectra of Na-boltwoodite grains. TOP FIGURE FROM RILEY AND ZACHARA 1992; LOWER LEFT FIGURE FROM PEARSONS 2000; LOWER RIGHT FIGURE FROM JIM MCKINLEY, PERS. COM.; XAFS SPECTRA FROM CATALANO ET AL. 2004)

mineral surfaces resulting from abiotic and biotic reactions, which cause oxidation and dissolution of mineral surfaces. For example, the oxidation and dissolution of pyrite surfaces by *Acidithiobacillus* sp. have been studied by oxygen *K* edge and iron *L* edge XAFS (pers. com., B.C. Bostick 2004), and the oxidation and dissolution of pyroxene surfaces have been studied by STXM spectromicroscopy (Benzerara et al. 2005). Another example of the unique information provided by synchrotron radiation studies is the use of long-period X-ray standing wave fluorescence yield spectroscopy to study the partitioning of heavy metals such as  $\text{Pb}^{2+}$  between  $\alpha\text{-Al}_2\text{O}_3$  (and  $\alpha\text{-Fe}_2\text{O}_3$ ) single-crystal surfaces and *Burkholderia cepacia* biofilms grown on these surfaces (Templeton et al. 2001). In addition, XAFS and synchrotron-based XRD methods are providing important insights into the formation and structure of nanominerals resulting

from bacteriogenic processes (e.g. Suzuki et al. 2002). The study of mineral–bacteria interactions using synchrotron radiation methods is anticipated to grow significantly in coming years and to yield important new information on biomineralization, bioweathering, and the biogeochemical cycling of elements (Kemner et al. 2005).

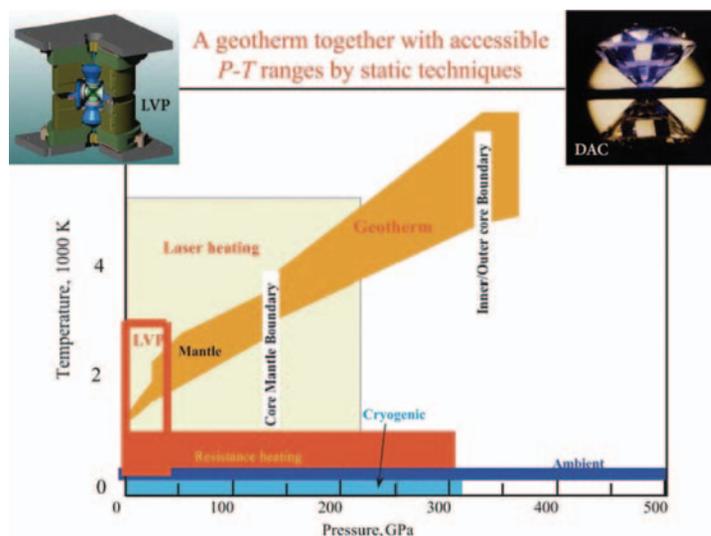
## Environmental Mineralogy and Geochemistry (Molecular Environmental Science)

Synchrotron radiation methods have played a major role in studies of the chemical forms, spatial distribution, and phase association of contaminant elements in environmental samples. These materials range from mine wastes and soils contaminated by various heavy metals, radionuclides, and xenobiotic organics to plants that hyperaccumulate specific elements and fish that contain high concentrations of methyl mercury. The new field of *molecular environmental science* has developed in response to the need for such information for understanding the transport behavior, toxicity, and potential bioavailability of contaminants (Brown et al. 1999). A great deal of attention in this new field has focused on contaminant speciation in soils, which are the products of chemical and biological reactions at the interfaces among the solid Earth (lithosphere), atmosphere, hydrosphere, and biosphere. Soils host crops and support most human activities. Their high reactivity makes them sensitive to environmental modifications and contamination by heavy elements and xenobiotic organics. The finely divided texture of soils, the importance of surface reactions, and the need to determine the speciation of inorganic, biological, and organic components explain the growing number of soil-related studies at national user facilities such as synchrotron light sources.

Lead and other heavy metals are major contaminants in some soils, raising environmental concerns; however, the bioavailability and chemical lability of these contaminants often show little correlation with their bulk concentrations. The key to understanding this observation is the molecular-level speciation of contaminants (i.e. their chemical form). For example, mineralogical and X-ray spectroscopic studies have shown that in smelter-contaminated soils from northern France, lead is sorbed to humic material as well as to both manganese and iron oxides, oxyhydroxides, and hydroxides (Morin et al. 1999). In mine tailings from Colorado, USA, carbonate-buffered tailings with near-neutral pH contain up to 50% of the total lead sorbed on iron-(oxyhydr)oxides, whereas Pb-bearing jarosites  $[\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6]$  dominate in sulfide-rich low-pH samples (Ostergren et al. 1999). In both cases, sorbed Pb may become potentially bioavailable if the local Eh and pH conditions change. Another example is the speciation of uranium in the vadose zone beneath Tank BX-102 in the 200-East Area Tank Farm at Hanford, Washington. This problem has also been addressed with synchrotron radiation methods (Catalano et al. 2004) (Fig. 3). Using a combination of XAFS and  $\mu\text{XRD}$ , this study showed that  $\text{U}^{6+}$  occurs in fractures in plagioclase feldspar grains dominantly as the uranophane group mineral Na-boltwoodite  $[\text{Na}(\text{UO}_2)(\text{SiO}_3\text{OH}) \cdot 1.5\text{H}_2\text{O}]$ , which is moderately soluble in the interparticle pore waters.

However, the location of this phase in feldspar grain fractures and the low moisture content in the Hanford vadose zone make it unlikely that commonly used remediation methods will be successful in removing this phase or that this phase will release  $\text{U}^{6+}$ . These types of studies of heavy metal and radionuclide contaminants are providing much-needed understanding of their phase association, potential bioavailability, and environmental fate.

Although not strictly in the field of molecular environmental science, recent studies of the structure of water using synchrotron radiation methods (O K-edge XAFS and X-ray Raman scattering) (Wernet et al. 2004) have led to the revolutionary suggestion that the 4-hydrogen bonded structure of water that has heretofore been assumed is not correct. Instead, compelling experimental and theoretical evidence has been found for about 80% of water molecules in



**FIGURE 4** Temperature and pressure range accessible using laser-heated diamond anvil cells (DAC) (light tan area), resistance-heated DAC (reddish brown area), and DAC at ambient (dark blue area) and cryogenic temperatures (light blue area). Also shown is the P-T range accessible using large volume presses (LVP) (area outlined by reddish brown boundary). Earth's geotherm is shown as the light brown area. Also shown are a schematic diagram of a large volume press (upper left) and a photograph of a diamond anvil cell (upper right). FROM BASS 2004. PICTURE AND DIAGRAM AT THE TOP OF THIS FIGURE ARE FROM THE GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON

liquid water having an asymmetric 2-hydrogen bonded structure. The implications of this discovery in aqueous geochemistry have yet to be detailed, but it is likely that this new structure of water, if correct, will lead to revisions in our thinking about its structure-property relationships and the hydration of ions in aqueous solutions.

## Mineral Physics

Recent years have witnessed many advances in the use of synchrotron techniques in high-pressure mineral physics, including XRD, spectroscopy, inelastic scattering, and radiography, as well as infrared spectroscopy using laser-heated diamond anvil cells, which currently permit access to simultaneous temperatures and pressures of 5000K and 225 GPa, respectively (Fig. 4). Polycrystalline XRD includes simultaneous high P-T diffraction using double-sided laser heating methods, and newly designed cells allow determination of stress-strain conditions and the measurement of second-order elastic tensors at ultrahigh P-T conditions. Single-crystal methods have been extended to above 100 GPa using high-brightness X-ray sources. These developments have also opened a window for studying local chemical environments, including atomic coordination, structures, and bonding character with a diversity of X-ray spectroscopies and scattering techniques. Other experiments involve the use of X-ray radiography over a range of pressures. The enormous flux advantage of infrared synchrotron radiation relative to conventional thermal IR sources provides a significant improvement in spectroscopic studies of microscopic samples at very high pressures. The following examples illustrate the application of multiple techniques to Earth and planetary materials under extreme conditions. Specifically, a growing number of studies utilize the complementary roles of synchrotron X-ray and neutron scattering methods.

One of the major developments in mineral physics of the last several decades has been the discovery of the post-perovskite phase of  $\text{MgSiO}_3$  above 100 GPa with synchrotron radiation and laser-heated diamond cell techniques (Murakami et al. 2004). The post-perovskite phase can take

up to 80% iron in the Mg site and exists in the low-spin (i.e. magnetic spin-paired) state at conditions of the D'' region at the base of the Earth's mantle, as shown by subsequent synchrotron X-ray and emission experiments (Mao et al. 2004). Such high P-T diffraction measurements have been complemented by an array of high-pressure X-ray spectroscopic techniques that have now come on line. Most recently, the X-ray emission technique has been applied to more chemically complex deep-Earth minerals such as (Mg,Fe)O and (Mg,Fe,Al)SiO<sub>3</sub> perovskite to identify high-spin/low-spin transitions of iron, which are expected to have profound implications for compositional layering in the lower mantle (Badro et al. 2004; Lin et al. 2005a).

Studies of the high P-T behavior of iron represent an excellent example of the use of multiple synchrotron radiation techniques (Hemley and Mao 2001). In situ high P-T synchrotron XRD studies demonstrate that the hexagonal close-packed phase ( $\epsilon$ -Fe) has a wide stability field extending from deep mantle to core conditions. Seismological observations of inner core anisotropy and structure present new questions about the dynamics and magnetism of the core. The aggregate longitudinal velocity ( $V_p$ ) and shear velocity ( $V_s$ ) at high P and T are the primary data obtained from seismic observations. Radial diffraction measurements also provide information on single-crystal elasticity, deformation mechanisms, preferred orientation, slip systems, plasticity, failure, and shear strength (Wenk et al. 2000). The nuclear resonant inelastic X-ray scattering (NRIXS) technique has been developed for the measurement of phonon densities of states and elasticity of materials containing <sup>57</sup>Fe. The observed compressional and shear wave velocities of  $\epsilon$ -Fe decrease with increasing temperature at high pressures, and a strong temperature effect on the linear sound velocity-density relations (Birch's law) was found (Lin et al. 2005b). High-pressure phonon dispersion measurements have been carried out to megabar pressures (Fiquet et al. 2001). The structure of molten Fe has been determined over a range of P-T conditions generated using both large volume and diamond cell methods (Sanloup et al. 2000; Shen et al. 2004).

Detailed information on crystal structures is an essential starting point for understanding the origin of the chemical and physical properties of materials that comprise not only the Earth but also other planets. The single-crystal X-ray diffraction method first used for H<sub>2</sub> (Mao et al. 1988) has been extended to megabar pressures (Loubeyre et al. 1996). Integration of new synchrotron X-ray microdiffraction methods is opening up new fields of micro- to nanomineralogy, as shown by the refinement of the crystal structures of new Fe-Si phases identified in a lunar meteorite (Anand et al. 2004).

Continued advances in high-pressure synchrotron infrared spectroscopy have led to a series of studies of materials at ultrahigh pressures, including the discovery of a number of unexpected phenomena in dense hydrogen. Synchrotron infrared reflectivity spectra of H<sub>2</sub>O to 210 GPa showed that the transition of ice to the long-sought, non-molecular, symmetric hydrogen-bonded structure occurs at 60 GPa (Goncharov et al. 1996). A particularly important new development has been the extension and improvement of far-IR measurements in ice (Klug et al. 2004) and biomolecules (Klug et al. 2002). The inelastic K-edge scattering has been used to probe bonding changes in materials, including most recently in ice, providing evidence for a new low P-T phase (Cai et al. 2005).

Finally, it is useful to point out the complementarity between X-ray and neutron experiments. Recently, the evolution of the structure of amorphous GeO<sub>2</sub> at high pressure was determined by combining high-energy synchrotron

X-ray and neutron diffraction techniques (Guthrie et al. 2004). Variable P-T neutron diffraction techniques reveal new findings concerning the magnetic properties of the high-pressure rhombohedral phase of Fe<sub>1-x</sub>O (wüstite) (Ding et al. 2005b), whereas zone-axis synchrotron XRD experiments on single crystals reveal that Fe<sub>1-x</sub>O has a long-range defect-cluster order-disorder transition (Ding et al. 2005a). Recent neutron and X-ray diffraction studies of hydrogen isotopes provide a direct probe of pressure-induced transformations in this important planetary material (Goncharenko and Loubeyre 2005). Another example where both techniques have been exploited is H<sub>2</sub>O-H<sub>2</sub> clathrate, which is important for diverse problems ranging from condensation in solar nebulae to use as a hydrogen storage material for automobiles (Mao et al. 2002).

## CONCLUDING REMARKS

Molecular-level studies of the type discussed above provide the main intellectual interfaces between Earth sciences and disciplines such as chemistry, materials science, microbiology, physics, and structural molecular biology. They are also one of the main conduits for students from these other disciplines to enter the Earth sciences and make truly interdisciplinary contributions. Moreover, the analytical instrumentation and techniques developed in other disciplines, such as transmission electron microscopy, electron microprobe analysis, mass spectrometry, X-ray absorption spectroscopy, NMR spectroscopy, SQUID magnetometry, and X-ray and neutron diffraction, have had and will continue to have enormous impacts on Earth sciences research. Without this cross-fertilization of ideas and techniques from other disciplines, vital Earth sciences research areas such as isotope geochemistry, geomicrobiology, surface and interface geochemistry, mineral physics, and paleomagnetism would have taken longer to develop. Breakthroughs in most areas of science depend strongly on the development of new experimental methods and the new observations and new theories they provide, which guide our thinking and lead to new paradigms. National user facilities of the type highlighted in this issue of *Elements* are providing new experimental capabilities that are making new discoveries about Earth materials and processes possible. Such facilities also play another important role in Earth sciences. They are fertile ground for new ideas because of the mix of scientists from many different disciplines and different countries they attract and the many chances for young Earth scientists to interact with young scientists from other fields. They are well worth the investment because of the advances in science and technology they enable as well as the cross-disciplinary collaborations they stimulate.

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# Accessing User Facilities and Making Your Research Experience Successful

Richard J. Reeder<sup>1</sup> and Antonio Lanzirotti<sup>2</sup>



New users at the Advanced Photon Source receive facility orientation and safety training before starting their experiments. PHOTO COURTESY OF GEO/ENVIRO/CARS, UNIVERSITY OF CHICAGO

**A**ccess to many of the world's leading user facilities is easier than ever before, with web-based tutorials providing everything from instrumental overviews and example applications to online safety training. Submission of proposals for experiment time at large, heavily subscribed facilities, including synchrotron and neutron sources, has been streamlined with web-based submission. Support, which is commonly the key to successful experiments, is provided by facility staff and experienced users, allowing new users to begin experiments with minimal experience. Increasingly Earth scientists are taking advantage of the wide range of unique instrumentation at user facilities. Here, we explain how you can, too.

KEYWORDS: user facilities, synchrotron, neutron source, electron microscopy, user access, safety training

## INTRODUCTION

A research facility is most valuable if it is available when we wish to use it and if it provides a level of user support that maximizes the likelihood of experimental success. The necessary support must include adequate user training, but it should also ensure that the instrumentation is running optimally and accommodates individual experimental needs. Let's not overlook safety, which may be as important to the continuing operation of the facility as it is to the success and well-being of the user. Meeting these goals is quite a challenge, one that requires effective organization, management, and resources. Today, most successful research facilities are heavily subscribed by users and operate with limited, hard-earned funding. Consequently, access generally requires prior approval and justification, often involving merit-based review. Although some users are able to complete their experimental project after one visit to a facility, many find it necessary to make return visits, with some becoming regular users. In this article, we describe access styles, management models, and aspects of user support at research facilities. We focus mainly on large, heavily subscribed user facilities, such as synchrotrons and neutron sources, which offer a wide variety of experimental techniques and have large user communities. Our goal is to offer

*So, you'd like to use an ion microprobe to determine the oxygen isotopic difference between a microscopic inclusion and its host mineral, or you need to use a synchrotron facility beamline to characterize the chemical speciation of chromium in a contaminated soil. Just hop on a plane, show up at the front door, and before you finish your first cup of coffee a cheerful staff scientist is already mounting your sample on the stage!*

*Wake up... were you dreaming?*

potential new users in the Earth science community a better understanding of the path to using research facilities and the resources they provide. Because the specific policies of each facility may differ, the description we provide should be considered as a starting point only, and users should investigate facilities of interest further.

In preceding articles, different classes of user facilities were described, including large multi-instrument laboratories, such as the Environmental Molecular Science Laboratory (EMSL) at Pacific Northwest National Laboratory and the several planned US nanocenters; synchrotron radiation and neutron sources, such as the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory and the neutron facility ISIS at the Rutherford Appleton Laboratory (UK); and individual instruments typically located at universities. Some large facilities have a particular scientific focus and support multiple types of instrumentation, examples being the EMSL and the Bayerisches Geoinstitut in Bayreuth (Germany). In contrast, synchrotron, neutron, and electron beam facilities offer techniques specific to their source characteristics but support users from diverse scientific disciplines. The infrastructure and management of larger facilities are generally dictated by the size of the facility and user community, as well as by the funding source. Individual instruments or small collections of instruments that are made available to

external users are typically housed in university departments and overseen by the department or sometimes an individual investigator.

Large user facilities are generally government funded and provide instrumentation and experimental capabilities whose costs for construction and operation are beyond the means of individual research groups or even universities. Good examples are the user facilities funded and managed by the US Department of Energy's Office of Science. These state-of-the-art facilities are available to the science community worldwide and offer some technologies and instrumentation not available elsewhere. They include particle and nuclear physics accelerators, synchrotron light sources, neutron scattering facilities, electron beam facilities, supercomputers, and high-speed computer networks. Access is

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typically determined by merit-based review of proposals, the necessary training and experimental oversight are provided by the facility itself, and no user fees apply to access the facility and conduct the experiment (although ancillary costs are covered by the user).

## WOULD MY RESEARCH BENEFIT FROM ACCESS TO A USER FACILITY?

For many Earth scientists, a significant hurdle is recognizing the availability of techniques that could benefit their research project. Technique development has traditionally not been as strongly promoted in the Earth sciences as in other fields, such as physics. Consequently we often learn about emerging techniques only after they have been developed and applied in other fields. Peer-reviewed publications are an important avenue for disseminating information about emerging technologies and techniques available to Earth scientists at user facilities. Also valuable are short courses and workshops, such as those sponsored by the Mineralogical Society of America, the Geochemical Society, and the European Mineralogical Union. For example, upcoming or recent short courses have highlighted neutron scattering in the Earth sciences (2006) and the applications of synchrotron radiation in geochemistry (2002).

Nearly all user facilities provide informative web pages describing aspects of their operation. Many facilities even offer online tutorials that serve as introductions to scientific approaches or applications of methods to different problems. *Facility web pages should be the first point of information for any new user.* In addition, new “first point of contact” websites are emerging, such as [www.envirosync.org](http://www.envirosync.org), which provide information on facilities specializing in particular areas of science.

## ARRANGING EXPERIMENT TIME AT A RESEARCH FACILITY

Access to most facilities generally requires submitting a proposal beforehand. This applies for all synchrotron and neutron facilities and most electron beam characterization facilities. Exceptions may include smaller facilities or single instruments, where access may commonly be arranged informally. Here we describe some general aspects of access policies and the proposal process, focusing primarily on synchrotron and neutron facilities, which have large, diverse user communities representing nearly all science, engineering, and health disciplines and spanning academic, industrial, and private foundation sectors.

Access for outside users is primarily based on scientific merit, usually as determined by peer-review of proposals. The process begins with identifying the appropriate facility for your experiment (FIG. 1; STEP 1). Importantly, the facility web pages usually provide contact information so that potential users can discuss their research needs with experienced scientists and support personnel to determine if a method is suitable for providing the information desired. In instances where scientific staff are unfamiliar with the particular nature of your Earth science problem, further inquiry may be required, perhaps with Earth scientists with prior experience.

An access proposal is then developed. It is normally brief (1–4 pages) and includes a description of the scientific question to be addressed and its significance, justification for a requested instrument or experiment station, and a request for a specific amount of experiment time. Most synchrotron and neutron facilities have gone to great lengths to streamline the proposal process, with submissions made online through easy-to-follow web pages. After submission (STEP 2), a proposal is either reviewed by a panel of scientists or sent



**FIGURE 1** Generalized process for obtaining access to large user facilities, such as synchrotron and neutron centers.

out for external review (STEP 3). Owing to the range of techniques available at synchrotron facilities, multiple review panels are used to evaluate proposals. For example, at the National Synchrotron Light Source (Brookhaven National Laboratory), the review process uses as many as 12 separate subpanels to evaluate proposals (TABLE 1). Each facility has developed its own procedures, which are explained on their web pages.

Proposals are reviewed for scientific merit and technical feasibility and assigned a numerical rating. Depending on the scope of each facility's panels, proposals from Earth scientists may be rated along with those from other fields, based on the technique to be employed. New users should be aware that some review panels may not have Earth scientists as members. If such proposals are not sent out for external reviews, they may be reviewed by scientists with expertise in the chosen method but with limited knowledge of Earth science issues. Therefore, Earth scientists may want to include sufficient explanation and justification in their proposals to allow experts from other disciplines to make a fair evaluation. The scientific question to be addressed, the relevant hypothesis, and the significance of the research should all be emphasized. It is also important to justify the use of the requested instrument or experimental beamline, since the total time requested by all users may exceed what is available. As more Earth scientists become regular users of synchrotron, neutron, and electron beam facilities, it is encouraging to see our representation on review panels increasing. In some instances factors other than scientific merit alone may influence ratings; these might include feasibility, time or resources requested, and prior results. Review panels nearly always provide users with comments on their proposals.

After the review process, allocations are made, with available beamtime generally being assigned first to the proposals having the best ratings (STEP 4). Users are then informed of their allocation, specific dates are assigned for the experiment through interactions with the facility staff, and the experiment is conducted (STEP 5). At heavily subscribed facilities or beamlines, requests often exceed available time. Unfortunately, this means that some proposals may not be allocated experiment time for the requested period or cycle. In our experience, allocation panels usually go to great lengths to achieve a fair and optimal balance in assigning

beamtime. For example, it is common for even the best-rated proposals to be restricted in the amount of beamtime, in order to accommodate additional users. First-time users often do not have a good sense of how much time they can reasonably request. Contacting the experimental staff beforehand can be invaluable in assuring that your request for time is not deemed excessive. In cases where first-choice beamlines or instruments are oversubscribed, a user may be allocated time at other beamlines or instruments with comparable capabilities.

**TABLE 1** PROPOSAL REVIEW PANELS AND SUBPANELS AT THE NSLS

- **Imaging and Microprobes**
  - Biological and Medical
  - Chemical and Material Sciences
  - Environmental and Geosciences
- **IR/UV/Soft X-ray Spectroscopy**
  - Chemical Sciences/Soft Matter/Biophysics
  - Magnetism/Strongly Correlated Electrons/Surface
  - Methods and Instrumentation
  - Macromolecular Crystallography
  - Powder/Single Crystal Crystallography
- **X-Ray Scattering**
  - Magnetism/Strongly Correlated Electrons/Surface
  - Soft Matter and Biophysics
- **X-Ray Spectroscopy**
  - Biological, Environmental and Geosciences
  - Chemical and Material Sciences.

Most synchrotron and neutron facilities have two or three cycles of submission, review, and allocation per year. This provides several target deadlines for submission of proposals. At many facilities, a user may choose to submit a proposal that remains active for up to two years rather than being applicable to a single cycle; however, separate requests for experiment time must be made for each cycle. The total process—from submission to actual experiment—may range from three to eight months, depending on the operating schedule of the facility. Using the Advanced Photon Source (APS) at Argonne National Laboratory (USA) as an example, a user would submit a proposal by the mid-July deadline to be considered for experimental beamtime in the October through December cycle. These access models require awareness of the proposal process and advance planning. The web page [lightsources.org](http://lightsources.org) provides information about proposal deadlines for all the world's synchrotrons.

