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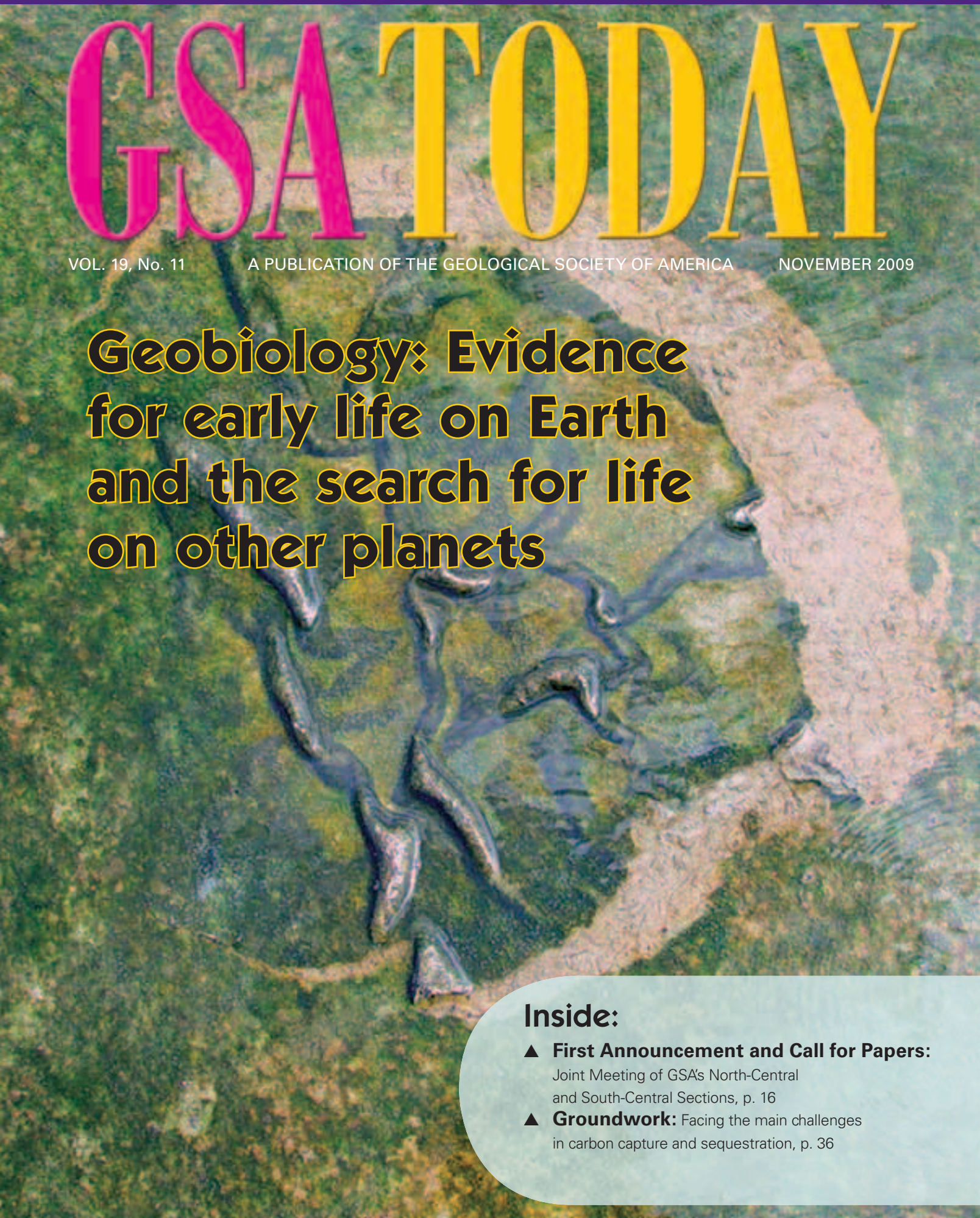
Geobiology: Evidence for early life on Earth and the search for life on other planets



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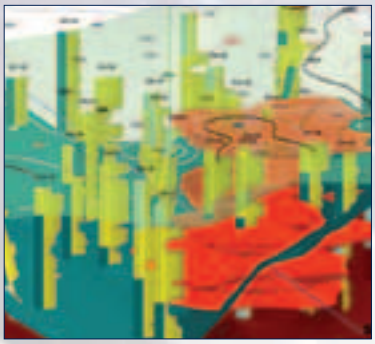