If a user has a particular project that simply cannot wait for a typical submission and review process, some facilities offer a rapid access option, which may provide experiment time in as little as days to weeks. However, this rapid access is reserved for circumstances where timeliness is crucial to an experiment and must be well justified.

New users should be aware that most of the large research facilities require approval and notification prior to arrival, and issue identification badges on site. At all research facilities in US national laboratories, non-US citizens are subject to further security and clearance scrutiny. In short, it is essential to consult facility web pages or representatives to determine access requirements well before experiments are actually scheduled. Although facilities strive to improve the speed of this process, it may still require months for scien-

tists from certain countries to receive clearance. Even though the US Department of State continues to re-assess the timely issuance of visas to visiting scientists (Flatten 2005), further reforms may require a stronger voice from US scientists who seek more effective international collaborations.

## HOW MUCH TIME IS AVAILABLE AT A USER FACILITY?

Having forewarned readers that they should not expect unlimited experimental time at large user facilities, it is useful to consider some of the additional constraints that determine how much time is actually made available to external users. Facilities such as synchrotrons and neutron sources routinely set aside time for maintenance, upgrades, and studies of source characteristics. The fraction of time available to outside users not only varies among facilities but also among the experiment stations within a facility, depending on the technique(s) implemented, their development and maintenance needs, and management style. Many of the large scientific facilities “work concurrently in two modes—operating the overall facility and operating the experimental stations within the facility” (Kelly et al. 2003). The facility itself assumes responsibility for overall operations, stability, maintenance, and upgrades. For most users, however, their experience at the experimental stations is critical for the success of their experiment. In many cases these end-stations and their instruments are operated by the facilities themselves, encompassing design, development, and maintenance, as well as providing experiment time to outside users. Typically the fraction of user time at facility-operated stations is 50–85% of the total available. This mode of operation maximizes the time available to users and allows the facility to pool its technical expertise among various beamlines.

At some user facilities, however, a consortium of scientists or an external organization may use independent funding to design and operate an experimental station, thereby assuming responsibility for design, development, and maintenance. Because the member scientists secured funding and undertook this responsibility in order to conduct their own research projects, they have generally negotiated with the facility for a certain allocation of experiment time to accommodate their own needs and still provide time for external users. Consortia may also receive funding to support a specific scientific community, making all of the beamtime available to external users. Hybrid models combining components of both styles also exist. Although less overall time may be available to external users in these cases, these consortium-operated experimental stations offer more specialized user support and innovation in instrument development. Because funding for such groups often comes from programs with a particular research focus, these experimental stations can be optimized for particular research needs or modified to accommodate specialized instrumentation suited to the focus area. For example, synchrotron experimental stations that are partly supported by the US National Science Foundation's Earth Sciences Program and the US Department of Energy's Geosciences Research Program have Earth scientists as full-time staff and house unique instrumentation, one example being large presses for in situ studies of mineral samples at high pressure and high temperature. This level of specialization specifically serves the Earth science community. Facility- and consortium-operated experimental initiatives each have their own merits and both should be encouraged.

At electron beam characterization facilities supported by the US Department of Energy's Office of Science, there are no instrument cycles, and proposals are welcome at any time. However, they should generally be submitted two

months prior to requested experiment time. Some electron beam characterization facilities give priority usage to in-house staff, with experiment time available to external users on request. The majority of instrument time at the Center for High Resolution Electron Microscopy at Arizona State University is used by in-house scientists, but this facility also has many external users. The Instrument National de Microscopie Electronique en Sciences de la Terre (French National TEM Facility in Earth Sciences), with locations in Lille and Marseille (France), provides electron microscope access primarily to scientists at supporting laboratories of the Centre National de la Recherche Scientifique (CNRS), but access is also available to outside users.

Because the available experimental time at large facilities is so limited, careful planning of experiments and preparation of samples are essential. Assembling a small team often works best, allowing researchers to work in shifts, which is particularly useful for 24-hour, 7-days-a-week operations. Many experimental stations allow automated data collection over extended periods of time, permitting users to take extended breaks.

### SO, WHAT DOES IT COST?

The great news is that many facilities have no user charges. In other words, the actual experiments are free for approved users, except for proprietary work. This includes all of the synchrotron and neutron facilities throughout the world, and any of the user facilities supported by the US Department of Energy, such as the Environmental Molecular Science Laboratory at Pacific Northwest National Laboratory and the National Center for Electron Microscopy at Lawrence Berkeley National Laboratory. The philosophy underlying this free access is that the research ultimately benefits the taxpayers who have paid for it. Consequently, it is incumbent on the academic, industrial, and government scientists using these facilities to publish their findings in the open literature. Government-funded facilities also make experiment time available for proprietary research. Such users request confidentiality of proposal, data, and results for a certain period of time, and usually are required to pay for access.

Most facilities operating within universities and nearly all single-instrument labs have user charges, which is not surprising in view of their limited funding base. For example, access to electron microscopes at most facilities incurs user charges (except at US DOE facilities), which vary in amount. Users at the Bayerisches Geoinstitut (University of Bayreuth, Germany) are expected to cover the basic cost of their research, although charges may be reduced when the research is conducted in collaboration with Geoinstitut scientists. In addition, users from European Union countries (except for Germany) may apply to the Geoinstitut for EU support to cover travel, subsistence, and experimental costs. Users pay a modest fee at the Northeast National Ion Microprobe Facility, located at Woods Hole Oceanographic Institute in Massachusetts (USA); however, discretionary funds are sometimes made available. The Purdue Rare Isotope Measurement Laboratory (PRIME Lab), located in West Lafayette, Indiana (USA), provides accelerator mass spectrometry analyses for a modest fee, but also accepts applications for a limited number of initial analyses done free of charge.

### USER SUPPORT AT RESEARCH FACILITIES

Now that you've obtained access to a user facility, how do you make sure your experiments will be successful? New users will find themselves working with instrumentation that is unfamiliar (at least initially) and complex. The phys-

ical environment of synchrotron and neutron facilities may appear daunting, with a seemingly endless maze of electrical wiring and cables, vacuum systems, lead shielding, and interlock systems. Work practices in a user facility can be quite different from those found in many university Earth science departments. For example, at synchrotron facilities, experiments are conducted continuously when the beam is available (i.e. 24/7). Although many new users know the principles behind the instrumentation and the method, they usually lack the hands-on operational knowledge required to make the most effective use of experimental



**FIGURE 2** Beamline scientists and technical staff provide support allowing new users to maximize the effectiveness of their experiment time. Here, NSLS scientist Lisa Miller (center) shows new users how to operate software. PHOTO COURTESY OF BROOKHAVEN NATIONAL LABORATORY

time, to obtain the highest quality data, and to interpret it properly. This is when user support becomes crucial and is often the key to a successful research experience.

### Learning how to Operate the Equipment

During the first visit to a large facility, a significant amount of time is invested in familiarizing the users with the facility and training them in the mechanics of conducting the experiment. This may include aspects of instrument operation, software usage, sample mounting and preparation, data quality optimization, and data collection and interpretation. While some general familiarization with the facility can be accomplished by group training or by computer-based tutorials, the training needed to operate instrumentation safely is provided on an individual basis by a facility scientist or staff member who works specifically at that experimental station (FIG. 2). In some cases, users may be given initial training and then allowed to take over the controls for their experiment time, with the support staff available if problems arise. In other instances, a support staff member may actively assist users during the entire duration of their experiments. As users become more expert and require less support, the level of involvement usually decreases. Most user facilities strive to provide an optimal level of support for outside users; however, adequate fund-

ing for support staff may be a limiting factor. For example, the number of support staff available to help outside users at synchrotron beamlines may range from less than one (i.e. part-time) to more than four.

In our experience, users benefit greatly from collaboration with facility staff, and we strongly encourage new users to develop such collaborations. This can be particularly beneficial when the facility staff includes someone with an Earth sciences background. The quality of publications is often greatly enhanced by such collaborations.

Some facilities supplement hands-on training through their websites. Thus, users may familiarize themselves with instrumentation and operations prior to their arrival at the facility. These websites are also valuable for answering questions that arise during and after an experiment, particularly with regard to data processing and interpretation once the user has left the facility. At some facilities, web-based tools have even made it possible to conduct experiments remotely, with local staff mounting and removing samples mailed by the user.

### Safety Training

Not only must users familiarize themselves with the mechanics of the actual experiment, they must also comply with safety and training requirements of the facility. Protection of personnel and the environment is the highest priority at all user facilities, and great efforts have been made to ensure that work is conducted safely. Large facilities, including all synchrotrons, require users to take regular safety training courses covering safety aspects relating to the facility and to general radiological hazards. Much of this safety training is available online, allowing users to satisfy these requirements on arrival or even before arrival at the facility. Additional training may be required if experiments involve specific hazards, such as use of radioactive substances or certain electrical equipment.

All activities are planned and conducted in accordance with stated safety policies. At synchrotron and neutron facilities, a user's proposed experiment undergoes an experiment safety review prior to receiving authorization. These mandatory reviews may be quite rigorous and are intended to ensure that risks are minimized through proper design and operation of equipment and proper handling and disposal of materials. Safety staff members are highly experienced and can provide valuable assistance to users in the design of equipment or material handling. *We can't stress enough how important it is to have a dialog with safety staff in the early stages of planning your experiment.*

Safety and beamline staff can also make users aware of shipping, handling, and labeling requirements, to ensure that samples will be allowed into the facility and that they are handled safely during the experiment. By following the correct protocols, it can be relatively easy to work even with radioactive and toxic samples at most facilities.

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### Outreach and Education

Regular users of research facilities are some of the best resources for information about specific techniques and applications, and are also potential collaborators for new users. Large facilities regularly host short courses and hands-on workshops, which serve to introduce new users to different methods and also permit experienced users to exchange ideas. Such workshops are very popular in the biosciences and have proven to be a critical training resource. Typically held over a span of several days, they allow for in-depth coverage of topics and an opportunity for researchers to collect data. Relatively few workshops have focused exclusively on applications to the Earth sciences. One recent example was a workshop sponsored jointly by the Mineralogical Society of America and the Geochemical Society, resulting in a publication in the *Reviews in Mineralogy and Geochemistry* series (Fenter et al. 2002). The Mineralogical Association of Canada has also published several short course volumes covering Earth science applications of facility-based techniques (e.g. Henderson and Baker 2002). Two groups of synchrotron users in the Earth and environmental sciences—GeoSync ([millenia.cars.aps.anl.gov/geosync](http://millenia.cars.aps.anl.gov/geosync)) and EnviroSync ([envirosync.org](http://envirosync.org))—serve as advocates for increased involvement and support for these valuable resources. The latter group has co-sponsored a series of workshops, entitled "Synchrotron Environmental Science," highlighting new synchrotron applications in environmental science, and has also held workshops for new users. National meetings of Earth science and sister societies also provide valuable opportunities to highlight research applications using the unique instrumental capabilities at user facilities. We hope that professional societies, government funding agencies, and user-based initiatives will continue to make Earth scientists aware of opportunities for novel research opportunities at the world's user facilities. The small investments required to sponsor such workshops have enormous payoffs in later research.

This overview has shown that gaining access to research user facilities is relatively simple. With the many interesting techniques they have to offer, there is likely to be something that can benefit your research. Moreover, by conducting high-quality research at government-supported user facilities, you will be contributing to their continued success.

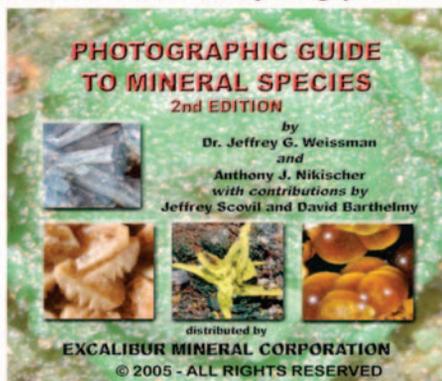
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# New Opportunities at Emerging Facilities

John B. Parise<sup>1</sup> and Gordon E. Brown Jr.<sup>2,3</sup>

**S**ynchrotron X-ray sources and pulsed neutron sources are getting brighter. This permits new opportunities for scattering, spectroscopy, and imaging studies of Earth materials and processes that were not possible a decade ago. The impact of these latest-generation facilities on Earth sciences research requiring nanometer- to micrometer-scale resolution is growing and will continue to grow as next-generation X-ray and neutron sources become available over the next six years. These facilities will include the world's first X-ray free-electron lasers in the US (2009) and Europe (2012) and the Spallation Neutron Source at Oak Ridge National Laboratory, USA (2006). In addition, five nanoscale science research centers are under construction in the US and will impact the emerging field of nanogeoscience.

KEYWORDS: national user facilities, synchrotron X-ray, neutron scattering, X-ray fluorescence, imaging

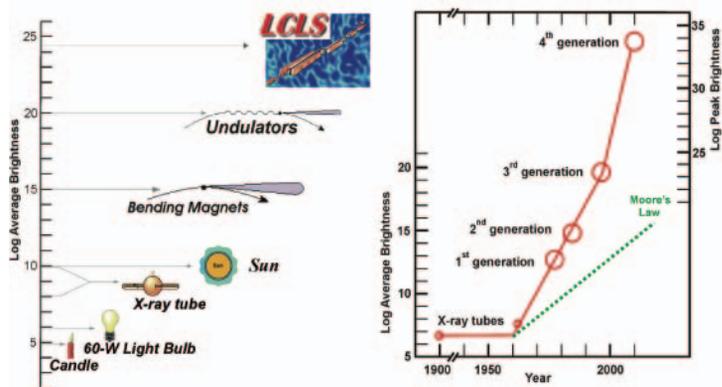
## INTRODUCTION

The trend over the past two decades at national user facilities has been toward brighter sources and focusing optics with higher energy resolution. This has led to major improvements in flux on smaller samples and sample areas. These developments have enabled elastic and inelastic scattering and spectroscopy studies of inorganic materials (both crystalline and amorphous), including those under extreme conditions of pressure and temperature, and biomolecules. They have also permitted more precise and spatially resolved imaging and fluorescence studies of nanoparticles, compositionally and structurally heterogeneous inorganic materials, natural organic matter, mineral-organic matter mixtures, biomaterials, bacterial cells, and microbial biofilms. Often this science has changed our worldview, as was recently demonstrated by the discovery of the post-perovskite transition at conditions of the Earth's core-mantle boundary (Murakami et al. 2004). In this brief overview, we present a snapshot of current developments in user facilities of potential interest to mineralogists, geochemists, mineral physicists, geomicrobiologists, and other Earth scientists interested in atomic-, molecular-, and meso-scale biological, chemical, and physical processes. Many of these developments are ongoing, and the technologies underpinning them are immature. We believe several will be mainstream and this review will be obsolete within the next few years.

Up-to-date information on capabilities, guidelines for choosing instruments, and research highlights is provided at synchrotron X-ray (<http://www.lightsources.org>) and neutron (<http://neutron.neutron-eu.net/>) web portals.

**X-RAY SCATTERING, ABSORPTION, AND IMAGING – RECENT PROGRESS AND NEW OPPORTUNITIES**

X-ray scattering has become the “workhorse” technique of condensed matter scientists and structural biologists. In the Earth sciences, mineralogists, mineral physicists, and inorganic geochemists have long utilized X-ray scattering methods to determine the atomic-level structure of minerals; to study the mechanisms of phase transitions in minerals as a function of temperature and pressure; and to derive information on the short-range structures of cation coordination environments in silicate glasses and melts (at temperature and pressure), metamict minerals, and aqueous solutions under both ambient and hydrothermal conditions. Such studies were greatly facilitated in terms of data quality, sample throughput, and reduced sample size by the introduction of synchrotron light sources in the mid-1970s. Over the years, the flux and brightness of X-ray sources have increased (Fig. 1), and

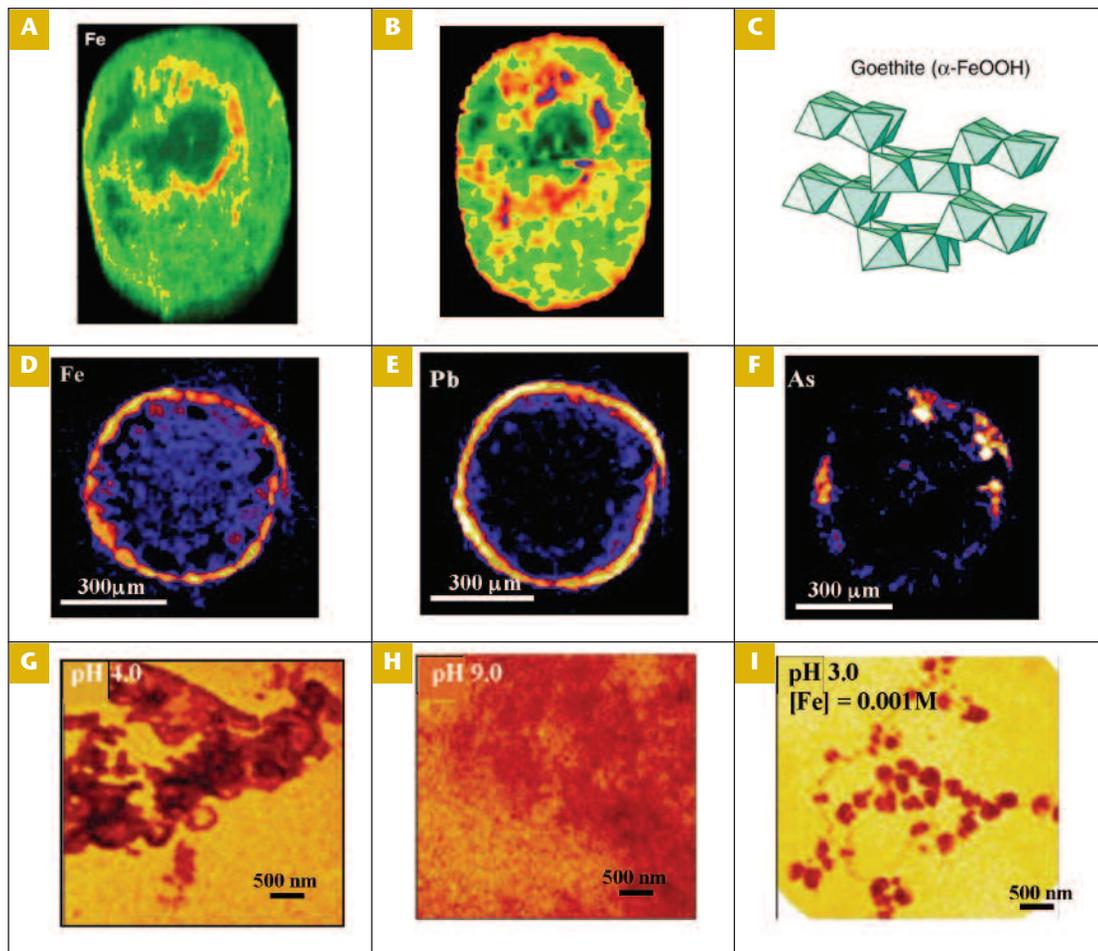


**FIGURE 1** Comparison of the brightness or brilliance of various light sources, including a candle, a 60-watt light bulb, a sealed 3 kW X-ray tube, the Sun, synchrotron light from a bending magnet, synchrotron light from an undulator magnet, and synchrotron light from an X-ray free-electron laser (FEL) such as the Linac Coherent Light Source (LCLS) that is currently under construction at the Stanford Linear Accelerator Center (SLAC). Also shown for comparison is the rate of growth of computer storage density over the past 40 years. FIGURE COURTESY OF PROF. JO STÖHR, STANFORD SYNCHROTRON RADIATION LABORATORY.

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**FIGURE 2** (A)  $\mu$ XRF image showing intensity distribution of Fe  $K\alpha$ , with orange indicating higher Fe concentration; (B)  $\mu$ XRD image showing intensity distribution of 4.19Å diffraction maximum, with blue indicating highest intensity and green lowest intensity, from a soil ferromanganese nodule with Fe in the form of goethite, whose crystal structure is illustrated in (C) (Manceau et al. 2002). XRF  $\mu$ -tomography images of a plant root showing the distribution of Fe-plaque (D), Pb (E), and As (F) (Hansel et al. 2001); (G–I) TXM images of fulvic acid in water as a function of pH and ionic strength (Myneni et al. 1999).

X-ray detectors and focusing optics have improved. These advances have made feasible techniques such as X-ray absorption fine-structure (XAFS) spectroscopy, micro-XAFS spectroscopy, micro-X-ray diffraction (XRD), micro-X-ray fluorescence imaging, and surface X-ray scattering. Such techniques are now routinely used to study matter in various forms at unprecedented levels of elemental sensitivity, energy resolution, Q-range ( $Q = 4\pi/\lambda\sin\theta$ ), reduced sample size, and sample throughput. For example, third-generation synchrotron light sources utilizing multipole undulator-magnet insertion devices offer an increase in source brightness of  $10^{12}$ – $10^{14}$  relative to sealed X-ray tubes. This enormous gain in brightness has permitted new classes of elastic and inelastic scattering, absorption, emission, and imaging experiments on Earth materials that were simply not possible with sealed X-ray tubes or with first- or second-generation synchrotron light sources.

Among the new classes of experiments made possible by third-generation synchrotron light sources, we focus here on several examples that illustrate emerging opportunities for Earth and environmental scientists. The first example illustrates the ability to obtain element and phase distribution and phase identification at the 5  $\mu$ m level using a combination of micro-X-ray fluorescence (XRF) mapping and micro-XRD. Manceau et al. (2002) carried out a detailed  $\mu$ XRF,  $\mu$ XAFS, and  $\mu$ XRD study of the distribution and speciation of Ni in a soil ferromanganese nodule that contained a complex mixture of phases. Using 20  $\mu$ m  $\times$  20  $\mu$ m beams on bend-magnet beamlines 7.3.3 ( $\mu$ XRF and  $\mu$ XRD) and 10.3.2 ( $\mu$ XAFS) at the Advanced Light Source (Berkeley, CA), they mapped out the distribution of Fe (Fig. 2A) as well as Mn, Ni, and Zn (not shown) and measured the main diffraction lines of various Mn-, Fe-, Ni-, and Zn-bearing phases

as a function of location on the nodule. The intensity distribution of the 4.19Å diffraction maximum is shown in FIGURE 2B, indicating that Fe is mainly in the form of goethite (FIG. 2C) in this nodule. Hexagonal birnessite, a Zn-phyllsilicate, and lithiophorite were found to account for the Mn, Zn, and Ni, respectively, in the nodule. Phase identification was consistent with the  $\mu$ XAFS results. This work represents the first use of  $\mu$ XRF and  $\mu$ XRD mapping of a complex environmental sample and adds phase identification to the arsenal of tools available using microbeam radiation methods at third-generation synchrotron radiation sources.

The second example comes from an X-ray fluorescence microtomography study of major and trace elements in the intact root of *Phalaris arundinacea*, a common grass (Hansel et al. 2001). This study used a 5  $\mu$ m  $\times$  5  $\mu$ m X-ray beam on beamline 13-ID-C at the Advanced Photon Source to show that lead (FIG. 2E) correlates spatially with the location of iron plaque (FIG. 2D) on the outside of the grass root and that As (FIG. 2F) and Zn (not shown) contaminants are not spatially associated with the iron plaque. Such information is crucial for determining how effectively contaminants are sequestered by plants.

The third example is a transmission X-ray microscopy (TXM) study of natural fulvic acid in aqueous solution as a function of pH and electrolyte concentration at 25 nm spatial resolution using TXM beamline 6.1.2 at the Advanced Light Source (Myneni et al. 1999). FIGURE 2G shows the macromolecular structure of fulvic acid at pH 4.0. When pH is increased to 9.0, the molecules uncoil and disperse (FIG. 2H), suggesting that the hydrogen bonding changes dramatically with increasing pH. FIGURE 2I shows that micromolar concentrations of iron also have a significant effect on the conformation of fulvic acid. These first in situ images of fulvic acid show that the macromolecular conformation is quite different than assumed in earlier studies.