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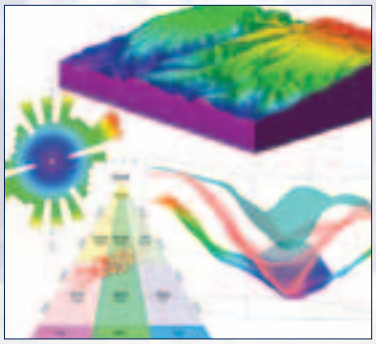

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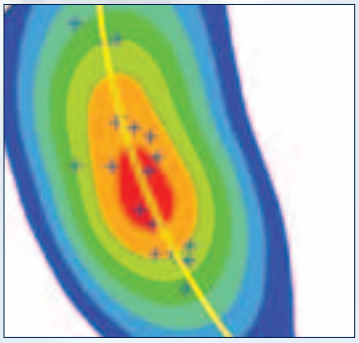

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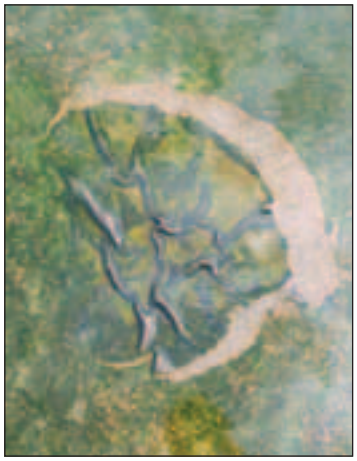

Cover: Modern microbial mat on a sandy depositional surface (photo by Nora Noffke). In modern tidal environments, benthic cyanobacteria form carpet-like microbial mats of sometimes square kilometers in extent—one of Earth's largest ecosystems. The interaction of sediment-stabilizing microbial mats with the physical sediment dynamics causes the characteristic "microbially induced sedimentary structures" (MISS). See "Geobiology: Evidence for Early Life on Earth and the Search for Life on Other Planets" by S.L. Cady and N. Noffke, p. 4–10.

Erratum

A symbol on p. 8 of the October *GSA Today* science article (v. 19, no. 10, p. 4–10), in the first sentence under the heading "NATURAL REACTORS—THEORETICAL CONSIDERATIONS," was dropped during typesetting. The sentence should read, "A critical fission reactor requires that the number of fission-inducing neutrons emitted per fission is ≥1."

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Geobiology: Evidence for early life on Earth and the search for life on other planets

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ABSTRACT

Extensive research efforts in the subdisciplinary field of geobiology have focused on the interactions between Earth and life through time. As a consequence, gaps in our knowledge of Earth's history are closing, and the search for life beyond Earth is expanding. A few examples of geobiology studies designed to advance our understanding of life on early Earth and to improve the chances of finding life on other planets are provided to highlight recent developments and research areas that are on the verge of new discoveries.

INTRODUCTION

A central theme in geobiology is the coevolution of biological and surficial geological processes. As illustrated in Figure 1, the synthesis of data sets gleaned from modern ecosystems, ancient deposits, and experimental systems enables geobiologists to test hypotheses generated from key interdisciplinary questions. Such an integrated approach makes it possible to refine increasingly sophisticated models designed to reconstruct past environmental and evolutionary events, predict future fluctuations over a range of spatial and temporal scales, and improve experimental study of the influence of biology on chemical and physical processes, and vice versa. Never before has the potential for interdisciplinary research among geoscientists and bioscientists been more fruitful, as is reflected in our expanding comprehension of Earth's history and early life.

LIFE'S IMPRINT—DECIPHERING ANCIENT BIOSIGNATURES

An understanding of the coevolution of life and its physical and chemical settings relies on the ability to decipher evidence of life preserved in the rock record. While any phenomenon produced by life (modern or ancient) can be considered a biosignature (cf. Steele et al., 2005), the main challenge in ancient and extraterrestrial life detection is determining whether the phenomenon (or suite of phenomena) can be uniquely attributed to life. Taphonomic changes inevitably alter the chemical and structural fidelity of all biosignatures over time.