A final example of the new types of experiments made possible by high-brightness third-generation synchrotron light sources is a recent nuclear resonant inelastic X-ray scattering (NRIXS) study of iron up to a pressure of 73 GPa (720,000 atmospheres) and up to a temperature of 1700K (Lin et al. 2005). This experiment was carried out on Sector 3 at the Advanced Photon Source, and these P-T conditions were generated using a laser-heated diamond anvil pressure cell. The NRIXS technique allowed measurement of the phonon density of states of  $^{57}\text{Fe}$ , from which vibrational, elastic, and thermodynamic parameters were derived as a function of temperature and pressure. Their finding—that sound wave velocity decreases with increasing temperature at the highest pressures—led these researchers to conclude that there is a greater abundance of light elements in Earth's iron core than previously inferred from linear extrapolation of velocity-density relations at room temperature (i.e. Birch's Law).

The next revolution in X-ray science will be initiated with the completion of the Linac Coherent Light Source (LCLS) at the Stanford Linear Accelerator Center (SLAC) in California, USA. When fully operational in early 2009, the LCLS will provide the world's first X-ray free-electron laser, with X-ray pulses one femtosecond ( $10^{-15}$  second) in length containing  $10^{12}$  photons. As shown in FIGURE 1, the LCLS will have a peak brightness  $10^{10}$  times greater than any existing X-ray source on Earth, including all existing third-generation synchrotron X-ray sources. This extreme brightness will be produced using a 150 m long undulator (located in the last third of the SLAC Linac) and electron bunch compression. Using a single X-ray pulse from the LCLS, it will be possible to carry out X-ray scattering (speckle) studies on single biological macromolecules, such as proteins, without the need to crystallize them. This advance is particularly important for membrane-bound proteins, which are notoriously difficult to crystallize. One potential application of the LCLS relevant to Earth sciences is the structural study of nanominerals (mineral particles between 1 and 100 nm in diameter). Such particles are abundant in Earth's atmosphere and in soil and aquatic environments at Earth's surface, where they interact with the atmosphere, aqueous solutions, and environmental contaminants. The structures of nanoparticles of all types, particularly their surface structures, are currently poorly understood, and very few experimental methods can yield this type of information. Another exciting application of the LCLS is in the emerging field of femtochemistry (i.e. the study of chemical reactions at the femtosecond time scale, which is the time scale on which chemical bonds break and reform). Molecular vibrations occur on somewhat longer time scales, and thus the extremely short pulses from the LCLS can be used to observe, in "snap-shot" fashion, these ultrafast transformations and their dynamics. Using "pump-probe" techniques, which involve excitation of a molecule using an appropriate femtosecond optical laser followed by measurement of an X-ray spectral feature of the molecule sensitive to struc-

tural change, it will be possible to follow the pathways of chemical reactions, including reaction intermediates, in a way that has heretofore not been possible. Detailed descriptions of these and other types of unique experiments planned for the LCLS can be found at the following URL: <http://www-ssrl.slac.stanford.edu/lcls/science.html>.

A suite of instruments for exploiting the unique scientific capabilities of the LCLS will result from the LUSI (LCLS Ultrafast Science Instruments) project at SLAC, which is scheduled to start in 2007. Assuming success in funding, the LUSI project will initially build four instruments over a five-year period. Two will be optimized for hard X-ray studies of ultrafast dynamics at the atomic level. A third will be optimized for hard X-ray coherent imaging of nanoparticles and large biomolecules, and a fourth will utilize soft X-rays from the LCLS to study magnetic structures and surface chemistry. This suite of instruments will complement other planned instruments at the LCLS that will be directed toward atomic and plasma physics.

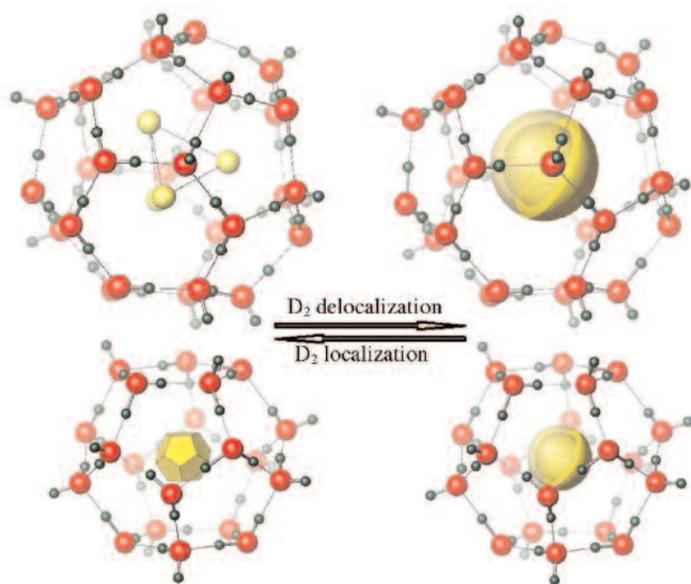
A second X-ray free-electron laser (TESLA) is planned for construction at DESY in Hamburg, Germany (see TABLE 1 on page 13), with commissioning scheduled for 2012. As shown in Figure 3 of Brown et al. (2006, this issue), TESLA will produce an average spectral brightness comparable to that produced by the LCLS. A description of some of the science planned for the TESLA facility can be found at [http://xfel.desy.de/science/stiroundtablemeetingjune2004/index\\_eng.html](http://xfel.desy.de/science/stiroundtablemeetingjune2004/index_eng.html) and <http://www.desy.de/pr-info/desyhome/html/presse/fotos/xfel/index.en.html>.

The challenge to the next generation of Earth scientists is to conceive and implement new classes of experiments at the LCLS and TESLA that will provide unique information on Earth materials and processes. Given the unique characteristics of these X-ray free-electron lasers, it is likely that at least some of these experiments will focus on ultrafast dynamics of chemical reactions and physical transitions (such as phase transitions and melting) controlling Earth's processes.

## NEW CAPABILITIES FOR NEUTRON SCATTERING

Neutrons possess unique properties, which make them an indispensable and complementary structural and spectroscopic probe. For example the neutron's sensitivity to hydrogen is particularly important in the Earth sciences, since hydrous minerals are implicated in many important surficial and internal processes, such as water cycling in the mantle (Jacobsen et al. 2004). Hydrogen-bonded networks are also responsible for the formation of ice and for building polyhedral cages around guest molecules to form solid clathrate hydrates. Clathrates, stabilized at high pressures and low temperatures, trap guest molecules such as methane and hydrogen, which are important for energy storage and recovery (Lokshin et al. 2004). Neutron scattering is the only structural probe sufficiently sensitive to hydrogen (and deuterium) to address questions of occupancy in the cages of the clathrates (FIG. 3). A recent experiment by Lokshin et al. (2004) used the deuterium isotope rather than hydrogen to avoid the undesirable contributions from  $^1\text{H}$  incoherent scattering. The study revealed that the  $^2\text{H}$ -guest occupancy can be reversibly changed by variation of pressure and temperature and that the maximum density of deuterium in the clathrates is higher than the value in most metal hydrides being considered as hydrogen-storage materials. Neutrons reveal not only the composition of the clathrates but also the interactions important in stabilizing them.

Neutron experiments are “flux hungry,” requiring samples of many  $\text{mm}^3$  to obtain data leading to the structure models shown in FIGURE 3. The need to obtain data on smaller samples is driving the development of ever more powerful neutron sources and continual instrument improvement to make the most of every neutron. Developments include improved area detectors with wider coverage, neutron focusing using monochromators, neutron guides, and most recently, adaptation of Kirkpatrick-Baez focusing optics utilized by the synchrotron radiation community. Many of the latest developments in instrumentation, and their application to Earth science research, were summarized in a series of presentations at the Second General Assembly of the European Union of Geosciences (EUG), Vienna, Austria, 25–26 April 2005. NESE (Neutrons at the Frontier of Earth Sciences and Environment) was one of a series of conferences organized jointly by European, American, and Japanese scientific institutions with a strong affiliation to neutron scattering ([http://neutron.neutron-eu.net/n\\_nmi3/n\\_networking\\_activities/n\\_nese](http://neutron.neutron-eu.net/n_nmi3/n_networking_activities/n_nese)).

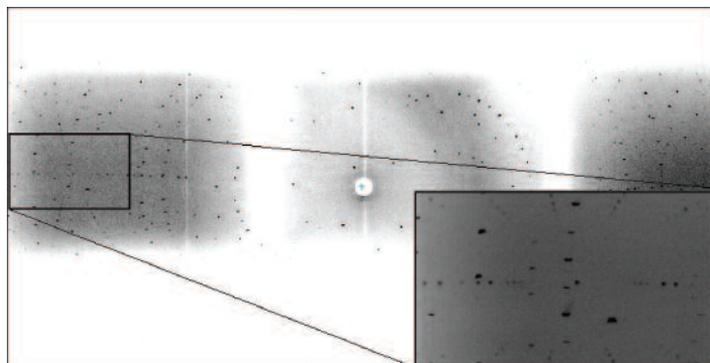


**FIGURE 3** Structural views of the distribution of  $\text{D}_2$  guests (yellow) in the large (top) and small cages of solid clathrate hydrates as a function of temperature determined using neutron scattering. Below 50K (left), four guest  $\text{D}_2$  molecules are localized in a tetrahedral cluster in the large cage, while in the small cage one  $\text{D}_2$  molecule is statistically distributed over 20 positions. At higher temperature (right), the  $\text{D}_2$  molecules rotate more freely, yielding a nearly spherical density distribution inside the cages. Larger red spheres represent oxygen atoms and the smaller dark green ones represent hydrogen atoms. REPRODUCED FROM LOKSHIN ET AL. (2004).

As with X-rays, focusing is a technique used to concentrate and direct a neutron beam onto a small area. The micro-capillary optics first developed for X-rays can be adapted to focus neutrons but often lead to considerable divergence. An alternative method developed by the group of Gene Ice at ORNL uses Kirkpatrick-Baez neutron super mirrors, again adapted from earlier work with X-rays (<http://www.ornl.gov/info/awards/cf/cfcitations/cfbios/ice.shtml>). Neutron focusing is used to improve spatial resolution and lower detection limits in neutron-based analytical methods. Beams as small as  $90\ \mu\text{m} \times 90\ \mu\text{m}$  have recently been produced in trials at the Chalk River reactor, Canada. With further optimization of the optics and the promise of at least an order of magnitude increase in flux provided by the Spallation Neutron Source, we may be close to “routine” neutron crystallography on samples of a size comparable to those now used with sealed-tube X-ray sources. This should

produce new scientific advances with small mineral samples, including those held in environmental chambers under high pressure.

The current state-of-the-art in studies of small crystals using neutrons is represented by the VIVALDI diffractometer (Very-Intense Vertical-Axis Laue Diffractometer; Chung et al. 2004) (<http://www.embl-grenoble.fr/groups/instr/instruments/finder.html>) at Institut Laue-Langevin (ILL, Grenoble, France), which routinely collects data at ambient and low temperatures on crystals with edge dimensions of about  $150\ \mu\text{m}$  (Cole et al. 2001). This facility is well suited to small crystals, rapid chemical crystallography, reciprocal-space surveys, and studies of structural and magnetic phase transitions. In its first years of operation, VIVALDI produced gains in data collection rates of up to 100 fold over conventional diffractometers. The advantages of the large-solid-angle Laue technique can also be implemented in high-pressure crystallography (FIG. 4). Early results from diamond anvil cells (DAC) developed by the Carnegie Institution of Washington, USA (Xu et al. 2002; Xu et al. 2004), and the Laboratoire Léon Brillouin, Saclay, France, (Goncharenko et al. 1995) groups suggest that with some design parameter changes it will soon be possible to carry out neutron scattering studies on samples of a size ( $150\ \mu\text{m} \times 150\ \mu\text{m} \times 50\ \mu\text{m}$ ) close to that associated with DAC high-pressure studies in individual investigator laboratories.



**FIGURE 4** Laue diffraction patterns from a 0.5 mm natrolite sample in a moissanite anvil cell:  $\phi = 65^\circ$ , exposure time 1 hour. TAKEN FROM MCINTYRE ET AL. (2005)

FIGURE 4 shows a neutron diffraction pattern taken from a natrolite crystal in a “panoramic” moissanite anvil cell from the Carnegie Institution of Washington (Xu et al. 2002). On close inspection we identify three diffraction patterns—one from the natrolite sample and two from the two tips of the conical moissanite anvils. Each pattern was indexed, and the data were integrated for normal single-crystal data analysis. The structure of natrolite refined well, with all coordinates agreeing within three estimated standard deviations with previously published neutron diffraction data (McIntyre et al. 2005); this result demonstrates that full crystallographic investigation in a pressure cell is quite feasible using the white-beam neutron Laue technique. This situation will improve dramatically when coupled with neutron focusing. The next generation of high-pressure devices may have large CVD-grown diamond anvils. This will complete the synergy between synchrotron-based high-pressure work and new capabilities being developed for neutron scattering (Yan et al. 2002).

VIVALDI is part of a wider program at the ILL dubbed the “Millennium Project,” instigated to upgrade the optics and detection systems on several components of its “instrument park.” This has led in many cases to factors of two, or better, gains in overall performance. Of particular interest to the

powder and single-crystal scattering community is the high-resolution powder diffractometer, Super D2B, in which powder samples of only several hundred milligrams are sufficient to provide high-resolution diffractograms. The large unit cell diffractometer D19 will be fitted with large area detectors, which will allow routine data collection on small crystals.

Exemplary of the new generation of neutron diffractometers optimized for small samples will be DRACULA at ILL, which will be the world's fastest Diffractometer for Rapid ACquisition over Ultra Large Angles (<http://www.ill.fr/dif/AlanHewat/>). Large solid-angle detectors will provide the increased sensitivity required for the study of small single-crystal or powder samples. As detector technology advances, CCD-based detectors coupled to white neutron beams promise even larger gains (<http://www.ill.fr/dif/AlanHewat/BCA-April-2005.pdf>).

Currently the world's most intense pulsed neutron source, ISIS, at Rutherford Appleton Laboratory in the UK, continues to add capabilities for more rapid data collection and work on smaller samples. A new target station nearing completion (<http://www.ts-2.isis.rl.ac.uk>) is designed to complement the existing suite of instruments on target station 1, with the new instruments designed to take advantage of the higher resolution and high intensity, colder (longer wavelength) neutron beams. The long wavelength (2–20 Å) neutron instruments tend to employ longer flight paths (20–100 m) and are optimized for higher resolutions. For Earth and environmental scientists, the new instrument suite will probably include capabilities for ultras-small-angle neutron scattering to bridge the nanometer-micrometer regime in studies of inorganic-organic interactions, complex inorganic-organic assemblies, surfaces and interfaces, and nucleation behavior.

Structural complexity—in the form of very large unit cells, phase coexistence, subtle superlattices and distortions, or expanded length scales—is important in Earth science research. Increasingly this complexity is being observed at non-ambient conditions. Especially when light elements such as hydrogen are involved, the highest possible resolution is required for ambient and non-ambient *in situ* studies. Existing synchrotron X-ray diffractometers offer excellent resolution ( $\Delta d/d \sim 10^{-4}$ ), and neutron diffractometers with comparable or better resolution and good data rates are being proposed. While resolution was not considered important at the time of construction of high-pressure neutron diffraction capabilities at the PEARL beamline at ISIS, technical developments have made resolution an important consideration in these studies, and a high-pressure beamline is being proposed in the next round of instrument construction for the ISIS Second Target Station. Magnetic investigations, including studies of systems with small moments, requiring high flux, will also be highlighted.

The Spallation Neutron Source (SNS) being built in Oak Ridge, Tennessee, by the US Department of Energy is designed to operate initially at 1.4 MW and to provide the most intense pulsed neutron beams in the world (Fig. 5). Construction began in 1999 and will be completed in 2006 with a suite of instruments covering the range of interests for condensed matter scientists ([http://www.sns.gov/users/instrument\\_systems/index.shtml](http://www.sns.gov/users/instrument_systems/index.shtml)). A similar facility is being constructed at the JAERI/Tokai site, about 130 km northeast of Tokyo, Japan, with an anticipated first beam in April 2008.

The capabilities of the instrument suite at SNS will mirror those available in Europe, with an initial emphasis on neutron scattering for research related to the Earth sciences. The increased flux will be used for high-resolution powder diffraction and time-resolved studies. Construction of new

facilities allows for progress on a “green field site,” along with continued improvement and optimization based on accumulated experience with existing instruments. For the high-pressure community, several decades of steady improvement in pressure capability, detector sensitivity, and accumulated community experience is being utilized in the construction of the world's first dedicated high-pressure instrument, the Spallation Neutron and Pressure (SNAP) beamline. This instrument, and others being proposed at ISIS, will allow the study of the structural and dynamic properties of materials under extreme conditions, such as those found in the deep Earth and other planetary interiors. A suite of high-pressure devices will cover the range of pressures (0.1–100 GPa) of interest to members of the Earth and materials science communities who are engaged in solving problems ranging from the formation and stability of gas clathrates at the low end of the pressure scale, to core-mantle interactions and planetary interiors at the more extreme conditions. The outer planets in our solar system are composed mostly of ice at very high pressures. Very-high-pressure phases of ice are currently poorly understood, and the SNAP diffractometer may enable new understanding of the mineralogy and petrology of non-terrestrial planets.



**FIGURE 5** Artist's rendition of the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory, USA. Also shown is the location of the Center for Nanophase Materials Science, one of five new nanoscale science research centers in the US.

The SNAP beamline is inspired, in part, by the success of high-pressure programs at X-ray sources, where flexible optics have led to versatile instruments adaptable to user needs as scientific opportunities arise. The SNAP instrument is designed to integrate recent progress in the design of high-pressure cells with flexible optics, including recently developed focusing methodologies. It is also optimized for the collection of single-crystal data while maintaining capabilities for powder diffraction.

Other SNS instruments available at the time of commissioning in 2007 will include a high-resolution powder instrument capable of stroboscopic diffraction studies with a time resolution of 0.5 milliseconds or better. This instrument will allow detailed, time-resolved investigations of a wide range of metal-oxide displacive phase transitions. Time-resolved experiments will also be possible on the small-angle instrument, with applications for contrast variation studies of colloidal particles, including their precipitation and ripening (Duits et al. 1991; Janßen et al. 1997; Vrij 2003). The SNS engineering materials diffractometer, as well as those already in operation at other neutron facilities such as ILL, LANSCE (Los Alamos Neutron Science Center)

and ISIS, will incorporate greatly improved capabilities for mapping localized stresses. In situ measurements to investigate how stresses change the behavior of real rocks will also be possible.

## US NANOSCALE SCIENCE RESEARCH CENTERS

Earth's near-surface environment, including the troposphere, contains enormous quantities of nanometer-scale particles (one to 100 nm in diameter), which are produced by both abiotic and biotic processes. These particles play major roles in chemical and biological processes affecting the biogeochemical cycling of elements and the transport of environmental contaminants and plant nutrients; they also affect the quality of the air we breathe (Hochella 2002). Nanogeoscience, which focuses on the geochemistry and mineralogy of natural nanoparticles and nanometer-sized features on mineral surfaces, is an emerging field in the Earth sciences. Nanogeoscience has developed over the past five years in response to the realization that natural nanoparticles have properties, such as chemical reactivity, that can be quite different from those of bulk materials of the same compositions (Banfield and Navrotsky 2001). The more general fields of nanoscience and nanotechnology have developed over the past decade in order to gain an understanding and take advantage of the unique properties of nanomaterials and their applications in modern technology and medicine. As a result of the growing interest in nanoscience, the US Department of Energy, Office of Basic Energy Sciences, provided funding in 2003 to establish five nanoscale science research centers (see Table 1 in Brown et al. 2006, this issue, for a listing of these centers, their locations, and the techniques they will make available). These centers are currently under construction and will be available to users beginning in 2006–2007. They will provide

research facilities for the synthesis, processing, and fabrication of nanoscale materials and have been collocated with existing user facilities such as the Advanced Light Source and National Center for Electron Microscopy at LBNL (Molecular Foundry), the Advanced Photon Source at Argonne National Laboratory (Center for Nanoscale Materials), the National Synchrotron Light Source (Center for Functional Nanomaterials) and the Spallation Neutron Source at ORNL (Center for Nanophase Materials Sciences). This collocation will provide state-of-the-art characterization facilities. These emergent nanoscience facilities should have a significant impact on nanogeoscience research. Detailed descriptions of each of these facilities can be found at [www.sc.doe.gov/bes/NNI.htm](http://www.sc.doe.gov/bes/NNI.htm).

## CONCLUSIONS

The impact of the current generation of national user facilities on Earth science research has been dramatic. The next generation of beam facilities will emphasize higher brightness, and consequently greater spatial and time resolution. Tighter integration of these beam facilities with sample preparation and new environmental cells will allow unprecedented experiments under conditions characteristic of Earth and other bodies.

## ACKNOWLEDGMENTS

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## PEOPLE BEHIND MINERAL NAMES: HUBERT PUTZ, A KEEN OBSERVER AND A STAR STUDENT

The newly described species putzite,  $(\text{Cu}_{4.7}\text{Ag}_{3.3})_{\Sigma 8}\text{GeS}_6$ , named after Hubert Putz, was found in old dumps near the Rosario vein, Capillitas mining district, Catamarca Province, Argentina. It can be considered the copper-dominant analogue of argyrodite,  $\text{Ag}_8\text{GeS}_6$ . This dry account provides the essentials about the new discovery, but falls short of giving insight into what led to it.

Hubert was born on March 12, 1973, in Bad Ischl, Austria. By the age of 8, he had started collecting fossils near his home in the foothills of the Calcareous Alps. Only later did he develop a keen interest in minerals; he first began to specialize in quartz in its many manifestations. He acquired his first books on mineralogy at age 16, and at age 18, he attended his first mineral fair. By that time, he had built up a respectable collection of 300 or 400 specimens, with little representation from ore minerals, ironically enough.

In 1994, he began his studies at the University of Salzburg and obtained a MSc degree in 2000. During this period, he took classes in mineralogy, ore microscopy, and economic geology, given by Professor Werner H. Paar. By this stage, his mineralogical interests had shifted to ore minerals. He became fascinated in combining the traditional approach of reflected-light microscopy with modern analytical techniques. For his Diploma thesis, he studied gold mineralization in a long-abandoned mining district in the Province of Salzburg. He studied the microparagenesis of the complex auriferous ores, evaluated their conditions of formation using fluid inclusions, and published his results in *Mineralogy and Petrology*.

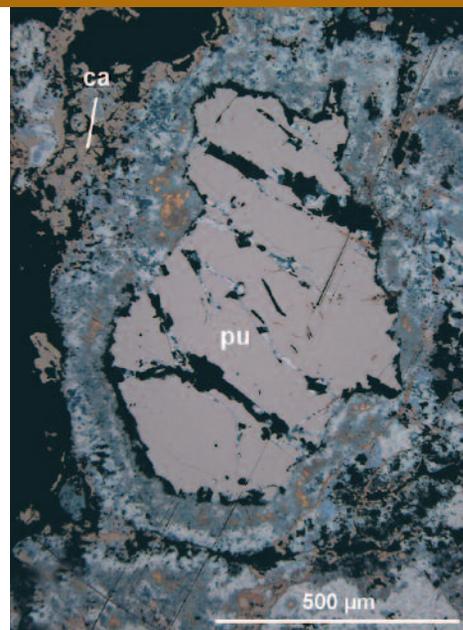
In 2000, he was asked by his thesis advisor, Professor Paar, whether he would consider a «risky» three-year project on ore districts in



Putzite is named after Hubert Putz, presently a doctoral candidate in the Department of Geography, Geology and Mineralogy of the University of Salzburg. Hubert discovered the mineral during the preparation of his PhD thesis on the Capillitas district, and was the first to document a significant Ge anomaly in the region.

Argentina, with the support of grants by the Austrian Science Foundation. He jumped at the opportunity, a decision that was a turning point in his young career. He accompanied his advisor on many expeditions to remote mining locations in Argentina and later Bolivia. He became quite fluent in *castellano*. He thus started a PhD thesis on the Farallon Negro Complex of Catamarca in Argentina, with special emphasis on ore mineralogy and conditions of formation of low- and high-sulfidation epithermal mineralization at Capillitas. He anticipates finishing his thesis in 2005 or early 2006. He has participated in several national and international conferences, at which he presented the results of his various discoveries on ore deposits.

Hubert's collection now contains close to 5000 specimens, which represent over 1000 different species. With his knowledge and keen sense of observation, he has discovered at least three germanium-bearing species that are new to science. The most abundant of these was named putzite in his honor by his advisor (Paar et al. 2004), in recognition of his



Putzite (pu) rimmed by a fine-grained matrix of chalcocite, sphalerite, chalcopyrite, and covellite. This matrix is associated with catamarcaite (ca).

PHOTO COURTESY OF THE CANADIAN MINERALOGIST

special accomplishments in the field of ore mineralogy and his discovery of a Ge metallogenic province in this historically famous mining district. A second mineral is named catamarcaite,  $\text{Cu}_6\text{GeWS}_8$ , and the third is possibly the Ge-dominant analogue of stannoidite. Keep up the good work, Hubert!

I acknowledge the major contribution of Werner H. Paar to this profile.

Robert F. Martin  
(bobm@eps.mcgill.ca)

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BALTIMORE, MARYLAND 23-26 MAY 2006

## Abstract Submissions: 1 March 2006

(Submitted not later than 2359 UT online)

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Housing: 13 April 2006 • Pre-Registration: 20 April 2006

For more information about the meeting, or for details about sessions, speakers, and deadlines, check the AGU Web site at [www.agu.org/meetings/sm06](http://www.agu.org/meetings/sm06).



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## Société Française de Minéralogie et de Cristallographie

### FROM THE PRESIDENT



As the incoming president of the Société Française de Minéralogie et de Cristallographie (SFMC), I am delighted that we have joined this new publishing initiative. The SFMC brings together French scientists in the fields of mineralogy and crystallography, but also petrology and geochemistry. It is therefore natural that we have become a partner in *Elements*. The first issues have been exciting, and our members are going to benefit greatly from this partnership.

The SFMC coordinates and promotes scientific activities in the field of mineralogy (s.l.) in France. We organize meetings on focused scientific topics and we sponsor symposia and special sessions at national and international conferences. We also play an active role in training and in organizing short courses, which gather large numbers of students every year. We award annually the "prix Haüy-Lacroix" to the best PhDs in the field. Of course, our activities are in French when they are addressed to the national community. But we also hold joint meetings with other societies at the European level. The last one, in November 2005, was co-organized with the Sociedad Española de Mineralogía, and was held in French, English, and Spanish!

The SFMC also shares the responsibility for publishing the *European Journal of Mineralogy*, a journal probably familiar to most of you, with three other European societies, the Deutsche Mineralogische Gesellschaft, the Società Italiana di Mineralogia et Petrologia, and now the Sociedad Española de Mineralogía.

Our internal publication, the "Bulletin de Liaison", is the link between our members. Joining *Elements* will give us more visibility on the international scene and help us strengthen our links with other societies.

Catherine Mével  
President

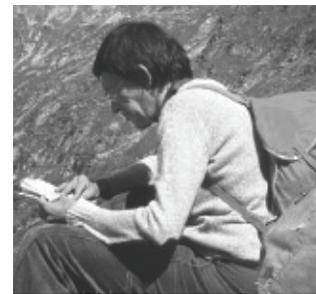
### IN MEMORIAM



#### Olivier Jaoul (1944–2005)

We are saddened to report that Olivier Jaoul of the Université Paul Sabatier in Toulouse, France, died on November 15. Born in Neuilly sur Seine in 1944 and trained as a physicist in the laboratory of Jacques Friedel, Jaoul was recruited into geophysics by Claude Froidevaux at the Laboratoire de Géophysique et Géodynamique Interne at the Université Paris Sud in Orsay. In 1997, he moved his laboratory to Toulouse and joined the Laboratoire d'Étude des Mécanismes et Transferts en Géologie. In both Orsay and Toulouse, Jaoul's laboratory pioneered new experimental techniques to study plastic deformation and atomic diffusion in mantle minerals; this research was always characterized by care in the design and execution of the experiments. The acquisition of new data for atomic diffusion led Jaoul and his colleagues to formulate a new model for creep in olivine via multicomponent diffusion. Olivier was a master teacher, at both the undergraduate and graduate levels, with a refined pedagogical style which was didactic and philosophical, typical of a person whose first foreign language was Greek. He enjoyed teaching young students, not only in the laboratory, but also in the field. Lastly, Olivier was a warm and generous colleague who leaves a long list of protégés and collaborators in his scientific and educational legacy. He is survived by his wife, Martine, and their two children, Nicolas and Delphine.

R.C. Liebermann, F. Béjina,  
and J. Ingrin



#### Alain Weisbrod (1936–2005)

Professor Alain Weisbrod sadly died on October 18, 2005 after a long illness. He taught at the School of Geology (ENSG) and carried out research at the Centre de Recherches Pétrographiques et Géochimiques (CNRS) in Nancy.

After defending a doctoral thesis in 1970 on metamorphism in the Cévennes (France), he founded, together with Bernard Poty and Jacques Touret, a research team focused on the equilibrium between fluids and minerals. He spent one year at the Geophysical Laboratory (Carnegie Institute of Washington) to study the influence of water and manganese on the garnet–cordierite equilibrium. He calibrated experimentally the K/Na geothermometer for fluids in equilibrium with alkali feldspars. His scientific interests also included fluid immiscibility and fluid mixing during the formation of ore deposits based on fluid inclusion studies; alpine metamorphism; oceanic hydrothermal metamorphism; boron geochemistry in hydrothermal fluids; and tin, tungsten and porphyry copper deposits.

Alain Weisbrod combined field work, the acquisition of analytical and experimental data, and thermodynamic modelling. He was among the first to introduce thermodynamics in the Earth sciences through his book *Basic Thermodynamics for Mineralogists and Geologists*, which was first published in French in 1963 and subsequently translated into Russian in 1966 and English in 1967. He introduced many Earth scientists to this approach, which was very new at the time.

Jean Dubessy

## PRIX HAÛY-LACROIX TO ROSKOSZ



Each year the SFMC awards the "Prix Haüy-Lacroix" to a young scientist for the quality of his PhD in the fields of mineralogy, geochemistry, petrology, or materials science. In 2005, it was awarded to Mathieu Roskosz, who did his PhD at the Centre de Recherche Pétrographiques et Géochimiques in Nancy, with M. Toplis and P. Richet as advisors. Dr Roskosz is now a postdoctoral fellow at the Geophysical Laboratory, Carnegie Institution of Washington, USA. The following is a summary of his research on the nucleation and crystallization of silicate melts.

The crystallization of silicate liquids is central to many processes of geological and industrial interest. Nevertheless, crystal nucleation and growth rates in silicate melts are still poorly predicted, mainly because microscopic factors that control them are not yet precisely understood. This study has concentrated on determining these factors at temperatures below the solidus, but above the glass transition ( $T_g$ ). Synthetic glasses in the system  $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2$  have been heat-treated at one atmosphere, time and temperature being the two experimental variables. Experimental charges have been characterized over a wide range of scales (SEM, TEM, electron microprobe, X-ray diffraction and Raman spectroscopy) in order to determine textures, compositions, and unit-cell parameters of the crystalline phases.

The first phase to crystallize is generally one of the solidus phases. However, some metastable minerals also precipitate. At the temperatures studied, crystals are never stoichiometric and are generally enriched in Ca but have Si/Al approaching that of the parent liquid. With increasing temperature, the transition to phase compositions expected near the solidus takes place via a gradual change of Si/Al, this change being a systematic function of  $(T-T_g)$ . Thus, provided that  $T_g$  of the parent composition is known, the compositions and the microstructures of devitrified materials may be predicted. These features may be explained by the relative mobilities of the different cations, the mobility of the network modifier Ca becoming several orders of magnitude greater than that of the network formers Si and Al around  $T_g$ . Thus, during nucleation at large degrees of supercooling, the low mobility of Al and Si restricts the compositional field explored during random fluctuations in composition in the liquid, and thus restricts compositions of crystal nuclei. Furthermore, the enrichment of the nuclei in low-field-strength cations decreases the number of strong bonds (i.e. Si-O) that need to be reordered in order to reach a crystalline structure. These mechanisms may explain why observed nucleation rates are systematically larger than those predicted by the classical nucleation theory.

Previous considerations have empirically related crystal growth rate to the viscosity of the liquid. With this in mind, we have observed two different behaviors. When the Si/Al ratios of minerals and melt are the same, the temperature dependence of crystal growth rate (i.e. the activation energy) is identical to that of viscous flow. In the case of congruent crystallization, this may be explained because crystal growth and viscous flow have a common microscopic origin involving the breaking and formation of Si-O bonds. When the Ca content varies between melt and crystal, growth rate and viscous flow are still related because the Ca mobility is rapid relative to the characteristic life time of an Si-O bond. Conversely, when the Si/Al ratios of crystals and liquid are different, the activation energy for crystal growth is significantly lower than that of viscous flow of the parent melt. To explain this observation, it is proposed that coupled diffusion of Al and Ca lowers the frequency of Al-O bond breaking, which then becomes the rate-limiting process.

## SFMC AND SEM MEET IN BIARRITZ

### "HYDROTHERMALISM, AQUEOUS SOLUTIONS AND MINERALOGY"

The SFMC and SEM (Sociedad Española de Mineralogía) jointly organised a scientific meeting entitled "Hydrothermalism, aqueous solutions and mineralogy" held on November 3 and 4, 2005. The organizers were Prof. Fernando Rull (SEM) and Jean Dubessy (SFMC). This meeting was held in Biarritz, France, near the border between the two countries. The first of the four sessions was mainly devoted to the study of aqueous solutions with different spectroscopic techniques (vibrational), and especially those possible now with the light beam FAME available at ESRF and dedicated to Earth sciences. The second session was devoted to thermodynamic modelling in inorganic and organic systems. Solid solutions were especially considered. In addition, transport phenomena such as diffusion were also addressed. Experimental work and numerical models were always linked to natural case studies. Several papers in the

third session were focused on submarine hydrothermal systems and ore deposits. The interesting case study of the Rio Tinto mine with its acidic sulfate fluids was emphasized. Finally, the fourth session dealt with acid gas storage from an experimental point of view.

As is often the case for small meetings, discussions were always lively after each presentation. It is worth noting that speakers used mostly their native language, with slides in English. This demonstrates that several languages can be used in scientific meetings, especially those involving neighbouring countries.

Finally, SEM and SFMC have decided to strengthen their links and have proposed a scientific meeting to be held jointly with the Portuguese mineralogical society in the spring of 2007.

SFMC information:  
[www.sfmc-fr.org](http://www.sfmc-fr.org)

Contact: [neuville@ipgg.jussieu.fr](mailto:neuville@ipgg.jussieu.fr)

## HUBERT CURIEN, CRYSTALLOGRAPHER AND MINERALOGIST



A special meeting will be held on **MAY 19, 2006**, at the Ministry of Research in Paris, Amphithéâtre Poincaré, in memory of Hubert Curien, who passed away suddenly on February 6, 2005 at the age of 80.

He was professor of crystallography at the Laboratoire de Minéralogie-Cristallographie of Paris. Former president of the Société Française de Minéralogie et de Cristallographie, he had major responsibilities in Europe and in France, when he was Minister of Research. As a crystallographer and mineralogist, Hubert Curien had interests ranging widely from solid-state physics to mineralogy. This meeting will be dedicated to the major advances in which he was involved in the 1950s and 1960s, in the fields of Compton scattering, ionic conductivity, and the radiation effects on ionic crystals. In mineralogy, his contributions included the determination of the structure of several minerals, the early development of the electron microprobe, and the significance of structural defects. A new mineral was named after him—curienite,  $\text{Pb}(\text{UO}_2)_2\text{V}_2\text{O}_8 \cdot 5\text{H}_2\text{O}$ . Several colleagues who worked with him, as well as younger researchers active in these areas, will participate to this meeting, which will show how fascinating it is to conduct research outside classical tracks.

For further information, contact: Georges Calas ([calas@lmc.jussieu.fr](mailto:calas@lmc.jussieu.fr)) or Bernard Capelle ([capelle@lmc.jussieu.fr](mailto:capelle@lmc.jussieu.fr))



www.eag.eu.com

## European Association for Geochemistry

### EAG NEWS AND ANNOUNCEMENTS

*Chemical Geology* is the official journal of the European Association for Geochemistry. Members of the EAG can subscribe to *Chemical Geology* at discount member rates. *Chemical Geology* publishes top-rate manuscripts in all areas of geochemistry as well as regular special issues on emerging or hot topics in our field. The two most recent special issues are:

**New Results in Fluid and Silicate Melt Inclusion Research – XVII European Current Research on Fluid Inclusions (ECROFI XVII)**, edited by Csabo Szabó, Alfons M. van den Kerkhof and Robert J. Bodnar (volume 223, issues 1–3, pages 1–178). This special issue presents 15 papers collected from the seventeenth biennial meeting of the European Current Research on Fluid Inclusions (ECROFI XVII), which was held on June 5–9, 2003 at the Eötvös University, Budapest, Hungary. Topics in this special issue include (1) new analytical and experimental techniques, (2) application of silicate melt inclusions to the study of igneous petrology, (3) the behavior of fluids during metamorphic processes, and (4) metal transport and deposition.

**Shallow-water Hydrothermal Venting**, edited by R.M. Prol-Ledesma, P.R. Dando and C.E.J. de Ronde (volume 224, issues 1–3, pages 1–182). This issue brings together contributions from several groups working on subaqueous hydrothermal activity occurring at shallow depths and is based on a thematic session at the 2003 annual meeting at the Geological Society of America. The focus of this volume is on vents in water less than 200 m deep, as deeper vents are dominated by vent-obligate fauna. Shallow-water vents provide accessible geological and chemical settings for studying the interaction of hydrothermal fluids with unconsolidated sediments, seawater and basement rocks. For example, in contrast to deeper vent sites, the lower pressures and consequently lower water-boiling temperatures lead to subsurface deposition of metals. The 11 papers published in this special issue present a survey of the current research being performed to characterize and better understand these unique geochemical systems.

### UPCOMING EAG-SPONSORED SESSIONS

The EAG is co-sponsoring two sessions at the 2006 European Geosciences Union (EGU) General Assembly, which will be held on April 2–7, in **Vienna, Austria**. The meeting website is <http://meetings.copernicus.org/egu2006>.

**Session GMPV15:**  
*Precipitation and dissolution of carbonates – mechanisms, kinetics, solid solution formation and fractionation effects*

Co-convenors: Martin Dietzel and Stephan Kohler

The precipitation and dissolution behavior of carbonates plays a major role in hydrogeochemistry and the formation of sediments and sedimentary rocks. Mechanisms and kinetics are strongly related to the physicochemical conditions of the respective systems, specific reactions at the solid–liquid interface and mineralogy. Element and isotope signatures of carbonates can be used to decipher, for example, formation conditions, sources of compounds, evolution of past climate and carbonate fluxes in anthropogenic environments.

Areas to be covered in this session include (1) carbonate crystallization and solid solution formation; (2) aspects and techniques for studies of precipitation kinetics; (3) incorporation of trace elements; (4) carbon, oxygen, and metal isotopic fractionation and implications for e.g. natural aquatic systems; and (5) applications for carbonate precipitation and dissolution studies.

**Session CL036:**  
*Physical and chemical weathering at diverse temporal and spatial scales*

Convenor: K. Burton

Co-convenors: J. Gaillardet, S. Gislason, and F. von Blanckenburg

This symposium will focus on past and present physical, chemical and biological processes of weathering, from nano- to global scale. In particular we welcome field, experimental and modelling studies of weathering processes in soil, catchment areas and deltas and the coupling of climate, hydrology, vegetation, lithology, topography and weathering. New elemental and isotopic tracers of past and present weathering rates are especially welcome as well as studies of how chemical fluxes have varied through time as a function of tectonics and climate.

### CALL FOR GEOSCIENTISTS INTERESTED IN INTERFACE MINERALOGY

Although crystal growth is a central theme in many areas of geosciences, it is surprising that there is relatively little interaction between the “crystal-growth community” and the “geosciences community”. The preoccupation for producing pure and large crystals for crystallographic study and for industrial applications has gradually distanced the crystal growers from the mineralogists for whom solid solutions, impurities, and the problems of crystal growth in experimentally difficult geological environments are the norm. However, there is much we can learn from the crystal-growth community, considering the current geoscience interest in areas such as the mechanisms of crystal growth and dissolution at a molecular level, mineral replacement and reequilibration in a fluid phase, self-assembly of nanoparticles, crystallisation in extreme conditions such as in space, etc. The development of high-resolution in situ observation systems has also contributed considerably to a better understanding of crystal growth mechanisms.

In an attempt to bring together experts in crystal growth and geoscientists interested in phenomena associated with mineral growth and dissolution processes in nature, we have initiated a series of occasional workshops using the title “Interface Mineralogy”. The first of these was held in Sendai, Japan, from 28 to 30 September 2005. The programme of the meeting can be downloaded from [www.congre.co.jp/ima2006/index\\_e.html](http://www.congre.co.jp/ima2006/index_e.html).

Further meetings are planned, and geoscientists interested in participating and in expanding on our embryonic project are welcome to contact Katsuo Tsukamoto and Andrew Putnis ([ktsuka@mail.tains.tohoku.ac.jp](mailto:ktsuka@mail.tains.tohoku.ac.jp) and [putnis@nwz.uni-muenster.de](mailto:putnis@nwz.uni-muenster.de)).

## EUROPEAN GEOCHEMICAL NEWS BRIEFS

During the past several months, three different European networks aimed at improving our understanding of various geochemical processes have been organized and funded. These networks are described below.

### Weathering Science Consortium

The WUN Weathering Science Consortium is a UK Natural Environment Research Council (NERC) funded grouping of three UK universities in partnership with government agencies and international institutions. This consortium is led by Steven Banwart of the University of Sheffield and includes Dr. Liane Benning of the University of Leeds and Vala Ragnarsdottir of the University of Bristol. In partnership with Pennsylvania State University and other associates in the USA, the consortium hopes to establish a global understanding of how weathering is affected by natural and human activities.

Research carried out by the consortium will develop new methods adopted from nanotechnology and molecular biology to improve the management of the whole life cycle of soil – from its formation to its depletion. The scientists will track how plant energy captured from sunlight is directed through roots and soil fungi to extract the elements that nourish ecosystems.

The four university partners are all members of the Worldwide Universities Network (WUN). The consortium seeks to integrate international weathering science and funding with a USA bid for a NSF-supported Critical Zone Exploration Network (CZEN). The CZEN will integrate field, laboratory and modelling research and many other activities from a wide range of natural environments on the Earth.

Additional information is available at [www.wun.ac.uk/wsc](http://www.wun.ac.uk/wsc)

### Mineral Surface Science for Nanotechnology (Mission) – Marie Curie Early Stage Training Network

This Marie Curie Early Stage Training Network, based at the University of Bristol (UK), aims to understand reaction mechanisms and structures of organic and biogenic molecules on mineral surfaces, and at the same time provide graduate students with specific scientific and technological competencies in nanoscale surface research. MISSION has been conceived to underpin the revolution underway in science and technology, based on the ability to measure, manipulate and organize matter on the nanoscale (0.1 to 100 billionths of a meter). This project has been funded to provide up to eight three-year PhD fellowships.

A crucial feature of MISSION is that it will extend interdisciplinary collaborations in nanotechnology beyond the more usual physics/chemistry grouping to incorporate mineralogy and Earth sciences. Thus, the MISSION project as a whole will help to integrate diverse techniques in investigating a single, but highly complex, theme of scientific and technological importance. MISSION is led by Vala Ragnarsdottir and includes contributions from Terence McMaster, Walther Schwartzacher, Geoffrey Allen, and Keith Hallam. It will bring together five scientists with complementary and overlapping expertise in a contemporary research field, which will require the best inter- and cross-disciplinary interactions.

Further information on this network can be found at [www.bris.ac.uk/mcest-mission](http://www.bris.ac.uk/mcest-mission)

### Mineral Surface Reactivity (MIR) – Marie Curie Early Stage Training Network

The Mineral–fluid Interface Reactivity (MIR) Early Stage Training Network (EST) brings together five research groups located in Germany, France, Spain, Denmark, and the United Kingdom and offers structured training for students pursuing PhD and Master's degrees. Funds have been provided for a total of 15 graduate fellowships. This training program is intended to produce young scientists to fill needs in industry, consulting engineering firms, regulatory agencies, and local governments, in addition to academic positions.

The core objective of the MIR network is the training and professional development of young scientists in the state-of-the-art field of mineral–fluid reactivity. Mineral–fluid reactions, including dissolution, adsorption, nucleation, precipitation, and solid-solution formation, are key to solving such pressing issues as the development of smart coatings on body

implants or drug-delivery systems, minimizing risk in groundwater extraction, safer pesticide application, optimizing CO<sub>2</sub> sequestration, assuring drinking water quality, safe storage of radioactive waste products, and minimizing pollutant transport. The ability to accurately predict reactions in these systems is of utmost importance for municipalities and for industry in Europe today, but it relies on a detailed description of mineral–fluid reactions.

The MIR network is led by Eric Oelkers (Toulouse) and includes Susan Stipp (Copenhagen), Andrew Putnis (Munster), Manolo Prieto (Oviedo) and Liane Benning (Leeds).

Please send any potential items for inclusion in future 'EUROPEAN GEOCHEMICAL NEWS BRIEFS' to Eric Oelkers ([oelkers@lmtg.obs-mip.fr](mailto:oelkers@lmtg.obs-mip.fr))




The Bavarian Geoinstitute at the University of Bayreuth  
invites applications for a

**Full Professorship (W3) in Experimental Earth Sciences**

The position is available from April 1, 2007. We are looking for an internationally renowned scientist from the fields of experimental geochemistry, experimental geophysics and/or mineral physics. Applicants should have a broad experience in development and application of experimental techniques at high and extreme pressures. Research activities should make a major contribution towards understanding the Earth's interior and the terrestrial planets. The successful applicant will be expected to participate in teaching, particularly in the education of graduate students, in a planned Master Course "Experimental Geoscience" and in basic courses for geocology students. Part of the teaching will be in English.

In addition to a Ph. D., applicants should have appropriate experience in research and teaching. Candidates must be less than 52 years old upon appointment. Women and handicapped people are especially encouraged to apply.

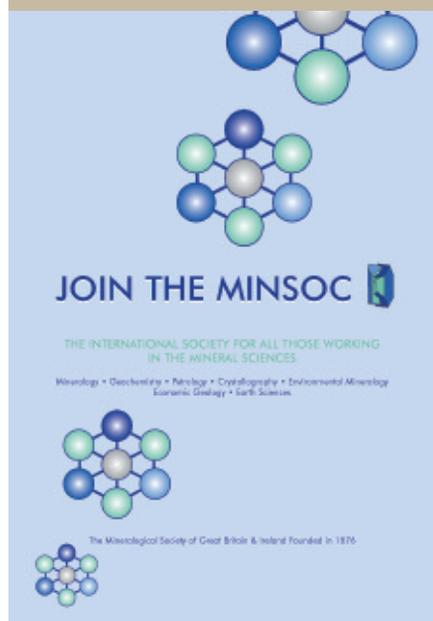
Applications, accompanied by a curriculum vitae, publication list, copies of university certificates, a statement on teaching experience and an outline of proposed research should be sent before April 24, 2006 to the Dekan der Fakultät für Biologie, Chemie und Geowissenschaften der Universität Bayreuth, 95440 Bayreuth, Germany.



www.minersoc.org

## Mineralogical Society of Great Britain and Ireland

### WHY JOIN THE MINSOC?



Over the last 25 years there has been an unprecedented expansion in analytical techniques for investigating minerals and rocks. As a result new subjects have been born, such as mineral physics, environmental mineralogy and modern geochemistry. The trend is for investigations to go from micro- to nano-scales, which are providing new understanding of the composition, behaviour and structure of minerals. This in turn is leading to new uses for them. If you already have a career in the mineral sciences or are just starting out on one, join the Society today and contribute

to the development of your science through active participation in the Society's meetings, special interest groups, training workshops and publications. The Society has links with a number of national and international organizations, which are together pushing forward the frontiers of the mineral sciences. The Society's three journals are of a very high standard and are highly respected throughout the world. Member benefits have never been greater, and yet in real terms we are offering the Society's lowest subscription rate ever for ordinary membership at just £55 per year.