Biosignatures of microorganisms fall into one of three categories (Cady et al., 2003): (1) bona fide cellular fossils (cf. Cady, 2002) and carbonaceous remnants of microbial cells and their extracellular matrices (Cady, 2001); (2) microbially influenced fabrics and sedimentary structures (which include some laminated stromatolites; cf. Grotzinger and Knoll, 1999); and (3) chemical fossils (e.g., organic compounds, such as biomarkers; inorganic phases, such as some minerals, mineraloids, and gases; stable isotopic patterns associated with life in organic and inorganic constituents; and disequilibrium phase enrichments [Des Marais et al., 2008a]).

A dramatic secular change in Earth's history has been the impact of life on the diversity of minerals. Hazen et al. (2008) estimated that, over the past 4.56 billion years, the number of different minerals has increased from about a dozen to more than 4300 known types. Though only a small number of these can be considered biominerals (i.e., chemical fossils), even their use as definitive evidence for life remains, justifiably, problematic (e.g., Golden et al., 2004; Altermann et al., 2009). In any case, biology has altered the relative abundances of different groups of minerals (most notably since the oxidation of the atmosphere), expanded the range of compositional variants (which include solid solutions and minor and trace element variations), affected the kinetics of mineral formation (hence the degree of ordering and density/type of defect microstructure), and created distinctive morphological habits. The emergence of key microbial metabolic innovations throughout Earth's history and development of bioskeletons during the Phanerozoic resulted in the biomineralization mechanisms that persist today (cf. Ehrlich and Newman, 2009). Collectively, the diverse metabolic and behavioral activities of life have created and sustained chemical gradients in geochemically dynamic environments, which has led to an abundance of mineral varieties distributed over scales that range from microenvironments around, and within, cells to regional-sized terrains.

Deciphering biosignatures and evidence of microbial activity in ancient rock remains a central challenge in geobiology studies (e.g., Rosing, 1999; Fedo and Whitehouse, 2002; Lepland et al., 2005). When surface-derived, organic-bearing rocks are transferred to Earth's shallow interior, the combination of burial and deformation can ultimately make it impossible to distinguish a biological signature in relict carbonaceous compounds (Pasteris and Wopenka, 2003; Brasier et al., 2005). Consequently, determination of the degree of metamorphism beyond which life's signatures are no longer recognizable in ancient carbon is a research topic of considerable interest in early Earth and extraterrestrial studies (e.g., Schopf and Kudryavtsev, 2009; Glikson et al., 2008; Oehler et al., 2009). For example, a recent approach focuses on the applicability and limitations of using Raman spectroscopy to characterize evidence of ancient life (e.g., van Zuilen et al., 2002; Schopf et al., 2005; McKeegan et al., 2007; Schiffbauer et al., 2007; van Zuilen et al., 2007; Marshall et al., 2007).

Isotopic studies continue to reveal new insight about the range of metabolic diversity on early Earth. For example, isotopic evidence for ancient sulfur-based metabolisms has recently been

GSA Today, v. 19, no. 11, doi: 10.1130/GSATG62A.1

advanced by the use of integrated ^{32}S, ^{33}S, and ^{34}S isotopic studies of sulfides and sulfates from chert-barite deposits at North Pole, northwestern Australia (Dresser Formation). Though the record of heavy sulfur ($^{34}S/^{33}S$) isotopes in microscopic sulfides preserved in early Archean barites has been known for some time (Shen et al., 2001), recent analyses of North Pole samples indicate that the combination of negative $\delta^{34}S$ and positive $\delta^{33}S$ values of these sulfides cannot be accounted for by microbial sulfate reduction (Philippot et al., 2007, 2008; Ueno et al., 2008). Microbial disproportionation of elemental sulfur is proposed as an alternative to sulfate reduction to explain the anomalous isotopic character of Archean sulfides from the Dresser Formation (Philippot et al., 2007, 2008).