Membership is open to everyone with a professional interest in the mineral sciences. Members are generally qualified at least to degree level in a relevant science. The Society welcomes geologists, chemists, biologists, physicists and minerals industry professionals. The Society particularly encourages student membership. Membership options are flexible, and the choice of journals included in the membership package now includes an online-only option for *Mineralogical Magazine* and *Clay Minerals*. All members receive free access to the essential research tool *MINABS Online*, which contains over 120,000 abstracts of papers in the mineral sciences built up over the past two decades. The preferred membership entry level is as an Ordinary or Student Member. If you, or a colleague, are interested in joining, send for a free information pack and application form to: The Executive Secretary, 41 Queen's Gate, London SW7 5HR, United Kingdom or e-mail [info@minersoc.org](mailto:info@minersoc.org)

### THE SOCIETY'S SPECIAL INTEREST GROUPS THE APPLIED MINERALOGY GROUP



Dave Lowry is Research Manager and founder of the Stable Isotope and Atmospheric Laboratories at Royal Holloway University of London. Here, as Chair of the Society's Applied Mineralogy Group, he follows the development of the group from its beginnings in ore microscopy to interests in a host of applications, from pollutant minerals to forensic mineralogy.

The Applied Mineralogy Group (AMG) was formed in 1963 as a 'Committee on Ore Mineralogy' to meet a rapid expansion of interest in the chemistry, crystal structure and optical properties of ore minerals. In the early days, it focused on hosting summer schools in ore microscopy. The group maintains close links with the Commission on Ore Mineralogy (COM) and the Mineral Deposits Studies Group (MDSG) of the Geological Society, but has widely diversified its activities to include new and expanding areas of applied mineralogy.

The interests of the group now include applications of mineralogical techniques in the fields

of industrial mineralogy, archaeology, metallurgy, pollutant minerals and forensic mineralogy in addition to the traditional field of ore mineralogy. The group is also involved in the applications of techniques specific to analysis of minerals; for example, it has recently organized conferences or symposia on the uses of microbeam, laser and isotopic techniques for understanding mineral formation and composition.

The group is involved in the organisation of two forthcoming major three-day conferences. The first is the Fermor Meeting on Minerals, Magmas and Megastructures organised with MDSG and the Volcanic and Magmatic Studies Group and to be held in London in September 2006. Next year is the Frontiers in Mineral Sciences 2007 meeting in Cambridge organised jointly by the Society, MSA and MAC. AMG has put forward suggestions for scientific sessions related to the petrogenesis of the North Atlantic Igneous Province and its PGE mineralization.

Each year we normally recruit two new members to the committee. If your interests fall within the broad field outlined above and you would like to be part of this group promoting applied mineralogy, then please contact the group secretary, Chris Hayward ([chay02@esc.cam.ac.uk](mailto:chay02@esc.cam.ac.uk)), or David Lowry ([d.lowry@gl.rhul.ac.uk](mailto:d.lowry@gl.rhul.ac.uk)).

David Lowry

### ANNOUNCEMENT

#### Mineralogical Society 2006 Medals Last Call for Nominations

Nominations are being sought from members of the Mineralogical Society for the 2006 award of the Society's Schlumberger Medal. This award is given to recognize scientific excellence in mineralogy and its applications by a key worker. Evidence of such excellence should be in the form of published work by a currently active scientist. Nominations are also sought from members for the 2006 Max Hey Medal, awarded to recognize existing and ongoing research carried out by a young scientist (normally under 35 years at the time of the award). Nominations with supporting evidence should be sent to the Mineralogical Society, 41 Queen's Gate, London SW7 5HR, UK, to arrive by 21 April 2006. Recipients of the awards need not be members of the Society. Full details on the awards and requirements for nomination can be found on the website [www.minersoc.org](http://www.minersoc.org) under the awards button.

## MARK WELCH TO BECOME THE NEXT EDITOR OF MINERALOGICAL MAGAZINE



Dr Mark Welch of the Mineralogy Department of the UK Natural History Museum is to succeed Prof. Simon Redfern in June 2006 as principal editor of this renowned international journal of the mineral sciences. The Society's Council is delighted to endorse this appointment as Mark has already played a very active role in the journal in recent years, both as an associate editor and structures editor. In addition he has acted as guest editor on

highly acclaimed collections of thematic papers for both *American Mineralogist* and *Mineralogical Magazine*. He is also UK representative on the IMA Commission on New Mineral Names. Mark is a keen researcher and teacher and has authored 48 peer-reviewed publications on mineralogy and crystallography. Since 1999 he has been an affiliate lecturer in crystallography and mineral sciences at Cambridge University. His main area of research concerns the structural and chemical responses of hydrous minerals at high temperature and pressure, including cation ordering, hydrogen bonding and phase-transition behaviour. Mark is a scientist of international standing and brings a great breadth of editorial experience to this post. The Society wishes him well in developing the journal in the years ahead.

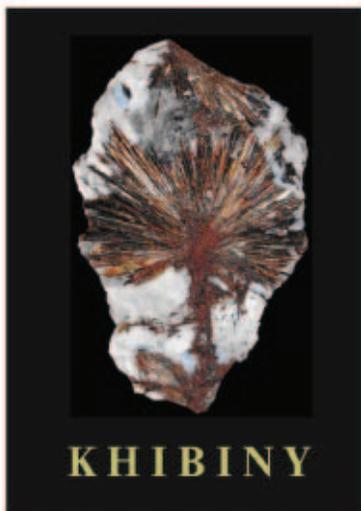
## Mineralogical Society Training Workshops in Electron Probe Microanalysis (EPMA) in Mineralogy For Postgraduates and Advanced Researchers



For full details and how to register for these 'hands on' training workshops go to <http://www.minersoc.org/education>

Natural History Museum, London

Course Dates  
20-23 June 2006  
7-10 November 2006



V.N. Yakovenchuk, G. Yu. Ivanyuk  
Ya. A. Pakhomovsky and Yu. P. Mem'shikov

### KHIBINY

English Edition edited by F. Wall — The Natural History Museum, London, UK

Just published in English, this stunning book on the rare minerals of one of the world's most outstanding mineral provinces is a must for all serious mineralogists and collectors. The book describes the geology, petrography and chemistry of over 70 mineral localities from the Khibiny Massif, a nepheline syenite complex in Russia's Kola Peninsula north of latitude 67°30'. 436 mineral species are described, of which 88 were found in Khibiny for the first time in the world.

#### SPECIAL OFFER TO READERS OF ELEMENTS

As a special limited period offer to readers of *Elements*, the MinSoc is offering this book for only £82.00 plus postage and packing. This offer is 50% off the list price. Please get your order to the Society before the end of March 2006. After that date it will be available at the list price of £164.00 plus P & P and at discounted prices to MinSoc members and affiliated societies.

Publisher: Laplandia Minerals Ltd. in association with the Mineralogical Society

Format: A4 hardback, 448 pages, 772 original microprobe analyses, 592 original colour and SEM-BSE photos, 342 references

ISBN 5-900395-48-0 ©2005 Laplandia Minerals

Special Offer Price: £82.00 valid until 31 March 2006

#### HOW TO ORDER

Please send your cheque in sterling pounds or credit card details to the Mineralogical Society, 41 Queen's Gate, London SW7 5HR, UK or fax +44 (0)20 7823 8021 or e-mail [admin@minersoc.org](mailto:admin@minersoc.org). Remember to add postage and packing UK £7.20, Europe £15.95 and rest of the world £25.00



www.clays.org

## The Clay Minerals Society



### IN MEMORY OF JOE WHITE

Dr. Joe Lloyd White, Emeritus Professor of soil chemistry and mineralogy, Purdue University in West Lafayette, Indiana, USA, died on October 5, 2005, at age 83. He was born and raised in Oklahoma, the son of Claud and Alta (Denney) White. He received both his BS and MS in soil science at

Oklahoma State University, and was awarded his PhD in soil chemistry and mineralogy from the University of Wisconsin under the direction of Prof. M.L. Jackson. He joined the Department of Agronomy at Purdue in 1947 and retired in 1988, after a distinguished 41-year career.

His career began in the post-World War II era when new techniques and equipment were emerging to advance scientific knowledge and discovery. He recognized the value of new advances in chemistry, such as infrared spectroscopy, and was a pioneer in bringing them into agronomy research and environmental molecular science. His research was at the forefront of soil chemistry and mineralogy, which led to significant improvements in environmental stewardship and improved crop productivity. Dr. White developed a highly successful collaboration with Dr. Stan Hem in the Pharmacy Department where these ideas were applied to research in pharmacy, including studies on antacids, adjuvants for vaccines, antiperspirants, and lake dyes, all based on hydroxy-aluminum compounds.



Joe (left) and Prof. Jim Ahlrichs demonstrating how an organic molecule interacts with a clay surface (ca. 1960).

He was active in dozens of professional societies, including The Clay Minerals Society, the Soil Science Society of America, the American Chemical Society, and the American Society of Agronomy. Throughout his illustrious career, he received many awards and honors both in the United States and in many other countries. Among these, he was appointed Distinguished Member of The Clay Mineralogy Society in 1990 and he received the Pioneer in Clay

Science Award in 1994, honoring his lifetime scientific achievements through interdisciplinary research.

Dr. White published over 190 papers on a wide range of topics. Even though he "officially" retired in 1988, he remained very active, attending scientific meetings and participating in research group meetings. He served on the council of The Clay Minerals Society and was a Fellow of the Mineralogical Society of America, the American Society of Agronomy, the Soil Science Society of America, the American Institute of Chemists, the Royal Society of Chemistry, and the American Association for the Advancement of Science.

Joe White was devoted to his family. On May 29, 1945 he married Wanita Irene Robertson. They celebrated their 60<sup>th</sup> wedding anniversary last May, with their five children and their families, including eleven grandchildren and one great-grandson. Joe White was a gentle intellectual and spiritual giant who was loved by all who knew him. His humble and kind spirit will remain in our hearts forever.

### ANNUAL MEETING REMINDER

Make your travel arrangements NOW!

Plan to attend the

## 43<sup>rd</sup> ANNUAL MEETING of The Clay Minerals Society

to be held jointly with  
the French Clay Group

(Groupe Français des Argiles), June 3–7, 2006,  
Oléron Island, France

Located off the French coast in the Bay of Biscay, south of La Rochelle and north of the Gironde Estuary, Oléron is the second largest French island (after Corsica). Linked to the mainland by a bridge, the island and its beaches are a popular destination offering many opportunities: sailing, beach activities, local specialties, and delicious seafood.

Convenor: Sabine Petit

Website: [www.c2s-organisation.com/gfacms06](http://www.c2s-organisation.com/gfacms06)

E-mail: [sabine.petit@hydrasa.univ-poitiers.fr](mailto:sabine.petit@hydrasa.univ-poitiers.fr)

Tel.: 33-(0)5-49-45-37-56

Workshop: Polymer-Clay Nanocomposites, by Faiza Bergaya and Kathleen A. Carrado

### TRAVEL

#### By train

Several Paris-Poitiers direct connections per day by high-speed train (TGV):

- from/to Paris airport (Roissy, Charles de Gaulle – TGV railway station), travel duration: 2h 30m
- from/to Paris downtown (Montparnasse railway station), travel duration: 1h 30m to 1h 50m

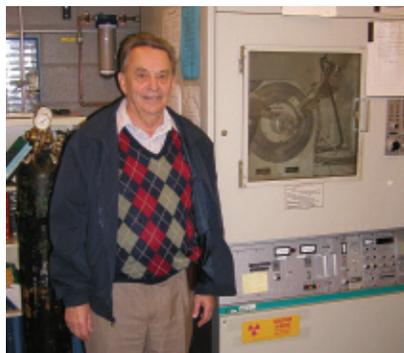
To check the TGV schedules and prices and to book a ticket online, please consult the SNCF website: [www.sncf.fr](http://www.sncf.fr)

#### By plane

A daily London (Stansted)-Poitiers connection

[www.poitiers.cci.fr/aeroport/lignes/ryanair\\_londres.asp](http://www.poitiers.cci.fr/aeroport/lignes/ryanair_londres.asp)

This should be a fantastic opportunity to visit the famous clay localities of France (Montmorillon and Nontron). Note that the island is located just off the Bordeaux region of France, home to beautiful 17<sup>th</sup>-century castles and full of history. Plan to bring your family and stay for an early summer vacation.



### Victor Drits

visited the Bob Reynold's Laboratory at Dartmouth College, after Bob's memorial service in June, 2005.

**3<sup>rd</sup> EUROPEAN WORKSHOP IN CLAY GEOSCIENCES****CHARACTERIZATION OF SOLID-WATER INTER-FACE REACTIONS OF METALS AND ACTINIDES ON CLAYS AND CLAY MINERALS****March 14–15, 2006****University of Jena (Germany),  
Geoscience Department**

The 3<sup>rd</sup> European Workshop of Clay Geosciences (ACTINET workshop) will focus on improving our understanding of solid-water interactions and will be of particular interest to those dealing with remediation of contaminated sites. Water-solid reactions are of widespread interest because they are fundamental to a large number of geochemical processes. Our understanding of processes that occur at the solid-water interface has dramatically increased over the past several years. This is largely due to the application of new or improved experimental techniques. Many of these techniques will be covered, including time-resolved laser fluorescence laser spectroscopy, which allows the in situ measurement of the binding form of trivalent actinides, and use of synchrotron radiation sources, which enables in situ identification of the species at mineral surfaces in the presence of reacting solutions.

**ORGANIZED BY****Dr. Andreas Bauer**

Institut für Nukleare Entsorgung  
Forschungszentrum Karlsruhe  
Postfach 3640  
D-76021 Karlsruhe  
e-mail: bauer@ine.fzk.de  
Tel.: ++ 49 (0) 7247/82-6293  
Fax: ++ 49 (0) 7247/82-3927

FOR REGISTRATION SEE:  
[www.igw.uni-jena.de/ahgeol/  
Workshops/actinet.html](http://www.igw.uni-jena.de/ahgeol/Workshops/actinet.html)

**STUDENT MEMBERSHIP**

The Clay Minerals Society offers a reduced student membership rate of only \$15 per year, entitling students to:

- a subscription to *Clays and Clay Minerals*<sup>®</sup>, a leading journal in the field of clay science
- online access to *Clays and Clay Minerals*<sup>®</sup>
- for North Americans, free membership in AIPEA, the international clay organization
- awards for best student papers and posters presented at the annual meeting
- the Source Clays Project, which provides homogenous clay samples for research purposes
- member discounts on publications of CMS and MSA
- discounts on selected books of interest to clay scientists from other publishers
- the most up-to-date information on the society's latest publications and registration materials for the annual CMS conference, including workshops and field trips
- free subscription to *Elements*

**The Marilyn and Sturges W. Bailey Distinguished Member Award** is the highest honor of The Clay Minerals Society (CMS). It is awarded solely for scientific eminence in clay mineralogy (in its broadest sense) as evidenced primarily by the publication of outstanding original scientific research and by the impact of this research on the clay sciences. This award is not restricted to members of CMS.

**The Pioneer in Clay Science Lecture** recognizes research contributions that have led to important new directions in clay minerals science and technology.

**The George W. Brindley Lecture** recognizes a clay scientist who will infuse the society with new ideas, someone who is both a dynamic speaker and involved in innovative research. Dr. Brindley himself approved the concept of

**CMS NEWS AND REMINDERS****Website Update**

Papers from the October 2001 issue of *Clays and Clay Minerals*, a special issue on baseline studies of the Clay Minerals Society Source Clays, are now available free to all. The decision to make these freely available was made at the June 2005 council meeting, and curators of the Society's Source Clays, which are housed at Purdue University, will now be able to direct purchasers of samples to the papers online. Go to [www.clays.org/sourceclays/SourceClaysCCM.html](http://www.clays.org/sourceclays/SourceClaysCCM.html)

**Journal Highlights**

The December 2005 issue of *Clays and Clay Minerals* includes the following papers of interest from a session entitled "Microbial Impacts on Clay Transformation and Reactivity," held during the 41<sup>st</sup> annual meeting of the Society (2004).

Sarah E. Hepinstall, Benjamin F. Turner, and Patricia A. Maurice  
**Effects of siderophores on Pb and Cd adsorption to kaolinite**

Nidhi Khare, Carrick M. Eggleston, and David M. Lovelace

**Sorption and direct electrochemistry of mitochondrial cytochrome C on hematite surfaces**

Jin-wook Kim, Yoko Furukawa, Hailiang Dong, and Steven W. Newell

**The role of microbial Fe(III) reduction on smectite flocculation**

Evgenya Shelobolina, Sam M. Pickering, and Derek R. Lovley  
**Iron cycle bacteria from industrial clays mined in Georgia, USA**

A full list of the contents in this and other issues is available at <http://gscem.highwire.org/> or at <http://www.ingentaconnect.com/content/cms/ccm>.

**Student Research and Travel Grant Applications due March 20**

The Clay Minerals Society annually awards several grants of up to \$2500 through its student research grant program.

**Purpose**

The research grant program is designed to provide partial financial support to graduate students doing master's and doctoral research in clay science and technology.

**Selection Criteria**

Applications will be judged on a competitive basis. The qualifications of the applicant and the objectives, design, and financial need of the project are evaluated. Applicants selected will be nominated by a five-member CMS committee and approved by the CMS Council. The grant awarded for the best proposal each year is named the Robert C. Reynolds Jr. Research Award. **Awards will be made by September 1, 2006.**

**Travel grants** can be requested for up to \$500 per grant for intracontinental travel or \$1000 for intercontinental travel to attend the CMS meeting. Funds can be used to pay for: (1) meeting registration at the student rate, (2) field trip(s) that are part of the meeting, (3) CMS banquet ticket, (4) premeeting workshop, (5) travel, and (6) lodging.

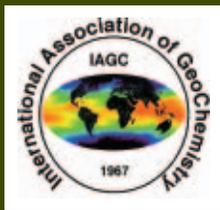
[www.clays.org/home/awards/  
HomeAwardsAndGrantsSRG.html](http://www.clays.org/home/awards/HomeAwardsAndGrantsSRG.html)

**Awards Nominations Solicited for the March 1 Deadline**

the lecture, and the speaker should deliver a lecture that Brindley himself would applaud.

**The Marion L. and Chrystie M. Jackson Mid-Career Clay Scientist Award** recognizes mid-career scientists for excellence in the contribution of new knowledge to clay minerals science through original and scholarly research. The awardee is to be within the ages of 39 and 60.

Nominations for all awards consist of a cover letter from the nominator, a curriculum vitae, and at least two supporting letters. Details for electronic submission are at: [www.clays.org/home/  
awards/HomeAwardsAndGrants.  
html](http://www.clays.org/home/awards/HomeAwardsAndGrants.html)



www.iagc.ca

## International Association of Geochemistry

### MEETINGS AND MORE MEETINGS!

The past year has seen IAGC take a prominent role in the organization or funding of several meetings, including the Goldschmidt Conference in Moscow, Idaho, USA; GES-7 ("Geochemistry of the Earth's Surface") in Aix-en-Provence, France; AIG-6 ("Applied Isotope Geochemistry") in Prague; and the GSA (Geological Society of America) meeting, Salt Lake City, Utah, USA.

The year 2006 promises to be more of the same, with ISEG-7 ("International Symposium on Environmental Geochemistry") in Beijing (25–30 September), the Goldschmidt Conference in Melbourne, Australia (27 August–1 September) and GSA in Philadelphia. (22–25 October). The IAGC hopes to be at all these meetings, so look out for our booth and enter the free draws!

To contact IAGC, write to us at [iagc@granite.mb.ca](mailto:iagc@granite.mb.ca) or visit our website [www.iagc.ca](http://www.iagc.ca). Alternatively, we still accept snail-mail at P.O. Box 501, Pinawa, Manitoba R0E 1L0, Canada.

**Mel Gascoyne**  
Business Office Manager and Newsletter Editor

### COUNCIL DISCUSSIONS AT GSA

The gathering of six council members and one working group chairman at the Geological Society of America meeting in Salt Lake City allowed an informal meeting of IAGC officers on 17 October, 2005. Some highlights of the meeting were:

- A report on the operation of the IAGC business office for the last 6 months was tabled.
- *Applied Geochemistry* is healthy, receiving about 21 papers per month and with a higher page count (~2500 for 2005).
- Two IAGC-sponsored sessions (on oil and gas exploration, and trace elements in the environment) were held at the GSA.
- An IAGC booth was set up and staffed by the business office manager at the GSA; 35 new members were signed up.
- Future support for Goldschmidt 2006 was discussed.
- IAGC awards will be given at Goldschmidt 2006.

More details can be found in the next IAGC Newsletter (December 2005).

**Russ Harmon**  
Vice President, IAGC

### WORKING GROUP ACTIVITIES

#### *Geochemical Training in Developing Countries Working Group*

On October 18, 2005, the United States and India signed a major science cooperation agreement. Under the terms of this agreement, a cooperative project is being planned whose objective will be to develop harmonious, ecologically sustainable, economically viable and people-participatory strategies for the management of environments in the coastal zones of India. This will involve not only designing

preparedness systems for environmental problems expected to arise, but also to roll back the existing environmental degradation. The cooperation is expected to involve R&D and training in the fields of data assimilation and technology transfer. The working group will use remote sensing to monitor riparian communities, stream flow, hyperspectral imaging of soils, biogeochemical processes, ecosystem modeling and soil moisture.

**U. Aswathanarayana**  
WG Chairman

### IAGC SUPPORT FOR MEETINGS

IAGC provides funding support for meetings organized by its working groups and for other requests on a case-by-case basis. Recently, Council decided that specific requirements must be met by those applying to IAGC for funding support:

- The business office will provide meeting organizers with advertising material, and the organizers will ensure that each participant receives an IAGC information leaflet and membership application form.
- The Executive Editor of the Association's journal, *Applied Geochemistry*, has 'first right of refusal' regarding the publication of the conference

proceedings. The organizer of each meeting shall, upon receipt of the notice of meeting support from IAGC, contact the Executive Editor of *Applied Geochemistry* regarding publication of the meeting proceedings or a subset of conference papers before considering any other publication alternative. Failure to do so will result in withdrawal of IAGC financial support for the meeting.

Applications for support should be sent to the appropriate working group chairman (see website for topics and addresses).

**Attila Demény**  
IAGC Secretary

### CALL FOR NOMINATIONS FOR AWARDS

The IAGC is pleased to invite nominations for the following awards, to be given in 2006:

- The VERNADSKY MEDAL, for a distinguished record of scientific accomplishment in geochemistry
- The EBELMEN AWARD, to a geochemist of particular merit and outstanding promise who is less than 35 years old at the time of nomination
- CERTIFICATES OF RECOGNITION, for outstanding scientific accomplishments in geochemistry, for excellence in geochemistry-related teaching or public service, or for meritorious service to the IAGC or the international scientific community

Nominations can be made only by IAGC members in good standing. They should be submitted before 31 January 2006 to the IAGC Business Office (Box 501, Pinawa, Manitoba R0E 1L0, Canada). For the Vernadsky Medal and the Ebelmen Award, a letter of nomination must be accompanied by a curriculum vitae and list of the nominee's publications. Four (Vernadsky) or three (Ebelmen) letters of support should be provided. Two of these letters must be from IAGC members in good standing, and not more than two may be from persons residing in the same country as the nominee.

**Jan Kramers**  
Chairman, IAGC Awards Committee

## FEATURE ARTICLE: GEOCHEMISTRY AND END-TRIASSIC EXTINCTION

The IAGC Secretary, Attila Demény, recently joined an IGCP Field Workshop to find geochemical evidence for the causes of the end-Triassic extinction in boundary sections of Hungary and Austria. He describes some of the workshop activities below.



In the last 25 years, since the hypothesis that a bolide impact led to the demise of dinosaurs was first put forward, the study of large biotic extinctions has become an increasingly interdisciplinary endeavour. A case in point is the flurry of research on the end-Triassic, which marks one of the Big Five extinctions. IGCP 458, a five-year project devoted to the Triassic–Jurassic boundary events, held its 5<sup>th</sup> Field Workshop in September 2005 in Tata (Hungary) and Hallein (Austria).

A full day of presentations and four days of field excursions, split between Hungary and Austria, were attended by 44 scientists from 13 countries. Oral papers and posters reflected the diversity of approaches used to unravel causes and effects of the environmental and biotic crises some 200 million years ago. Geochemical methods play an increasingly important role in this detective work, as extinction studies are no longer an arena for paleontologists alone.

Among the geochemically oriented papers, Anthony Cohen reported on how short-term changes in Sr and Os isotopic ratios in seawater, preserved in the sedimentary rock record, are used to monitor sudden changes in weathering rates. These changes are attributed to the climatic effect of coeval volcanism of the Central Atlantic Magmatic Province. Florian Böhm et al. also discussed the expected effect of CAMP volcanism, in the context of the demise of reefs and carbonate producers. Increased

delivery of Ca from weathering combined with prevailing low sea level could lead to alteration of the oceanic Ca budget and Ca isotopic composition.

One of the most intensively researched topics is stable isotope evolution across the Triassic–Jurassic boundary. Perturbations of the global carbon cycle and temperature maxima have been documented before on the basis of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  anomalies. New results appear to confirm and refine the isotopic patterns. The studied sections span the globe from Hungary (Attila Demény), through Italy and England (Cristoph Korte et al.) to Canada, USA and New Zealand (Ken Williford). The negative carbon isotope anomaly at the boundary was again demonstrated at high resolution from Hungary and using low-Mg shell carbonate from England, whereas new data from Canada suggest that it was followed by a large positive anomaly in the earliest Jurassic. Biomarker studies from a New Zealand section may provide new constraints for the extinction scenarios.

Interpretation of the isotopic signal is much debated. Methane release from gas hydrate dissociation, driven by volcanically induced climate warming, is one of the more popular models that needs further testing. Unlike the Cretaceous–Paleogene boundary, there is far less evidence for a possible impact at the

Triassic–Jurassic boundary, although the search continues. Larry Tanner reported a modest iridium enrichment at the T–J boundary in eastern Canada, although he proposed that both mantle-derived and extraterrestrial sources could be responsible for the PGE anomaly, and the multiple peaks may also bear evidence for diagenetic remobilization in mudrocks.

Group of participants on the Steinplatte summit, an uppermost Triassic reef complex.

crash of reef ecosystems, a prominent feature of the end-Triassic extinction.

A workshop of this size and format effectively promotes informal discussion among the participants. Credit for the smooth organization and



Close-up of a ~205 Ma-old coral reef. Corals were severely affected by the end-Triassic extinction.

Discussions that started in the conference room were continued at the outcrops. The field trips visited the Triassic–Jurassic boundary sections at Csővár (Hungary) and Kendlbachgraben and Tiefengraben (Austria), sites where new stable isotope data have been obtained recently. Literally, the high point was climbing to the top of Steinplatte (1869 m), arguably the world's most spectacular Late Triassic reef, in the Alps. It proved to be a prime location to discuss the

insightful leadership on the field trip goes to József Pálffy, Péter Ozsvárt and János Haas in Hungary and Leo Krystyn in Austria. The abstracts and field guide volume containing nearly 100 pages is a valuable source of information and can be downloaded from the project website at [www.paleo.cortland.edu/IGCP458](http://www.paleo.cortland.edu/IGCP458). József Pálffy, co-organizer of IGCP Project 458 is also thanked for contributing to this report.

**Attila Demény**  
IAGC Secretary

## UPCOMING MEETING OF INTEREST

A special session entitled “Isotopic and Chemical Approaches for Understanding the Sources, Transport, and Biogeochemical Cycling of Solutes in Aquatic Systems” will be held at the GAC-MAC 2006 annual meeting in Montreal, May 14–17, 2006. The session will address recent advances in the application of isotope ratios as biogeochemical and/or hydrological tracers in both freshwater and marine environments. More details can be found at <http://www.gacmac2006.ca>

**Moritz Lehmann**  
and **Ian Clark**



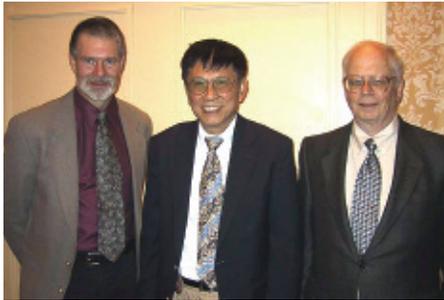
www.minsocam.org

## Mineralogical Society of America

### FROM THE PRESIDENT

#### News from the Annual Meeting

The MSA presence at GSA was strong this year, as usual. In addition to the well-attended technical sessions, we sponsored a short course entitled "Low-Temperature Thermochronology" (convened by Peter Reiners and Todd Ehlers), and gathered for the annual luncheon. The awards and lectures were highlights of the meeting:



2005 Roebling Medalist Ho-kwang (David) Mao with MSA president Robert Hazen (left) and citationist Charles T. Prewitt.

Ho-kwang (David) Mao received the 2005 Roebling Medal and presented the Roebling Lecture, "Four Decades of High-Pressure Mineralogy."

Robin P. Brett received the 2005 Distinguished Public Service Medal in absentia for his "extraordinary services to national or international science societies," which include the USGS, NASA, NSF, NAS/NRC, IUGG, and IUGS.

Tiziana Boffa Ballaran received the 2005 MSA Award and presented the MSA Award Lecture, "Local Strain Heterogeneity in Mineral Solid Solutions: The Relationship between Line Broadening in IR Spectra and Excess Enthalpy."

Robert Hazen gave the MSA President's Lecture, "Minerals, Molecular Selection, and the Origin of Life."



Left to right: 2005 MSA President Bob Hazen, 2005 MSA Award Recipient Tiziana Boffa Ballaran, and citationist Ross Angel.

The highly popular MSA Lecturer series has been expanded to include more institutions worldwide. Next year, two of the lecturers will visit a total of eight universities in Europe. We thank last year's lecturers, John Hanchar, Rod Ewing, and Bernie Wood, and look forward to the 2005–2006 talks: "Volcanoes in the Lab" and "Salts on Mars" by Penny King, "From Microscopic to Macroscopic" and "History Written in Stone" by Patrick O'Brien, "Subduction through the Transition Zone" and "High-Pressure Minerals in Meteorites" by Thomas Sharp.

### NOTES FROM CHANTILLY

□ The 2005 MSA elections were run, for the first time, on the Web. The 2006 president of the Society is John W. Valley, our 2006 vice president is Barb Dutrow, and in his second term as secretary is George Harlow. John M. Hughes, treasurer, remains in office, and the new councilors are Roberta Rudnick and Simon Redfern. They join the continuing councilors David London, Mickey Gunter, Ross John Angel, and Robert T. Downs. MSA thanks the outgoing councilors Barb Dutrow and Rebecca Lange for three years of dedicated service to the Society. A total of 709 ballots were received (28.5% of those eligible) by the August 1 deadline. This is the highest number of voters since 1995 when 713 members voted. This level of participation has been consistent for some time. Even in the early years of the Society (1920s–1930s) the number of voting members seldom reached 50%. Voting was more complex at that time because the fellows were on the ballot as well.

□ Accepting the recommendations of the respective award committees, the MSA Council has selected W. Gary Ernst as the 2006 Roebling Medalist, Daniel

Frost as the 2006 MSA Awardee, and Frank Spear as the 2007 Dana Medalist. The Distinguished Public Service Medal is biennial with no awardee for 2006.

□ The 2006 Kraus Crystallographic Research Grant recipient is Jason Bryan Burt for the study "Theoretical and experimental determination of potential sites for protonation in nominally anhydrous minerals," which will be conducted at Virginia Polytechnic Institute and State University. The 2006 Mineralogy/Petrology Research Grant recipients are Angelo Antignano for the proposal "Rutile, apatite, and zircon solubility in silicate-bearing fluids: Implications for HFSE and REE mobility in subduction zones," which will be carried out at the University of California, Los Angeles, and Gregory Dumond for the study "What are we dating?: Linking zircon growth to metamorphic reactions in high-pressure mafic granulites," which will be carried out at the University of Massachusetts–Amherst.

□ All 2004 and 2005 MSA members have been contacted by mail, electronically, or both about renewing their membership for



Left to right: 2006 MSA President John Valley receiving the MSA presidential gavel from 2005 MSA President Bob Hazen.

Last fall, I had the pleasure of writing to many of you in appreciation of your donations to MSA in 2005 and I look forward to writing more in the future. Our Society depends on the generous and dedicated members who give both time and money. This support provides the extra margin to enable special programs like student awards, the website, and the lecture program. Furthermore, in these uncertain times

when rapidly improving technology is reshaping the publication environment, MSA may need to call on its members to ensure the stability of *American Mineralogist* and our other important publications.

John W. Valley  
President

RECENTLY IN *AMERICAN MINERALOGIST*

2006. If you have not renewed your MSA membership, please do so. If you have not received a notice by the time you read this, please contact the MSA business office. You can also renew online at any time.

□ As of September 30, 2005, the total membership in the society was 2187, which represents a decrease of 87 from last year, mostly among regular members. 70% of MSA members subscribed to the journal in some form in 2005, which is up from 66% in 2004. There were 764 institutional subscriptions, a decrease of 27 from 2004, and part of a continuing decline since 1983.

□ With *The Lattice*, MSA would have included in the first issue after the annual meeting the secretary and treasurer reports that were presented at the MSA annual business meeting detailing the year's past events for the members. With the advent of *Elements*, it was decided that these would be posted online. They may be viewed on the MSA website by selecting "Officer Reports" under "The Society."

J. Alex Speer  
MSA Executive Director  
j\_a\_speer@minsocam.org

Up-to-date readers of *American Mineralogist* already know that 2005 was a terrific year for the journal, with many landmark papers, such as Cornelis Klein's presidential address about Precambrian banded iron-formations, Douglas Rumble's presidential address about atmospheric photochemistry, and a review paper by Papike et al. on comparative planetary mineralogy. The journal also had a special section in April about monazite geochronology and another in May/June that honored W.G. Ernst.

But even the most devoted reader probably doesn't know what a banner year this was for the

journal—in the midst of the upheaval of an office move, new software, new staff, new editors, and the launch of GeoScience-World (<http://ammin.geoscienceworld.org>), we published a total of 1972 pages, over a hundred more than last year and one of the largest totals ever. We also had more color pages than ever, well over 60 pages. In fact color in the journal in the last couple of years has increased 1200% because the more authors that want color, the more they can band together and share the costs.

Rachel Russell  
Managing Editor,  
*American Mineralogist*

## NEW MSA FELLOWS

The Society is pleased to announce and congratulate the following new Fellows:

Yong-Fei Zheng ♦ Donna Whitney ♦ Frederick J. Ryerson  
♦ Simona Quartieri ♦ Clark M. Johnson ♦ Reto Gieré  
♦ John FitzGerald ♦ Randall T. Cygan ♦ Joel Brugger  
♦ John Brodholt ♦ Lynn Boatner

## MSA 2006 ELECTION

The slate of candidates for the MSA Council elections is:

PRESIDENT  
**Barb Dutrow**

VICE PRESIDENT  
(one to be selected)  
**Jonathan Stebbins**  
**Peter Heaney**

TREASURER  
**John M. Hughes**

COUNCILLORS  
(two to be selected)  
**Jay Bass**  
**Klaus Mezger**  
**Jean Morrison**  
**John Parise**

**George E. Harlow** continues in office as secretary. Continuing councillors are **Ross John Angel**, **Robert T. Downs**, **Roberta L. Rudnick**, and **Simon A.T. Redfern**. Election materials will be available to MSA members in April in time for the voting deadline of August 1, 2006.

## Nominations Sought

Nominations must be received by June 1, 2006

The **Roebing Medal** is MSA's highest award and is given for eminence as demonstrated by outstanding published original research in mineralogy.

The **Dana Medal** recognizes continued outstanding scientific contributions through original research in the mineralogical sciences by an individual in mid-career.

The **Mineralogical Society of America Award** is given for outstanding published contribution(s) prior to the awardee's 35<sup>th</sup> birthday or within 7 years of the PhD.

The **Distinguished Public Service Medal** is awarded for distinguished contributions to public policy and awareness about mineralogical topics.

Society **Fellowship** is the recognition of a member's significant scientific contributions.

Mineralogical Society of America

Submission requirements and procedures are on MSA's home page: <http://www.minsocam.org/>

*The Mineralogical Society of America*

2007 Grants for

**RESEARCH IN CRYSTALLOGRAPHY,  
MINERAL PHYSICS OR CHEMISTRY,  
AND MINERALOGY**

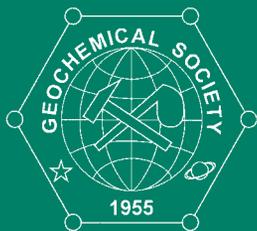
from the Edward H. Kraus Crystallographic Research Fund  
with contributions from MSA membership and friends

**STUDENT RESEARCH IN  
MINERALOGY AND PETROLOGY**

from an endowment created by MSA members



Selection is based on the qualifications of the applicant, the quality, innovativeness, and scientific significance of the research of a written proposal and the likelihood of success of the project. There are three US\$5000 grants with no restrictions on how the funds may be spent, as long as they are used in support of research. Application instructions and forms are available from the MSA home page, <http://www.minsocam.org>, or the MSA offices. Completed applications must be received by June 1, 2006.



<http://gs.wustl.edu>

## Geochemical Society

### NOTES FROM ST. LOUIS

#### Changes to the Board of Directors in 2006

Of the 17 positions on the Geochemical Society's Board of Directors, four members have rotated off in 2006. They are Judith McKenzie (ETH Zentrum), Michael Whittar (University of Victoria), Gilbert Hanson (Stony Brook University), and Harry Elderfield (University of Cambridge). Susan Brantley has stepped up as GS president, while Tim Drever has replaced Judith as past president. The four incoming members of the Board of Directors are:



**Marty Goldhaber – Vice President (2006–2007)**

Martin Goldhaber received his BSc in chemistry (1968) and PhD in geochemistry (1973), both from UCLA. After spending a year as a post doc at Yale, he joined the USGS in 1975. He is currently a senior scientist at the USGS, where he received the Department of the Interior's Meritorious Service Award and recently served a term as the chief scientist for geology. Marty has been a member of the

Geochemical Society since 1972 and has been involved in the Society in a number of roles, most recently as program chair. He is a fellow of the Geological Society of America and the Society of Economic Geologists. Marty has served on the editorial boards of *Economic Geology*, *American Journal of Science*, and *Geochimica et Cosmochimica Acta* (two terms) and has served on advisory boards for the Geological Society of America, the Ocean Drilling Program, NASA, and NSF. Marty's research interests have evolved during his career. His early work was on the biogeochemistry of sulfur in modern marine sediments. After joining the USGS, he applied these perspectives towards understanding the origin of sediment-hosted ore deposits. This interest in ore genesis led to a focus on large-scale crustal fluid flow processes that not only lead to the formation of some ore types, but also impact the modern environment by enriching shallow crustal rocks with potentially toxic constituents. His research then evolved into the study of the environmental impacts of these crustal flow processes. He is currently co-chief of a USGS project to map the inorganic and selected organic constituents in soils of the US, and together with the Canadian and Mexican geological surveys, all of North America.



**Mark McCaffrey – Organic Geochemistry Division Chairman (2006–2007)**

Mark McCaffrey received his BA in geological sciences (1985) from Harvard University, magna cum laude with highest honors, and his PhD in geochemistry (1990) in the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution joint program. Before he co-founded Oil Tracers LLC, Mark spent ten years at Chevron and Arco solving a variety of oil exploration and

production problems. Mark holds the titles of Registered Geologist in California, Professional Geoscientist in Texas, and Certified Petroleum

Geologist from the AAPG. He is a senior or co-author of 30 articles on petroleum exploration, reservoir management, oil biodegradation, hazardous waste remediation, paleoenvironmental reconstruction, and marine chemistry. Mark was the 1995 recipient of the Pieter Schenck Award from the European Association of Organic Geochemists for "outstanding work on biomarkers in relation to paleoenvironmental studies and petroleum exploration." In 1998, with project team members, Mark received the Arco Award of Excellence "for developing a new charge and migration model for the Brookian petroleum system, allowing improved charge risk assessment for prospects on the Central North Slope of Alaska." Mark was a 2001–2002 Distinguished Lecturer for the Society of Petroleum Engineers, and was the chairman of the 2002 Gordon Conference on organic geochemistry.



**Yaoling Niu – Director (2006–2008)**

Yaoling Niu is a professor of Earth sciences at Durham University, UK. He obtained a BSc degree in geology in 1982 (Lanzhou University, China), an MS degree in economic geology in 1988 (University of Alabama, USA), and a PhD degree in marine geology and geophysics in 1992 (University of Hawai'i, USA). Yaoling's research uses petrology and geochemistry as a means to understanding how the Earth works on all scales today and how it did in the

past. He has published over 60 refereed papers in leading Earth science journals. He has been honored with guest professorships by several Chinese universities (China University of Geosciences in Beijing, Northwest University in Xi'an, Nanjing University, and Peking University), and honored as an Outstanding Overseas Chinese Scientist by the Chinese National Science Foundation. He has recently taken the leadership as the chairman of the IUGS Commission on Solid Earth Composition and Evolution (SECE). Dr. Niu also serves as an executive editor of the *Chinese Science Bulletin* and is on the editorial board of *Earth Science Frontiers* and the *Geological Journal of China Universities*. (<http://www.dur.ac.uk/yaoling.niu/index.htm>)



**Andreas Luttgé – Director (2006–2008)**

Andreas Luttgé's research focuses on the processes that govern fluid–mineral or fluid–rock interactions from low-temperature conditions to the pressures and temperatures of the deep crust. He is particularly interested in the participation of microorganisms in these processes. His work includes various experimental and modeling techniques, which he applies to questions of mineral reactions in sedimentary basins, weathering, the fate of nanoparticles in the environment, atmospheric and global change, environmental pollution, hydrothermal systems, and the containment of radioactive wastes. Luttgé received his PhD in 1990 from the University of Tübingen (Germany), spent three years as a Humboldt fellow and associate research scientist at Yale University, and currently holds a double appointment as associate professor of Earth science and chemistry at Rice University.

### GEOCHEMICAL SOCIETY–RELATED QUESTIONS OR COMMENTS?

Send them to the Geochemical Society Business Office:

**Seth Davis, Business Manager**

Tel.: 314-935-4131

Fax: 314-935-4121

E-mail: [gsoffice@gs.wustl.edu](mailto:gsoffice@gs.wustl.edu)

Website: <http://gs.wustl.edu>



## 2006 GOLDSCHMIDT ABSTRACT DEADLINE FAST APPROACHING

April 13, 2006 is the deadline to submit abstracts for the 2006 Melbourne Goldschmidt Conference.

For more information on abstract guidelines as well as programs, field trips, events, and exhibits, visit the conference website at: <http://www.goldschmidt2006.org/>

## ARE YOU INTERESTED IN HOSTING A GOLDSCHMIDT?

The Board of Directors will be examining bids for the 2009 and 2010 Goldschmidt Conferences during the 2006 annual board meeting on August 26, in Melbourne. If you, your university, or your city are interested in submitting a bid, please contact the GS Business Office.

## THE 2006 GEOCHEMICAL SOCIETY BOARD OF DIRECTORS

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(Pennsylvania State University)

**Marty Goldhaber**, VICE PRESIDENT  
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**James "Tim" Drever**, PAST PRESIDENT  
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(Florida State University)

**Yaoling Niu**, DIRECTOR  
(Durham University)

**Andreas Luttgé**, DIRECTOR  
(Rice University)

## GEOCHEMICAL SOCIETY-SPONSORED SPECIAL SESSIONS AT THE SPRING AGU MEETING BALTIMORE, MD, MAY 23-26

- GS01 Geochemical Society General Contributions
  - GS02 Depleted Uranium Aerosols in the Surface Environment: Transport, Geochemical Speciation, and Implications for Human Health
- Sessions presented jointly with AGU*
- U02 Thermodynamic Variables in Magmatic and Metamorphic Processes in the Terrestrial Planets: Theoretical, Experimental, and Observational Constraints
  - U06 Atmospheric, Climatic, and Biological Evolution at both Ends of the Proterozoic Eon
  - U07 Evolution of the Andes
  - U08 Fluids in the Earth
  - U11 Microanalysis: Small Beams, Big Science (invited presentations only)

### *Sessions presented jointly with MSA*

- M01 Mineralogy and the Nuclear Fuel Cycle—The 2006 Dana Symposium
- M03 Spectroscopy in Mineralogy: Theory and Experiment

### *Sessions presented jointly with Mineral and Rock Physics*

- MR01 Mineral and Rock Physics General Contributions

### *Sessions presented jointly with the Microbeam Analysis Society*

- MB01 General Contributions to Microanalysis in the Earth Sciences
- MB02 From Earth to Mars and Beyond

### *Sessions presented jointly with Hydrology*

- H11 Water Quality of Hydrologic Systems (posters)
- H17 Chemical and Isotopic Tracing of Contaminated Groundwater
- H24 Scale Issues of Catchment Hydrology and Biogeochemistry

### *Sessions presented jointly with Volcanology, Geochemistry, and Petrology*

- V02 Origin, Behavior, and the Role of Magmatic Sulfur in Terrestrial Planets: Theoretical, Experimental, and Observational Constraints
- V04 Evolution of the Early Earth
- V05 Tracing Deep-Earth Processes with Light Elements: Insights into the Evolution of the Crust, the Mantle, and Magmas from B, Li and Be Isotope and Abundance Systematics
- V08 Sulfur in the Earth System: Insights into the Evolution of Surface Environments and Secrets of the Deep Earth
- V09 Biosignatures: Distinguishing Biology from Abiological Look-Alikes
- V10 Frontiers of Hydrothermal Geochemistry: Organic-Inorganic Interactions from Deep Crust to Volcanic Systems
- V11 Earth's Carbon Cycle: Sources, Recycling Pathways, and Geochemical Evolution

## DO YOU DIG ROCKS AND LOVE LIFE?

**Biogeosciences.org** is an innovative non-commercial website bridging the Earth and life sciences. Developed by the Geological Society of America (GSA) and its partnered professional societies, including the Geochemical Society, it provides a single resource for all things related to biogeoscience. Released in June 2004, the site has continued to grow and expand, becoming a natural home for biogeoscience discussion, resources, and promotion. Biogeosciences.org is supported by a grant from the biogeosciences program of the National Science Foundation.

The site offers biogeoscience links and program resources for children, students, undergraduates, and teachers; information on job openings, funding opportunities, and degree programs; interviews with people working



in the biogeosciences and links to useful publications and articles; a calendar of biogeoscience-related meetings, field trips, workshops, and symposia from around the world.

Biogeosciences.org also offers an interactive component. People are able to submit material of interest to the biogeosciences community, or add their names and research interests to a growing list of biogeoscientists. A discussion forum allows for sharing of ideas and opinions, as well as an opportunity to ask questions. Pictures are exchanged freely for educational purposes in the image gallery.

Any inquiries (including submission of material for posting) should be directed to Sarah Leibson ([web@biogeosciences.org](mailto:web@biogeosciences.org)), Website Coordinator, Biogeosciences.org.



www.mineralogicalassociation.ca

## Mineralogical Association of Canada

### MAC FOUNDATION SCHOLARSHIP TO JASON MACKENZIE

The Mineralogical Association of Canada awarded its 2005–2006 Foundation Scholarship to Jason Mackenzie from the University of Victoria. This scholarship is awarded annually to a student in the second year of an MSc program or the second or third year of a PhD program.