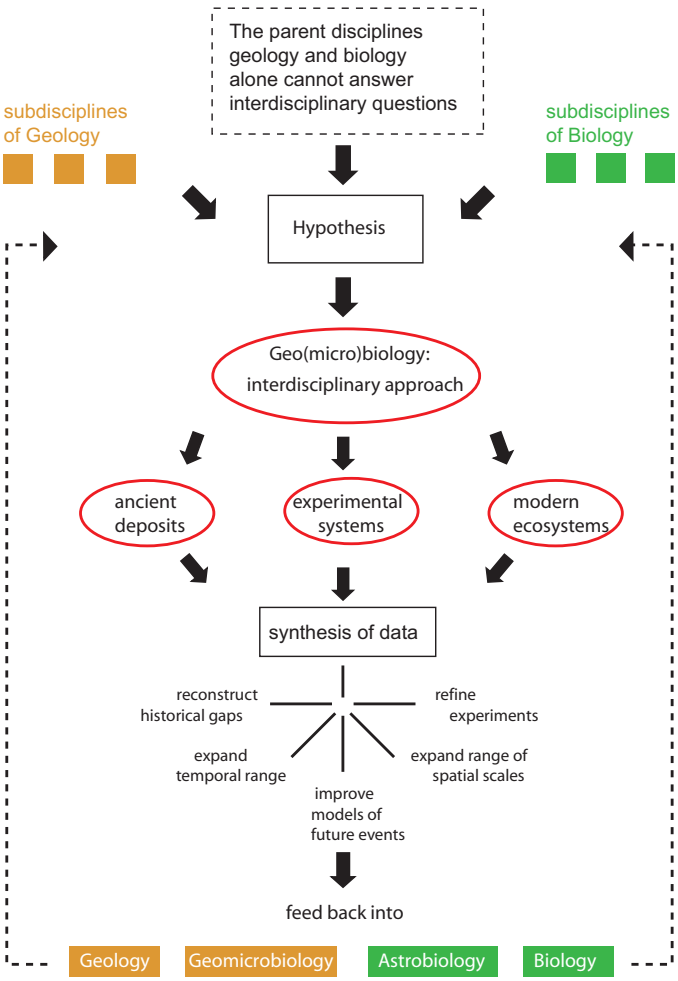

Figure 1. Schematic flow chart illustrating the logical outgrowth of the interdisciplinary science of geobiology. As hypotheses that involve topics and concepts from more than one discipline (i.e., from the parent disciplines geology and biology and related subdisciplines) arise, interdisciplinary approaches can be applied to study ancient deposits, experimental (abiotic and biotic) systems, and modern ecosystems. When such data sets are synthesized with one another in an iterative fashion, a new level of understanding can be achieved, one that makes it possible to reconstruct parts of Earth's history, expand our range of understanding across temporal (e.g., since the Archean Eon) and spatial (e.g., greater than planetary) scales, and refine our experimental approaches in laboratory and field settings. Results that improve the ability to model future events across the full range of spatial and temporal scales are particularly important at this time in Earth's history and allow us to predict the future impact of life on our planet. All of these outcomes can feed back into concepts needed to advance the parent disciplines of geology and biology and the subdisciplines of geobiology. They also typically contribute to fields like astrobiology. Illustration modified after Noffke (2005).

New evidence for a wider range of diversity in early metazoans and the microbial communities with which they lived has been found in recent years (e.g., Narbonne, 2005), in part because of the application of new analytical tools to characterize the morphology of these ancient life forms. A particularly rich contribution to our understanding of early metazoan life has come from synchrotron-radiation X-ray tomographic microscopy studies of the lower Ediacaran Doushantuo Formation in the Yangtze Gorges area in China, which contains centimeter-sized chert nodules that preserve metazoans, cyanobacteria, multicellular algae, spiny acritarchs, and animal eggs and embryos (Hagadorn et al., 2006; Donoghue et al., 2006; Xiao et al., 2007). For a recent review of the variety of synchrotron-based X-ray spectroscopy and microscopy techniques, see Templeton and Knowles (2009). It is worth noting that the application of a variety of nanotomographic techniques is on the rise. For example, three-dimensional renderings of different forms of acritarchs have been obtained with the use of optical microscope (Sugitani et al., 2009) and focused ion-beam (Kempe et al., 2005; Schiffbauer and Xiao, 2009) nanotomography.

MODERN ECOSYSTEM AND EXPERIMENTAL STUDIES: INSIGHTS INTO EARLY LIFE ACTIVITIES

Though the use of modern analog (similar but not identical) settings to gain insight into the processes that may have occurred in ancient environments is not new, such strategies have been key drivers in recent geobiology studies. For example, an ancient sedimentary deposit inextricably linked to biological activity is the banded iron formation (BIF). These iron-rich (~20%–40% Fe) siliceous (~40%–50% SiO_2) rocks, which often contain carbonate and sulfide facies, accumulated as sediments throughout much of the late Archean (2.7–2.5 Ga) and Paleoproterozoic (2.5–1.8 Ga) (e.g., Trendall, 2002; Klein, 2005). Though the mineralogy of BIFs dictates that some oxidation of Fe(II) had to have occurred, the relative contributions and nature of different types of abiotic and biotic (oxygenic photosynthesizers and Fe^{2+} oxidizers) mechanisms responsible for the formation of the iron in these deposits continues to be debated. Recent studies of ancient BIFs indicate that bacteria could have contributed in a number of ways to the accumulation of these visually stunning ancient deposits, which formed as sedimentary precipitates (e.g., Konhauser et al., 2002, 2007; Kappler et al., 2005; Johnson et al., 2008; Planavsky et al., 2009). Efforts to elucidate BIF accumulation mechanisms by studying modern analog ecosystems (e.g., Trouwborst et al., 2007; Parenteau and Cady, 2009) support the early hypothesis of Cloud (1965), which stressed the key role played by cyanobacteria. Reconciliation of theoretical arguments that focus on the range of possible microbial impacts with results from studies of modern ecosystems and ancient deposits may be possible by way of another approach essential to geobiology (e.g., Fig. 1); that is, a methodology based on the inclusion of experimental studies.

An example of an experimental approach carried out in a modern ecosystem involves recent studies of microbially

induced sedimentary structures (MISS) (Noffke and Paterson, 2008). Given that physical interactions between microbes and their environment are unlikely to have changed in a significant way throughout Earth's history, actualistic studies of such interactions can reveal the various ways in which microbial life affects the accumulation of detrital sediments. Studies in modern settings make it possible to observe and quantify the response of benthic microbiota to physical sediment dynamics. Biostabilization (Fig. 2) and baffling, trapping, and binding of microbiota associated with loose sediments generate a multitude of MISS (Noffke, 2009). For example, the sediment-stabilizing properties of the indigenous microbial consortium can be measured with a portable Manzenrieder flume chamber deployed in a modern ecosystem (Fig. 2A). In this experiment, an artificial water current that crosses the microbial mat surface is produced. A digital system analyzes the first release of sand grains from the flume chamber, an event that marks the start of erosion of the microbial mat. The effect of the microbial consortium on biostabilization of the sandy deposits is illustrated by the Shield's diagram in Figure 2B. Endobenthic microbial mats that colonize the uppermost millimeter of the sandy tidal surface reduce the erosive forces of the currents by 3–5 times compared to sterile sand (stars, Fig. 2B). Therefore, the mat-covered sand withstands currents of up to 0.90 cm/s. The biostabilization effect is caused by the lower degree of roughness of the mat-interwoven sedimentary surface. Since the grains do not protrude through the viscous sublayer, the flow across a microbial mat is hydrodynamically smooth, and only laminar flow, not the more intensive turbulent stress, affects the mat surface. Epibenthic microbial mats that cover the tidal sands like a carpet reduce the erosive forces up to magnitudes of 12 (dots, Fig. 2B). As a consequence, such thick mats withstand currents of up to 1.60 m/s. This biostabilization effect is due to the "slippery" mat surface, which prevents the direct influence of turbulent waters on the sand grains. This microbial effect can be expressed by a simple modification of the Shield's relation for sediment movement:

$$\Theta = \rho u_*^2 / (\rho_s - \rho_f)\, g\, D^n, \quad (1)$$

where u_* is the shear velocity; ρ_f is the density of fluid; ρ_s is the density of sediment; g is the gravity constant; D is the actual grain diameter under the influence of biostabilization; and n is the exponent to which D is raised for the data to comply to the Shield's relationship (cf. Führböter and Manzenrieder, 1987). Microbial sediment fixation is well documented in field and laboratory experiments (e.g., Neumann et al., 1970; De Boer, 1981; Grant, 1988, Dade et al., 1990; Schieber, 2007; and contributions in Noffke and Paterson, 2008).