Jason Mackenzie

Jason Mackenzie comes from southwestern Nova Scotia, and his interest in geology began when he became the inaugural president of the James Hutton Geology Club at age 14. Jason completed his BSc (geology) at Acadia University in 1996. Later that year, he started working on his MSc thesis with Dr. Dante Canil at the University of Victoria, where he studied kimberlite-hosted mantle xenoliths from the Slave Province. Jason worked in diamond

exploration in the Canadian Arctic and Finland from 1997 to 2001. Seeking a new challenge, he has since been working on developing a crystal growth process with Redlen Technologies in Victoria, BC. Experimenting with semiconductor crystal growth prompted him to pursue a PhD in experimental petrology under Dante Canil.

Jason's research seeks to answer questions regarding how, and at what rate, volatile elements (especially rhenium) are released from magma during ascent and emplacement. This work will help constrain the contribution of Re volatility to estimates of Re flux from the mantle to the crust.

Jason conducts experiments to quantify Re volatility and mobility in silicate liquids and establish the roles of melt composition, temperature,  $fO_2$ , and speciation on degassing behavior.

Jason's research also aims to establish a robust experimental and analytical procedure that captures the behavior of Re and several important heavy metals (Hg, Pb, As, Se). Volcanic emission of Re and other heavy metals may contribute a significant load to the hydrosphere and atmosphere. For example, it has been suggested that volcanic emissions of the volatile element Hg may represent as much as 40% of natural emissions of Hg to the atmosphere. A quantitative understanding of rates and processes related to volatile release of heavy metals will provide important constraints on the geochemical behavior of these elements and their flux across geochemical reservoirs.

### MAC-SPONSORED SESSIONS AT MONTREAL 2006 AND OTHER MEETINGS

MAC is sponsoring three special sessions and one symposium at its upcoming annual meeting Montreal 2006.

#### *Alkaline Igneous Systems: Dissecting Magmatic to Hydrothermal Mineralizing Processes*

This symposium will explore the entire range of processes involved in the generation, evolution, association, and mineralization of alkaline rocks of both plutonic and volcanic association. The convenors, David Lentz (University of New Brunswick), André Lalonde (University of Ottawa), Stefano Salvi (LMTG, Toulouse), and Jeanne Paquette (McGill University), have invited several keynote speakers, including Nelson Eby (University of Massachusetts), Anthony Mariano (consultant), Dima Kamenetsky (University of Tasmania), Ilya V. Veksler (GeoForschungsZentrum Potsdam, Germany), Alexander M. Dorfman and Donald B. Dingwell (Ludwig-Maximilian University, Munich, Germany).

#### *Advances in Micro- and Nanoscale Characterization and Analysis of Earth Materials*

This session will highlight recent advances in micro- and nanoscale techniques and their application to the study of selected regions in amorphous and crystalline materials. Presentations will focus on the analysis and imaging of (1) inclusions (glass, devitrified glass, and fluid) in minerals, (2) experimental run products, and (3) zones and intergrowths in accessory minerals. Convenors Alan Anderson (St. Francis Xavier University) and Penny King (University of Western Ontario) have invited two plenary lecturers: Richard Wirth (GFZ Potsdam, Germany) will talk on his recent work on nanoscale characterization of inclusions in diamonds using the focused ion beam and TEM, and Robert Mayanovic (Missouri State University) will present on XAFS analysis of high-field-strength elements in hydrous silicate melts and aqueous fluids.

#### *The Earth's Mantle: New Insights from Diamonds and Mantle Xenoliths*

Convened by Maya Kopylova (University of British Columbia) and Don Francis (McGill University), this special session will feature Dr. Larry Barron (Geological Survey of New South Wales, Australia) as plenary speaker. His talk will bear on identifying the parentage of alluvial diamonds using new techniques that are able to discriminate between ultrahigh pressure, mobile zone, cratonic, and transition zone diamonds.

#### *Metamorphism, Crustal Fluids, and Experimental Petrology: A Tribute to George Skippen*

This special session, convened by Dan Marshall (Simon Fraser University), Fred Ford (Inco), and Jo-Anne Goodwin Bell (Carleton University), will honor George Skippen, one of Canada's foremost metamorphic petrologists. Guest speaker Greg Dipple from the University of British Columbia will talk about carbonate phase diagrams and their application to  $CO_2$  (greenhouse gas) remediation. As Skippen published early on about carbonates, especially thermometry and the application of phase diagrams in the metamorphism of calc-silicate rocks, it will be a nice transition from the early experimental work of Skippen to the modern-day applications of petrology.

MAC will also sponsor two special sessions on weathering in the solar system at the 2006 Goldschmidt Conference: "Aqueous and Space Weathering of Asteroids, the Moon and Mars" and "Spectroscopic Analyses of Aqueous Weathering Products in the Solar System." Both sessions are convened by Penny King, University of Western Ontario, and Tom Sharp, Arizona State University.

MAC will also be a sponsor of the Geofluids V Conference (www.geofluids5.org), to be held in Windsor next May, immediately after the GAC-MAC conference.

www.gacmac2006.ca

## 2005 TRAVEL AND RESEARCH GRANT WINNERS

MAC awarded 17 travel and research grants to students in 2005. Amounts awarded ranged from \$400 to the maximum \$1200. We would like to recognize these deserving students.



**Anetta Banas** (University of Calgary) presented the results of her MSc thesis on trace element analyses of garnet inclusions in

diamonds from the DeBeers Pool, South Africa, at the symposium "From Cratons to Carats: a Symposium to Honour the Career of Herwart Helmstaedt" at Halifax 2005. The two-day symposium featured presentations on the structure and tectonics of Archean cratons and the geotectonic controls on diamond exploration. It provided Anetta with an opportunity to interact with some of the most renowned researchers in this field.



**Elsbeth Barnes** (University of British Columbia) is doing a PhD project on the Little Nahanni Pegmatite

Group, Yukon. She received some funding to carry out a halogen study of fluid inclusions from these LCT-type highly evolved pegmatites. She hopes that this will shed light on the evolution of the pegmatite-forming silicate fluid during the development of the dike system. Glacial erosion of the ridge has produced a series of immense cirque walls that expose vertical cross sections of numerous pegmatites.



**Tashia Dzikowski** (University of British Columbia) received funding to assist with field work in Florida,

where she collected natural carbonate mud samples. This gave her the opportunity to see

carbonate mud environments first hand and is now proving very beneficial to her MSc project, which is aimed at understanding how whittings form under controlled laboratory conditions and how they originate in nature. Whittings are produced in lakes or seas when fine-grained calcium carbonate precipitates in the open water column, giving the water a milky or white appearance. The origin of whittings is controversial, but recent work has shown that they are coincident with blooms of cyanobacteria in parts of the ocean, such as the Great Bahama Bank, and in some freshwater lakes.



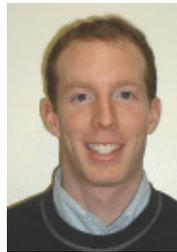
**Diana Loomer** (University of New Brunswick) presented a paper on the characterization of Mn-oxide

minerals and microbially mediated reductive dissolution of oxide at the Goldschmidt Conference and participated in a field trip to Yellowstone National Park with the aid of a MAC travel grant. She reports the following: "What a spectacular, living, breathing laboratory! Along with the hot springs, geysers, and fumaroles, what Yellowstone shows you is the dramatic impact that microscopic creatures have."



**John Moreau** (University of California-Berkeley) is studying microbial sulfur cycling and the fate of metals in mining-

impacted sediments, under Dr. Jill Banfield. Hoping to pursue the topic of biogeochemical mercury transformations in his postdoctoral research, he applied for a travel grant to attend the mercury short course in Halifax. Of his experience, he concludes: "All in all, the course served well to introduce and update newcomers and experts alike to the state of the science in mercury biogeochemistry."



**Ian Power** (University of Western Ontario) presented a talk at the Goldschmidt Conference on the results of his

undergraduate honours thesis. The topic: carbon dioxide sequestration through enhanced weathering of chrysotile mine tailings and subsequent microbial precipitation of magnesium carbonates.



**Gregory Shellnut** (University of Hong Kong) presented the initial results of his PhD research project on the petrological

association of peralkaline quartz syenites and layered Fe-Ti-V oxide-bearing gabbroic intrusions in southwest China in a special session on rift-related magmatism and associated mineralization at Halifax 2005. The feedback he received from his presentation was positive and insightful, and helped him develop and test new ideas.



**Kim Tait** is now working on her PhD at the University of Arizona (advisor Robert Downs). However,

she spends most of her time at the Los Alamos National Laboratory, as a graduate research assistant, where she is studying gas hydrates with neutron diffraction. Thanks to a MAC travel grant, she was able to present some of her ongoing work on the alluaudite-group minerals (with co-author Frank Hawthorne) and also attend the MAC 50<sup>th</sup> anniversary special session.



**Coby Wong** is a PhD candidate at the University of Hong Kong. She is currently studying environmental

mercury contamination in a village in Guangdong Province, China, where primitive processing of electronic waste has been conducted for nearly a decade. Her research project focuses on mercury contamination in the village and its potential environmental and health consequences. In order to build a solid foundation of understanding of the subject, she applied to the Mineralogical Association of Canada for a travel grant to attend the two-day short course "Mercury: Sources, Measurements, Cycles, and Effects" held just prior to Halifax 2005. She gave a presentation entitled "Environmental Mercury Contamination Arising from Mercury-containing Electronic Components in Southeast Asia" at the special session "Mercury in the Environment." She says, "I presented my study with the hope to raise public awareness of the ever-growing volume of e-waste and its potential environmental effects. I think I achieved that!"

The following students also received travel grants:

Allison Brand (University of British Columbia), Fernando Colombo (University of Cordoba, Argentina), Heather Kaminsky (University of Alberta), Paul Kenward (University of Windsor), Guangrong Ning (University of Western Ontario), Dustin K. Rainey (University of Alberta), Michael Schultz (University of Alberta), and Jingshi Wu (University of Western Ontario). Congratulations to them all.

Please check our website [www.mineralogicalassociation.ca](http://www.mineralogicalassociation.ca) for more detailed reports.



www.ima-mineralogy.org

# International Mineralogical Association

## FROM THE PRESIDENT

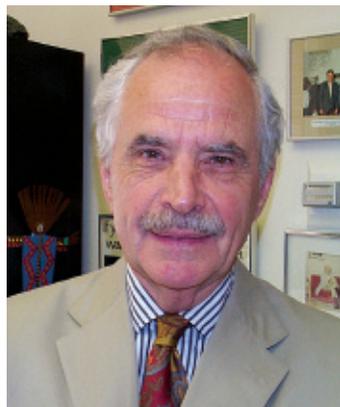
### MONEY MATTERS

First of all, some important news about a change in the executive committee of IMA. Cornelis Klein, of the University of New Mexico, who has worked extremely hard as treasurer of IMA since 1995, has decided that the time has come to pass this task to someone else. As well as dispensing the sums of money needed to keep IMA running, for items such as maintenance of the website ([www.ima-mineralogy.org](http://www.ima-mineralogy.org)), the operating costs of groups such as the Commission on New Minerals and Mineral Names, and support for meetings, Kase has worked tirelessly to collect the annual dues of member societies. What should be a routine activity is frustrating and time consuming because many supporting organizations seem to be unable or unwilling to transfer the relatively small sums involved. Based on Kase's experience I put forward below some ideas on how the situation might be improved by changes in the laws of IMA. We all have to be extremely grateful for the amount of work that he has put into this task over the last decade.



Robert T. Downs, incoming treasurer

We welcome as our new treasurer Robert T. Downs of the University of Arizona in Tucson, where he is associate professor of mineralogy and crystallography. Bob is Canadian and obtained his first degree (in mathematics) at the University of British Columbia before undertaking postgraduate work in mineralogy at Virginia Tech and completing a post-doc at the Geophysical Laboratory in Washington. IMA has tax-exempt status in the United States, so it is logical to pass the position of treasurer to someone based there.



Cornelis Klein, outgoing treasurer

For a person with Bob's background, balancing the books should be a piece of cake, but only if we can overcome the problem of non-payment of dues. Should you be the responsible person in one of the several countries that has still not paid its dues for 2005, please send your money now to:

**Dr. Robert T. Downs**  
1040 E 4<sup>th</sup> St., Dept of Geosciences, University of Arizona,  
Tucson Arizona 85721-0077, USA  
E-mail: [downs@geo.arizona.edu](mailto:downs@geo.arizona.edu)

### Modernizing IMA

IMA is living in a new world. It is no longer largely invisible between its four-yearly General Meetings. Now, through *Elements*, every two months, it can reach every mineralogist on Earth who has access to the Internet. If your country's mineralogical organization is not one of those supporting *Elements* directly, you (or your institutional library) may well receive a hard copy because you subscribe to one of the journals of the supporting societies. Even if you have no such access, *anybody*, two months after publication, can download a pdf from [www.elementsmagazine.org](http://www.elementsmagazine.org). I think that this is remarkable, and it is an opportunity the whole *international* mineralogical community must embrace. In the next paragraphs, I am going to review some of IMA's financial difficulties and make some personal suggestions (the bullet points) for their solution.

Our difficulty with getting some national groups to pay their annual dues is, I think, a symptom of a number of structural problems within IMA. You might imagine, since IMA exists to promote the interests of its supporting organizations, that collecting dues would be a comparatively routine activity. But in 2005 about a quarter of the 37 affiliated organizations had not paid by early December, making them at least one year late. Three organizations were more than two years behind in payment, and one was six years behind. Some of the defaulters are small communities in the less-developed world, and we should be sympathetic with their problems. But two defaulting organizations are located in countries that are among those with the biggest per capita incomes.

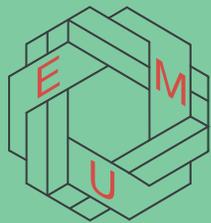
- At present IMA makes contact with societies through their National Representatives. Although many do an excellent job, some do not, and in future we shall also deal directly with society presidents and executive secretaries.
- At Kobe the Business Meeting should follow the rules of the IMA Constitution firmly. Countries in default for two

years or more will not be allowed to vote. Council will then consider whether any defaulting country should be deleted from the list of IMA members. This would, of course, be a matter of last resort, and we will always welcome letters of explanation from organizations who have genuine difficulties in paying.

A related problem concerns the formula used to calculate the subscription of each country. The amount (in US dollars) is calculated as  $60 \times D$ , where D is a number between 10 and 1 that depends upon the membership numbers of the supporting society. Thus the big societies of Germany, Russia and the USA, each with over 1000 members and  $D = 10$ , all pay \$600. At the other extreme, 16 societies have 25 members or less,  $D = 1$ , and they pay \$60. It isn't rocket science to figure out that an individual MSA member, for example, contributes a *maximum* of \$0.60, and a member of one of the little societies pays a *minimum* of \$2.40. This seems to me to be completely opposite to what is desirable.

- Societies should pay a per capita sum based on their exact paid-up membership. It would be up to each national society to decide how the money is collected, but it could form part of their own annual subscription and be identified as the IMA contribution. Of course, some individuals are members of more than one national society, but they have anyway been paying twice (sometimes more) under the present system.
- The exact sum will need careful consideration, but it will be not more than \$2 per member. Members of big societies will pay a little more than they do now, those in small organizations less.

This brings me to a final financial problem. Even if we do not change our funding formula, so that our 16 small societies continue to pay \$60, such is the avarice (defined, in my Oxford dictionary, as 'extreme greed') of the world's banks that the costs of international money transfer are almost as great as the amounts being



www.univie.ac.at/Mineralogie/EMU

## European Mineralogical Union

### EMU AND THE EUROPEAN GEOSCIENCES UNION

One of the largest geoscience events in Europe is the annual General Assembly of the European Geosciences Union (EGU). In 2005, this took place in Vienna (Austria) from April 24 to 29. Traditionally, the European Mineralogical Union meets in conjunction with the EGU (including holding its business meetings).

Contributions to the EGU meeting cover a broad spectrum of topics related to the geosciences, including space and planetary sciences. The mineralogical sciences were strongly represented in the 2005 programme. The programme section 'Volcanology, Geochemistry, Petrology and Mineralogy' (VGPM) included 22 sessions. In particular the EMU was involved in convening the following symposia:

- High-pressure and High-temperature Mineral Physics: Contributions towards the Understanding of Planetary Interiors
- Spectroscopy of Earth's Material: Experiments and Numerical Modelling

During the first of these symposia, the EMU medal ceremony took place. The EMU annually awards a silver medal to a young scientist who makes significant contributions to research and who is active in strengthening European scientific links. The EMU Medal for 2005 was awarded to David Dobson (University College London, UK; see the citation in volume 1, number 5, page 312 of *Elements*).

In addition, Eugen Libowitzky (University of Vienna, Austria), the 2003 EMU medallist, belatedly gave his medallist lecture entitled 'Dynamic disorder in crystal structures: results from diffraction and vibrational spectroscopy.' In this lecture, he noted that hydrogen can be a major, minor or trace constituent of a broad variety of minerals in the Earth's lithosphere. Hydrogen

atoms in crystal structures can be characterised by both diffraction and spectroscopic methods. Whereas the former are suitable for the investigation of stoichiometric phases exhibiting long-range order with atomic sites at least predominantly occupied by hydrogen atoms, IR spectroscopy is an excellent method for the characterisation of traces of hydrogen atoms in a crystal. The advantage of spectroscopy is the high time-resolution as compared to diffraction methods. Furthermore, the interaction between matter and radiation takes place on one site only. Spectroscopy using polarized radiation allows determination of the orientation of a vibrating molecule. As examples of phase transitions involving hydrogen, the minerals lawsonite and hemimorphite were discussed in detail. Both exhibit dynamic disorder-order processes involving hydrogen-bonded H<sub>2</sub>O molecules and OH groups at low temperatures. Furthermore, it has become clear that even anhydrous minerals may contain hydrogen atoms at structural defects in relatively large amounts. Such minerals persist to great depths in subduction zones and may be responsible for recycling water. Because of the enormous volume of the Earth's mantle, nominally anhydrous minerals under high P-T conditions, and which contain hydrogen only as a minor or trace constituent, may play an important role in the water budget of the Earth. Nevertheless, there is still controversy as to whether the mantle is enriched or depleted in hydrogen through the processes associated with subduction zones.

### FORTHCOMING GENERAL ASSEMBLIES OF EGU

The next EGU General Assembly will be held in Vienna from April 2 to 7, 2006. We would like to draw your attention to the following sessions planned for the VGPM section of the EGU meeting:

- Nanoscale Analytical and High-resolution (S)TEM Techniques for the Characterisation of Environmental and Geological Processes
- Accessory Minerals in Metamorphic and Igneous Rocks: Petrogenetic Indicators of Chemical and Physical Processes
- Urban Mineralogy
- Experiments under HP-HT Conditions: Applications in the Geosciences

We encourage you to participate in this conference. Further information is available at <http://meetings.copernicus.org/egu2006>.

Suggestions for sessions in mineral physics, mineralogy, and crystallography at the 2007 EGU General Assembly would be very welcome and should be addressed to Professor Peter Ulmer of ETH Zurich ([peter.ulmer@erdw.ethz.ch](mailto:peter.ulmer@erdw.ethz.ch)) before September 1, 2006.

Peter Ulmer, President  
David Vaughan, Past President  
Herta Effenberger, Secretary

### cont'd from p. 60

collected, particularly if electronic transfer is used; thus the originating society might pay \$45 and IMA a further \$10–\$15 on receipt. Banker's drafts sent by post are somewhat cheaper, but most of our members prefer not to use them. I can see two possible solutions:

- Recognize that the dues paid by societies with less than 25 members are almost trivial and allow them free membership. This does rely on high standards of honesty, but then, we are all scientists.
- Agree that payments by smaller societies can be made in cash at IMA business meetings, which now take place every two years.

One thing that the president of IMA rapidly learns is that the societies that support IMA vary enormously in their size and strength. On the one hand are large organizations like the Mineralogical Society of America, which have permanent staff and offices and are substantial publishing businesses. On the other hand there are small groups, sometimes within a national geological society, full of enthusiasm but lacking any formal structure. To members from richer countries \$2 may seem trivial (a litre of gasoline costs \$1.60 in the UK), but to less-well-off countries it may be substantial. Council appreciates all these issues. But making IMA work well is in

everyone's interest. International scientific collaboration should be a major force in the world, and we can all play our part in this.

Wherever you work I welcome your views and fresh ideas as to how we can achieve our aims. Please e-mail: [ian.parsons@ed.ac.uk](mailto:ian.parsons@ed.ac.uk), Bob Downs, or any member of the IMA Council (addresses at [www.ima-mineralogy.org](http://www.ima-mineralogy.org)). Any changes will be discussed fully by Council and by delegates at our business meetings in Kobe in July 2006 ([www.congre.co.jp/ima2006](http://www.congre.co.jp/ima2006)).