RECOGNIZING BIOSIGNATURES IN EXTRATERRESTRIAL SYSTEMS

Geobiological approaches provide a foundation for astrobiological studies that focus on the search for extraterrestrial life on other planetary bodies. Conceptual frameworks for research in astrobiology (Des Marais et al., 2008b; Worms et al., 2009) pose the most intriguing questions in this field of inquiry: How does life begin and evolve? Does life exist elsewhere? What is the future of life on Earth and beyond? The possibility that Mars samples could be returned to Earth in our lifetime provides additional impetus to identify and characterize a wide range of biosignatures, even if they are present in minute amounts and altered from their pristine state (Farmer et al., 2009). Geobiology studies of ancient environmental settings, where life could have thrived, or of modern ecosystems, especially extreme ecosystems, are key in this regard. It has become apparent that a wide variety of environmental settings (e.g., Nisbet and Sleep, 2001) may have supported a diverse range of anaerobic (Canfield et al., 2006) and extremophilic life on early Earth (e.g., Rothschild and Mancinelli, 2001).

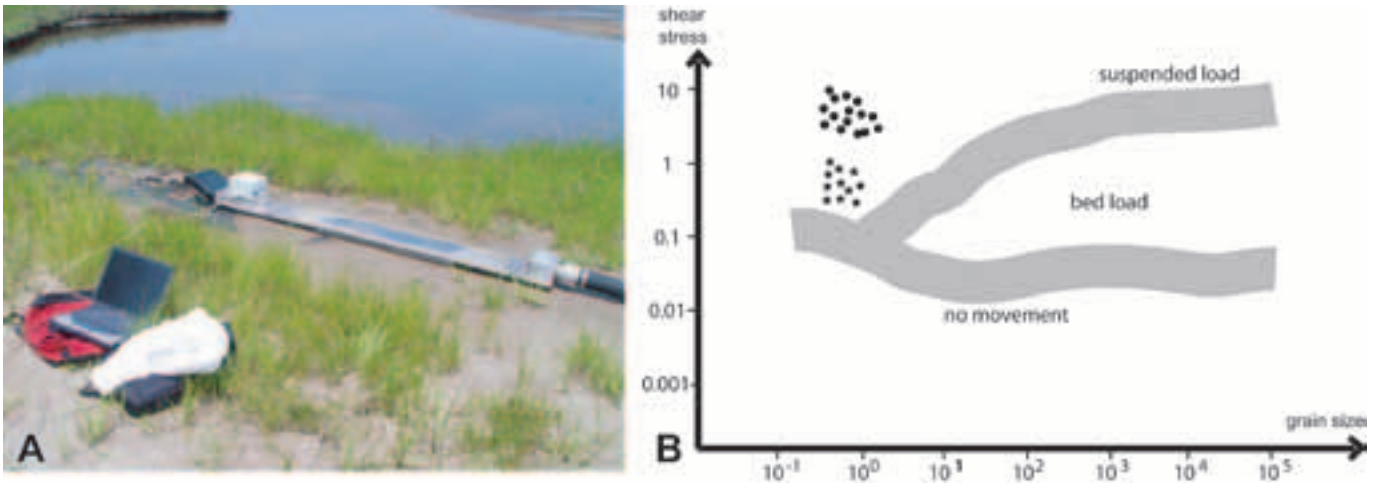

Figure 2. An example of a geobiological approach to the study of biostabilization of sediment by a microbial consortium (e.g., a microbial mat or biofilm). Photograph: Portable Manzenrieder flume chamber on a modern tidal flat surface. The Shield's diagram illustrates the impact of biostabilizing microbial mats on the potential for sediment transport. Dots—values of biostabilization by epibenthic microbial mats; stars—values of biostabilization by endobenthic microbial mats. Measurements from Portsmouth Island, USA, Aug. 2003–Nov. 2006, following Führböter and Manzenrieder, 1987.

It is possible that life emerged and became widespread on Earth prior to the Archean. Abramov and Mojzsis (2009) have used thermal models to argue that life would have persisted in subsurface niches during the late heavy bombardment period, a time when Earth's surface was being reworked by impactors of all sizes. Such findings reinvigorate the hypothesis that widespread hydrothermal activity, which produced subsurface biomes for chemotrophic hyperthermophilic communities, facilitated life's emergence and early diversification (Pace, 1997). Carbonaceous morphological remains of subsurface biofilms have now been found in hydrothermal precipitates produced by meteorite impacts (Hode et al., 2008, Fig. 3). Given the variety of fossil biosignatures likely to survive in hydrothermal deposits (e.g., Reysenbach and Cady, 2001; Konhauser et al., 2003), the possibility that ancient microbial life survived in hydrothermal niches has important implications for those involved in the search for ancient and extraterrestrial life (e.g., Farmer and Des Marais, 1999). Rock outcrops that could have resulted from hydrothermal activity on Mars have recently been reported (Squyres et al., 2008; Allen and Oehler, 2008).

Stromatolites have remained essential biological mileposts throughout Earth's history and are associated with a diverse range of microbial communities and environments (e.g., Reid et al., 2000; Grotzinger and Knoll, 1999; Cady et al., 2003; Allwood et al., 2007). Paleoarchean stromatolites, in particular, reveal the nature of Earth's earliest biosphere and the environmental conditions that supported and led to the preservation of this evidence for early life (e.g., Allwood et al., 2009). Studies of modern and equivalent fossil microbially induced sedimentary structures, the sandy counterpart of stromatolites (Noffke, 2009), will likewise be helpful in recognizing Earth's oldest environments and deciphering life's imprint on such structures, should they be found on Mars.

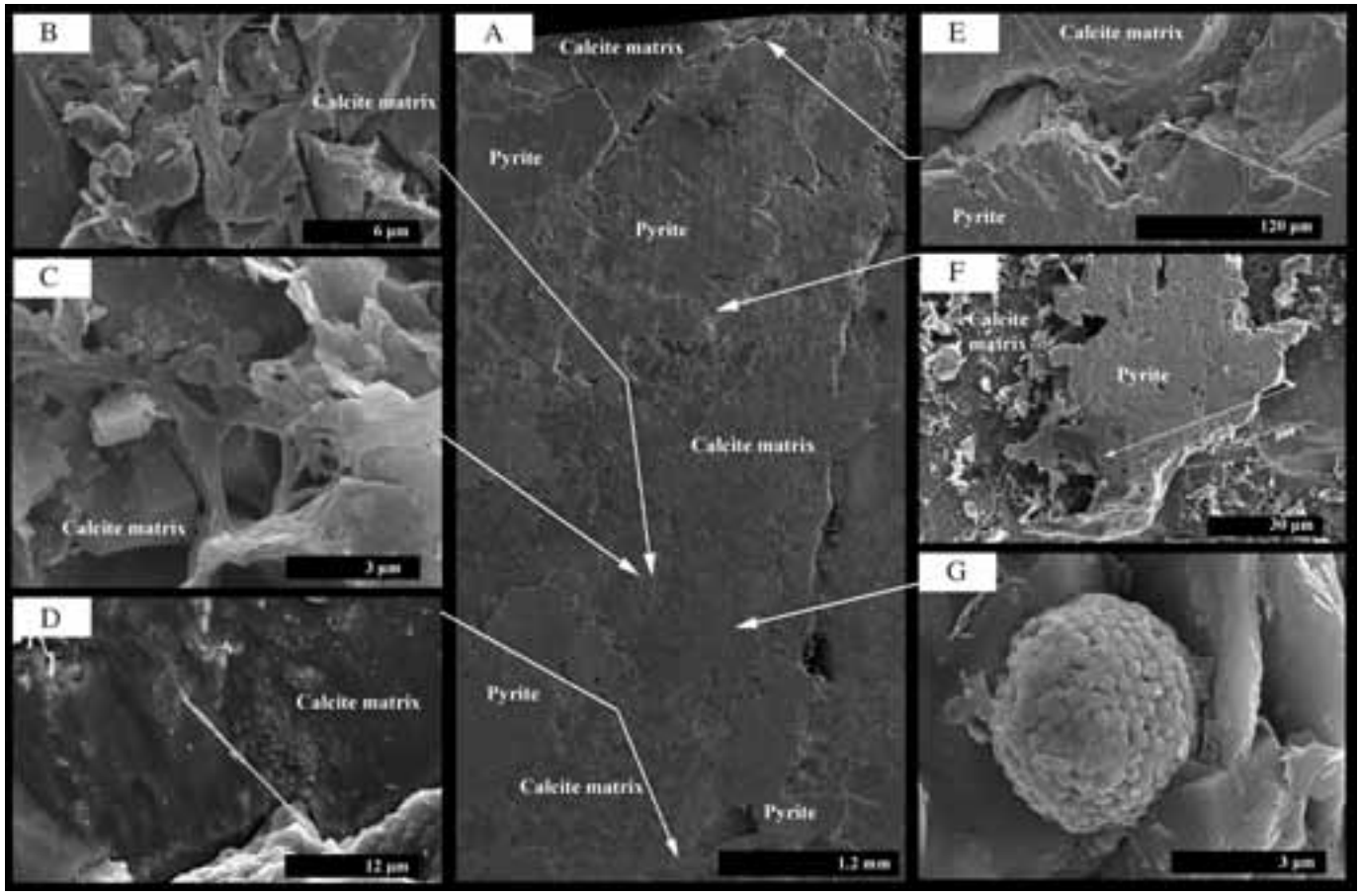

Figure 3. Examples of possible biosignatures revealed after chemical etching of calcite-filled veins that formed as a result of impact-induced hydrothermal activity associated with the Siljan Impact Structure, Sweden (see Hode et al., 2008, and references therein, for information on sample preparation and analytical methods). (A) Scanning electron microscope (SEM) photomicrograph montage of three low-magnification images provides an overview of the locations shown in B–G (arrows). Pyrite assemblages comprise the topographical highs because etching removed the top few tenths of micrometers of the surrounding calcite. Crack along the right side of image is the center of the hydrothermal vein. (B) Bundle of thread-shaped features shown in center of SEM image. (C) Adjacent area includes curved and torn features still partly embedded in the calcite crystal. (D) Filamentous feature attached to and extended between pyrite (topographical high) and the calcite matrix. (E) This perforated carbonaceous film (arrow) between a pyrite crystal and the calcite matrix was exposed after etching. A nuclear microprobe was used to identify the carbonaceous composition of the biofilm remnant. (F) Film-like feature wrapped around the edge of a pyrite aggregate (arrow) is fully pyritized as no evidence for carbonaceous matter could be found. Etching has removed the surrounding calcite and left the pyrite exposed as topographical highs. (G) Pyrite framboid inside the calcite matrix. Pyrite framboids are often found in reducing hydrothermal systems rich in carbonaceous matter. Figure originally published in Hode et al. (2008) and reprinted with permission.

CONCLUSION