Ian Parsons  
President

## 2006

**April 2-7 European Geosciences Union (EGU) General Assembly**, Vienna, Austria. Details: EGU Office, Max-Planck-Str. 13, 37191 Katlenburg-Lindau, Germany. Tel.: +49-5556-1440; fax: +49-5556-4709; e-mail: egu@copernicus.org; web page: www.copernicus.org/EGU/egu\_info/prevga.html

**April 3-7 Backbone of the Americas-Patagonia to Alaska**, Mendoza, Argentina. Details: Suzanne M. Kay or Victor Ramos, e-mail: smk16@cornell.edu or andes@gl.fcen.uba.ar; web page: www.geosociety.org/meetings/06boa/index.htm

**April 9-12 American Association of Petroleum Geologists and Society for Sedimentary Geology (SEPM) Joint Annual Meeting**, Houston, Texas, USA. Details: AAPG Conventions Department, PO Box 979, 1444 S. Boulder Avenue, Tulsa, OK 74101-0979, USA. Tel.: 918-560-2679; fax: 918-560-2684; e-mail: convence@aapg.org; web page: http://www.aapg.org/houston/index.cfm

**April 10-11 Workshop: "Surface Reactivity in Minerals,"** Gargnano, Brescia, Italy. Details: G. Artioli or M. Moret, e-mail: gilberto.artioli@unimi.it or massimo.moret@mater.unimib.it

**April 17-21 Materials Research Society 2006 Spring Meeting**, San Francisco, CA, USA. Tel.: 724-779-3003; fax: 724-779-8313; e-mail: info@mrs.org; web page: www.mrs.org/meetings/future\_meetings.html

**April 30-May 4 2006 International High Level Radioactive Waste Management Conference**, Las Vegas, NV, USA. Details: Daniel Bullen, General Chair, web page: www.ans.org/meetings/index.cgi?c=t

**May 3-5, 2006 International Workshop on the Isotopic Effects in Evaporation: Revisiting the Craig-Gordon Model Four Decades After its Formulation**, Pisa, Italy. Information: Roberto Gonfiantini, Istituto di Geoscienze e Georisorse del CNR, Via G. Moruzzi 1, 56124 Pisa, Italy; e-mail: iviee@igg.cnr.it; web page: www.geo.unifi.it/evaporationworkshop

**May 13-14 Melt Inclusions in Plutonic Systems: Mineralogical Association of Canada Short Course**, Montreal, Canada. Details: Jim Webster; e-mail: jdww@amnh.org; web page: www.mineralogicalassociation.ca/index.php?p=120

**May 14-16 Society of Economic Geologists 2006 Conference**, Keystone, Colorado, USA. Details: Society of Economic Geologists, 7811 Shaffer Parkway, Littleton, CO, USA 80127-3732. Tel.: 720-981-7882; fax: 720-981-7874; e-mail: seg2006@segweb.org; website: www.seg2006.org

**May 14-17 Planet Earth in Montreal: Geological Association of Canada and Mineralogical Association of Canada Joint Annual Meeting**, Montreal, Canada. E-mail: gacmac2006@uqam.ca; web page: www.gacmac2006.ca

**May 14-18 IAVCEI 2006: Continental Basalt Volcanism**, Guangzhou, China. Details: Dr. Yigang Xu, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, P.O. Box 1131,

510640 Wushan Guangzhou, PR China; e-mail: xlhuang@gig.ac.cn; website: www.iavcei2006.org

**May 16-20 Geofluids V, the Fifth International Conference on Fluid Evolution, Migration and Interaction in Sedimentary Basins and Orogenic Belts**, Windsor, Ontario, Canada. E-mail: geofluids5@uwindsor.ca; website: www.geofluids5.org

**May 23-26 2006 AGU Joint Assembly**, Baltimore, Maryland, USA. Details: AGU Meetings Department, 2000 Florida Avenue NW, Washington, DC 20009, USA. Tel.: 800-966-2481, ext. 333 or 202-777-7330; fax: 202-328-0566; e-mail: ja-help@agu.org (subject: 2006 Joint Assembly); web page: www.agu.org/meetings/ja06

**May 28-31 GERM (Geochemical Earth Reference Model) workshop**, Columbia University, NY, USA. E-mail: germ@igpp.ucsd.edu; web page: http://earthref.org/

**June 3-7 Joint 43<sup>rd</sup> Annual Meeting of The Clay Minerals Society and Annual Meeting of the Groupe Français des Argiles (French Clay Group)**, Oléron Island, France. Details: Sabine Petit, Université de Poitiers, CNRS HydrASA, 40 Av. du Recteur Pineau, 86022 Poitiers Cedex, France. Tel.: 33-(0)5-49-45-37-56; e-mail: sabine.petit@hydrasa.univ-poitiers.fr; web page: www.clays.org or www.c2s-organisation.com/gfacs06

**June 7-9 Sediment 2006: 4<sup>th</sup> Annual Conference of the Central European Section of SEPM**, Gottingen, Germany. E-mail: info@sediment2006.de; web page: www.sediment.uni-goettingen.de/sediment2006/index.html

**June 12-17 Walker Memorial Meeting: Advances in Volcanology, Volcanic and Magmatic Studies Group, Mineralogical Society, Reykholt**, Iceland. Details: Stephen.self@open.ac.uk; web page: www2.norvol.hi.is/page/nordvulk\_walker

**June 18-21 Chinese International Conference on Continental Dynamics and Environmental Change of the Tibetan Plateau**, Xining, Qinghai Province, PRC. Web page: www.geosociety.org/meetings/index.htm

**June 25-29 First International Congress on Ceramics**, Toronto, Canada. Details: Dr. Stephen Freiman, tel.: 301-975-5658, or Mark Mecklenborg, ACerS Staff Director, Technical Publications and Meetings, tel.: 614-794-5829. E-mail: stephen.freiman@nist.gov or mmecklenborg@ceramics.org; web page: www.ceramics.org/?target=/meetings/icc/home.asp

**July 2-6 Australian Earth Sciences Convention**, Melbourne, Australia. Details: Australian Earth Sciences Convention, c/o The Meeting Planners, 91-97 Islington Street, Collingwood, Victoria, Australia 3066; tel: +61 3 9417 0888; fax: +61 3 9417 0899; e-mail: earth2006@meetingplanners.com.au; website: www.earth2006.org.au

**July 10-12 Granulite and Granulites 2006**, University of Brasilia, Brazil. Details: Michael Brown, e-mail: mbrown@geol.umd.edu; web page: www.geol.umd.edu/pages/meetings/granulites2006.htm

**July 16-23 Zeolite '06, 7<sup>th</sup> Meeting of the International Natural Zeolite Association**, Socorro, New Mexico, USA. Details: Dr. Robert Bowman, e-mail: bowman@nmt.edu; web page: http://cms.lanl.gov/zeo2006.html

**July 22-27 American Crystallographic Association (ACA) Annual Meeting**, Honolulu, HI, USA. Details: Judith Kelly, 113 Uncle Sam Rd., Phippsburg ME 04562. Tel.: 207-389-9058; fax: 860-486-4331; e-mail: judith.kelly@uconn.edu; web page: www.hwi.buffalo.edu/ACA/meetingspg\_list/futuremeetings.html

**July 23-28 19<sup>th</sup> International Mineralogical Association (IMA) Meeting**, Kobe, Japan. Details: Dr. Kiyoshi Fujino, e-mail: 2006ima@congre.co.jp or 2006imapro@congre.co.jp; web page: www.congre.co.jp/ima2006

**July 30-Aug 2 International Symposium on Zeolites and Microporous Crystals (ZMPC2006)**, Yonago, Tottori Prefecture, Japan. E-mail: zmpc2006@chem.tottori-u.ac.jp; web page: www.chem.tottori-u.ac.jp/~zmpc2006

**July 30-August 4 Gordon Research Conference: Biomineralization**, Colby-Sawyer College, New London, NH, USA. Web page: www.grc.uri.edu/programs/2006/biomin.htm

**August 6-11 69<sup>th</sup> Annual Meeting of the Meteoritical Society**, ETH, Zurich, Switzerland. Details: Rainer Wieler, ETH Zurich, Isotope Geology, CH-8092 Zurich, Switzerland. Tel.: +41 44 632 37 32; fax: +41 44 632 11 79; e-mail: Wieler@erdw.ethz.ch; website: www.metsoc2006.ethz.ch

**August 6-11 23<sup>rd</sup> European Crystallographic Meeting (ECM23)**, Leuven, Belgium. Details: Organizing Secretariat, Momentum, Grensstraat 6, B-3010 Leuven, Belgium. Tel.: +32 16 40 45 55; fax: +32 16 40 35 51; e-mail: info@momentum-pco.be; website: www.ecm23.be

**August 21-24 IAGOD Symposium: 12<sup>th</sup> Quadrennial International Association on the Genesis of Ore Deposits**, Moscow, Russia. Details: Dr. Sergei Cherkasov, Executive Secretary 12<sup>th</sup> IAGOD, Vernadsky SGM RAS, 11-2 Mokhovaya str., Moscow, 125009 Russia. Tel.: +7-(095)-203-4667; fax: +7-(095)-203-5287; e-mail: iagod@sgm.ru; web page: http://www.rags.ru/about.shtm (in Russian); or http://nts2.cgu.cz/servlet/page?\_pageid=540,542,544&\_dad=portal30&\_schema=PORTAL30

**August 26-27 GIA Gemological Research Conference**, San Diego, California USA. Details: Dr. James E. Shigley, tel.: 760-603-4019; e-mail: gemconference@gia.edu; web page: www.gia.edu/gemsandgemology/30609/2006\_gia\_gemological\_research\_conference.cfm

**August 27-29 International Gemological Symposium (IGS)**, San Diego, CA, USA. Details: Gemological Institute of America, The Robert Mouawad Campus, 5345 Armada Drive, Carlsbad, CA 92008. E-mail: igs@gia.edu; website: www.symposium.gia.edu

**August 27-September 1 16<sup>th</sup> Annual V.M. Goldschmidt Conference**, Melbourne, Australia. Details: Goldschmidt 2006 Conference Managers, GPO Box 128, Sydney NSW 2001,

Australia. E-mail: goldschmidt2006@tourhosts.com.au; website: www.goldschmidt2006.org

**August 27-September 1 17<sup>th</sup> International Mass Spectrometry Conference (IMSC)**, Prague, Czech Republic. Details: CZECH-IN, spol. s r.o., 17<sup>th</sup> IMSC Conference Secretariat, Prague Congress Centre, 5. kvetna 65, CZ-140 21 Prague, Czech Republic. Tel.: +420 261 174 305; fax: +420 261 174 307; e-mail: imsc2006@czech-in.cz; website: www.imsc2006.org

**September 3-8 Gordon Research Conference: Rock Deformation**, Big Sky Resort, Big Sky, MT, USA. Details: Mark Jessell, UMR 5563, Laboratoire des Mécanismes et Transferts en Géologie, Université Paul Sabatier, 31400 Toulouse, France. E-mail: mjessell@lmtg.obs-mip.fr; web page: www.grc.uri.edu/programs/2006/rockdef.htm

**September 4-10 Volcano International Gathering, "Volcano: Life, Prosperity, and Harmony,"** Yogyakarta, Indonesia. Details: Secretariat, Faculty of Mineral Technologi, UPN "Veteran" Yogyakarta, Jl. SVK 104 (Lingkar Utara) Condongcatur, Yogyakarta 55282, Indonesia. Tel.: +62-274-486733, ext. 309; fax: +62-274-487814; e-mail: info@recent.or.id; website: http://vig2006.recent.or.id

**September 6-10 Engineering Geology for Tomorrow's Cities: The 10<sup>th</sup> IAEG Congress**, Nottingham, United Kingdom. E-mail: contact@iaeg2006.com; web page: www.iaeg2006.com

**September 10-13 International Symposium on Experimental Mineralogy, Petrology and Geochemistry (EMPG XI)**, Bristol, UK. Details: Bernard Wood, University of Bristol, Department of Earth Sciences; web page: www.univie.ac.at/Mineralogie/EMU/events.htm

**September 10-14 American Chemical Society 232<sup>nd</sup> National Meeting**, Atlanta, GA, USA. Details: ACS Meetings, 1155, 16th Street NW, Washington, DC 20036-4899. Tel.: 202-872-4396; fax: 202-872-6128; e-mail: natlmtgs@acs.org

**September 18-22 Third Mid-European Clay Conference (MECC'06)**, Opatjaja, Croatia. Details: Darko Tibljas, Institute for Mineralogy and Petrology, Faculty of Science, University of Zagreb, Horvatovac bb, HR-10000 Zagreb, Croatia; e-mail: mecc06@gfz.hr

**September 24-28 Crystallization 2006: Eighth International Symposium on Crystallization in Glasses and Liquids**, Jackson Hole, WY, USA. Details: Dr. Mark J. Davis, e-mail: mark.davis@us.schott.com; web page: www.acers.org/meetings/crystallization/home.asp

**September 25-30 7<sup>th</sup> International Symposium on Environmental Geochemistry (7<sup>th</sup> ISEG)**, Beijing, China. Details: Dr. Cong-Qiang Liu, State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, 46 Guanshui Road, Guiyang, Guizhou Province, 550002, P. R. China. E-mail: iseg2006@vip.skleg.cn or liucongqiang@vip.skleg.cn; website: www.iseg2006.com

**October 1-4 Water in Nominally Anhydrous Minerals, MSA/GS Short Course**, Verbania, Italy. Details: Hans

Keppler, Bayerisches Geoinstitut, Bayreuth, Germany and Joseph Smyth, University of Colorado, Boulder, CO, USA; web page: <http://www.minsocam.org/MSA/SC>

**October 1–6 Society of Exploration Geophysicists 76<sup>th</sup> Annual Meeting and International Exposition**, New Orleans, Louisiana, USA. Details: PO Box 702740, Tulsa, OK 74170-2740, USA. Tel.: 918-497-5500; fax 918-497-5557; e-mail: [meetings@seg.org](mailto:meetings@seg.org); web page: <http://seg.org/meetings>

**October 14–17 Materials Science & Technology 2006 (MS&T '06)**, Cincinnati, OH, USA. Contact: TMS Meetings Services, 184 Thorn Hill Road, Warrendale, PA 15086, USA. Tel.: 724-776-9000, ext. 243; e-mail: [mtgserv@tms.org](mailto:mtgserv@tms.org)

**October 22–25 Geological Society of America Annual Meeting**, Philadelphia, Pennsylvania, USA. Details: GSA Meetings Dept., PO Box 9140, Boulder, CO 80301-9140, USA. Tel.: 303-447-2020; fax: 303-447-1133; e-mail: [meetings@geosociety.org](mailto:meetings@geosociety.org); web page: [www.geosociety.org/meetings/index.htm](http://www.geosociety.org/meetings/index.htm)

**November 5–8 AAPG 2006 International Conference and Exhibition**, Perth, Australia. Details: AAPG Conventions Department, PO Box 979, Tulsa, OK 74101-0979, USA. Tel.: 918-560-2679; e-mail [convene2@aapg.org](mailto:convene2@aapg.org); web page: [www.aapg.org/perth/index.cfm](http://www.aapg.org/perth/index.cfm)

**November 27–December 1 Materials Research Society Fall Meeting**, Boston, MA, USA. Details: Materials Research Society, 506 Keystone Drive, Warrendale PA 15086-7573, USA. Tel.: 724-779-3003; e-mail: [info@mrs.org](mailto:info@mrs.org); web page: [www.mrs.org/meetings/future\\_meetings.html#f06](http://www.mrs.org/meetings/future_meetings.html#f06)

**December 2006 7<sup>th</sup> European Meeting on Environmental Chemistry**, Brno, Czech Republic. Details: Dr. Josef Caslavsky, Institute of Analytical Chemistry, Czech Academy of Science, Veveří 97, 61142 Brno, Czech Republic. E-mail: [caslav@iach.cz](mailto:caslav@iach.cz)

**December 11–15 American Geophysical Union Fall Meeting**, San Francisco, California, USA. Details: E. Terry, AGU Meetings Department, 2000 Florida Avenue NW, Washington, DC 20009, USA. E-mail: [eterry@agu.org](mailto:eterry@agu.org); web page: [www.agu.org/meetings](http://www.agu.org/meetings)

## 2007

**February 25–March 1 2007 TMS Annual Meeting & Exhibition**, Orlando, FL, USA. Details: TMS Meetings Services, 184 Thorn Hill Road, Warrendale, PA 15086. Tel.: 724-776-9000, ext. 243; e-mail: [mtgserv@tms.org](mailto:mtgserv@tms.org)

**March 25–29 American Chemical Society 233<sup>rd</sup> National Meeting**, Chicago, IL, USA. Details: ACS Meetings, 1155-16<sup>th</sup> St NW, Washington, DC 20036-489. Tel.: 202-872-4396; fax: 202-872-612; e-mail: [natlmtgs@acs.org](mailto:natlmtgs@acs.org); web page: [www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=meetings%5cfuture.html](http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=meetings%5cfuture.html)

**April 1–4 American Association of Petroleum Geologists and Society for Sedimentary Geology (SEPM) Joint Annual Meeting**, Long Beach, California, USA. Details: AAPG Conventions Department, PO Box 979, 1444 S.

Boulder Ave., Tulsa, OK 74101-0979, USA. Tel.: 918-560-2679; fax: 918-560-2684; e-mail: [convene@aapg.org](mailto:convene@aapg.org)

**April 9–12 Materials Research Society Spring Meeting**, San Francisco CA, USA. Web page: [www.mrs.org/meetings/future\\_meetings.html#beyond](http://www.mrs.org/meetings/future_meetings.html#beyond)

**May 23–25 Geological Association of Canada and Mineralogical Association of Canada Joint Meeting (GAC–MAC): Yellowknife 2007 – For a Change in Climate**, Yellowknife, Canada. Web page: [www.nwtgeoscience.ca/gac\\_mac](http://www.nwtgeoscience.ca/gac_mac)

**June 17–20 10<sup>th</sup> International Conference and Exhibition of the European Ceramic Society**, Berlin, Germany. Website: <http://www.ecers2007berlin.de>

**June 25–30 Combined Societies' Meeting – MinSoc, MSA and MS**, Cambridge UK. Details: M.A. Carpenter, e-mail: [mc43@esc.cam.ac.uk](mailto:mc43@esc.cam.ac.uk); web page: [www.minersoc.org/pages/meetings/frontiers/index.html](http://www.minersoc.org/pages/meetings/frontiers/index.html)

**July 2–13 International Union of Geodesy and Geophysics (IUGG) 2007 General Assembly**, Perugia, Italy. E-mail: [secretary@IUGG2007perugia.it](mailto:secretary@IUGG2007perugia.it); website: [www.iugg2007perugia.it](http://www.iugg2007perugia.it)

**July 9–13 11<sup>th</sup> Congress of the International Society of Rock Mechanics**, Lisbon, Portugal. Contact: Sociedade Portuguesa de Geotecnia, LNEC, Av. do Brasil, 101, 1700-066 Lisboa, Portugal. Tel.: +351 218443321; fax: +351 218443021; e-mail: [spg@Inec.pt](mailto:spg@Inec.pt); website: [www.isrm2007.org](http://www.isrm2007.org)

**July 22–27 Euroclay 2007**, Aveiro, Portugal. Details: Prof. Fernando Rocha or Prof. Celso Gomes; e-mail: [cgomes@geo.ua.pt](mailto:cgomes@geo.ua.pt); web page: [www.ing.pan.pl/ecga\\_js/confer1.htm](http://www.ing.pan.pl/ecga_js/confer1.htm)

**August 12–17 15<sup>th</sup> International Zeolite Conference (15<sup>th</sup> IZC)**, Beijing, China. Contact: Prof. Shilum Qiu, Organizing Secretary, 15<sup>th</sup> IZC, State Key Laboratory of Inorganic Synthesis and Preparative Chemistry, Jilin University, Linyuan Road 1788, Changchun 130012, China. Tel.: +86-431-5168590; fax: +86-431-5168614; e-mail: [izc@jlu.edu.cn](mailto:izc@jlu.edu.cn); website: [www.15izc.org.cn](http://www.15izc.org.cn)

**August 13–17 Meteoritical Society Annual Meeting**, Tucson, AZ, USA. Details: Dr. Tim Jull; e-mail: [jull@u.arizona.edu](mailto:jull@u.arizona.edu); web page: <http://metsoc2007.org>

**August 13–18 Twelfth International Symposium on Water–Rock Interaction (WRI-12)**, Kunming, China. Details: Secretary General, Yanxin Wang, School of Environmental Studies, China University of Geosciences, 430074 Wuhan, P. R. China. Tel.: +86-027-67885040; fax: +86-027-87481365; e-mail: [wri12@cug.edu.cn](mailto:wri12@cug.edu.cn); website: [www.wri12.org](http://www.wri12.org)

The meetings convened by the participating societies are highlighted in yellow. This meeting calendar was compiled by **Andrea Koziol**.

To get meeting information listed, please contact [Andrea.Koziol@notes.udayton.edu](mailto:Andrea.Koziol@notes.udayton.edu)

# When Art Meets *Elements* The Color of Iron

*The Color of Iron* exhibition, presented at the Chazen Museum of Art, Madison, Wisconsin, USA, from January 14 through March 19, 2006, explores the relationship between art and science and showcases iron and the range of colors it can produce by fusing an understanding of chemical techniques with applications in art. The exhibition features the work of four artists who use the chemical effects of iron-based materials to produce color in their art.

These parting shots were submitted by Joe Skulan, a scientist at the University of Wisconsin–Madison Geology Museum, who curated this exhibition.



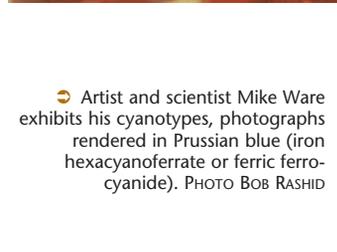
☞ Ceramic artist John Britt's work shows the effects of iron in glazes fired at high temperatures, including the creation of stunning reds and jewel-like blacks. PHOTO SCOTT SHAPIRO



☞ The centerpiece of the exhibit is a sculpture by Scott Shapiro called "Alchemy in Flight," made of krypton plasma in tubes of iron-tinted glass. PHOTO SCOTT SHAPIRO



☞ Sandra McPherson's paintings showcase the varieties of ochre pigments produced from iron. PHOTO BOB RASHID



☞ Artist and scientist Mike Ware exhibits his cyanotypes, photographs rendered in Prussian blue (iron hexacyanoferrate or ferric ferrocyanide). PHOTO BOB RASHID



☞ The exhibit also includes a collaborative installation titled *The Alchemist's Workbench*, featuring devices and materials that demonstrate the full spectrum of iron-based color. PHOTO BOB RASHID

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Canadian Light Source	30
CrystalMaker	64
Excalibur Mineral Corporation	36
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Meiji Techno America	36
National Science Foundation	64
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**The Hudson Institute of Mineralogy**  
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## DIRECTOR, DIVISION OF EARTH SCIENCES

National Science Foundation, Arlington, VA

NSF's Directorate for Geosciences seeks candidates for the position of Director, Division of Earth Sciences (EAR). The Division supports proposals for research geared toward improving the understanding of the structure, composition, and evolution of the Earth and the processes that govern the formation and behavior of the Earth's materials. Information about the Division's activities may be found at website: <http://www.nsf.gov/geo/ear/about.jsp>.

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Announcement S20060036-C, with position requirements and application procedures are posted on NSF's Home Page at website:

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Applicants may also obtain the announcements by contacting Executive Personnel Staff at 703-292-8755 (Hearing impaired individuals may call TDD 703-292-8044).

**Applications must be received by March 20, 2006.**

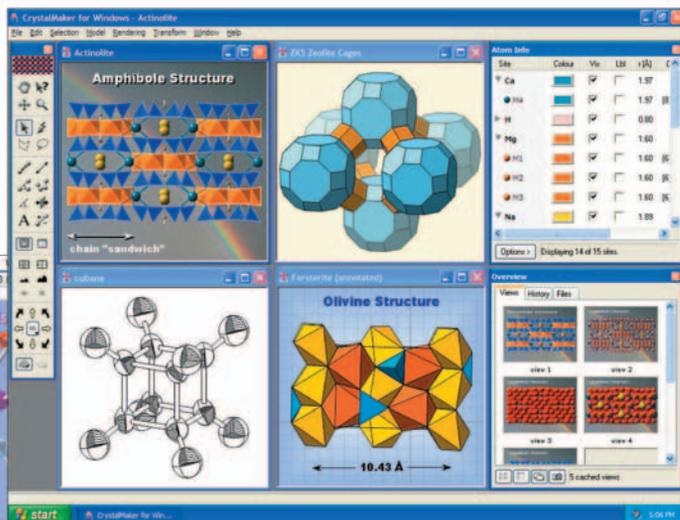
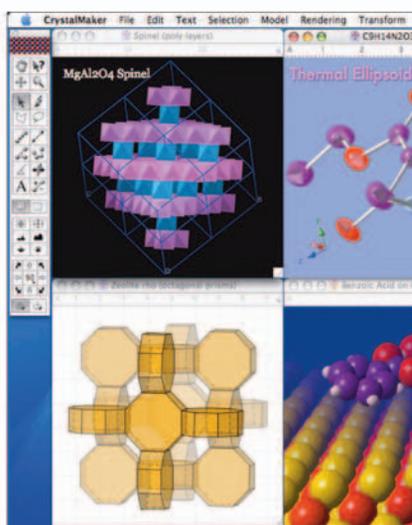
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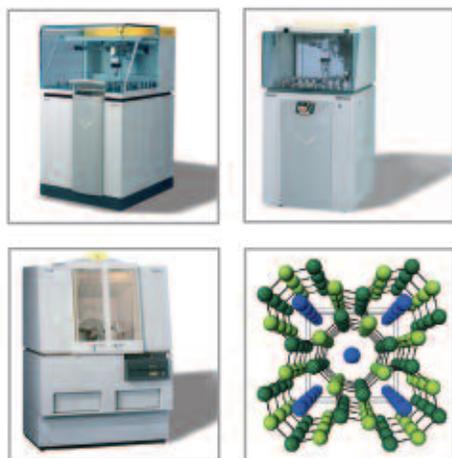
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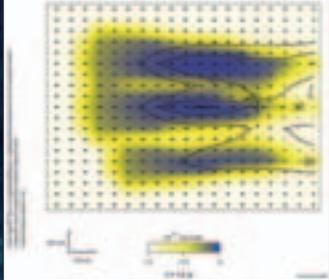
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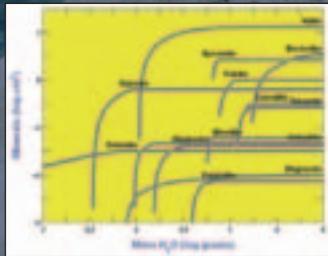


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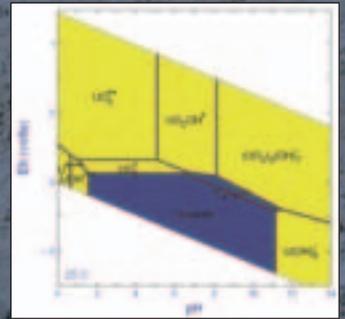


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