The topics covered here exemplify some of the most recent approaches in geobiology and illustrate the link with astrobiology. They also serve to remind us that, though some of the most intriguing questions about early life's impact on rocky planets are yet to be answered, a geobiological approach is essential to our understanding of life and the role it has played throughout Earth's history.

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Dialogue

How is GSA Weathering the Financial Storm?

Everything considered, GSA is weathering the financial storm in reasonably good shape. The Society ended Fiscal Year (FY) 2009 (1 July 2008–30 June 2009) slightly ahead of budget, thanks to an all-out effort to reduce expenses beginning in early 2009. Expense reductions were in response to a general decline in revenue due to budget cuts at universities and corporations around the world. The expense reductions included energy and water conservation, travel reductions, a hiring freeze, staff compensation reductions, and other efforts. For example, GSA completed an extensive energy audit of the headquarters building and grounds, and resulting conservation efforts have significantly reduced our energy and water consumption, saving thousands of dollars.

Also in early 2009, as we began to build the FY2010 budget, we realized that we were going to have to work with greatly reduced transfers from both GSA and GSA Foundation investments. The FY2010 budget approved by Council in May 2009 included continued staff compensation reductions, termination of one non-staff contract, a continued hiring freeze, and a request to withdraw up to US$200,000 from GSA investments to cover operations. So far, we have avoided any major program cuts. A major topic at the September 2009 GSA Executive Committee and Senior Staff Retreat was development of a contingency plan for further expense cuts if necessary.

We project that FY2010 will remain very tight financially, but hope that the global financial picture will brighten as we enter FY2011. As I write this column (September 2009), GSA membership remains strong, journal subscriptions are steady, the Portland Annual Meeting is looking great with over 4,000 submitted abstracts, and our investments continue to recover.

Through all of this, we continue to uphold great service to GSA members, Divisions, Sections, Associated Societies, and other customers. We are cutting back where possible but not withdrawing into a shell. GSA needs to remain visible and maintain its new momentum in government affairs and reaching out as a global player while preserving core meeting, publication, and education & outreach activities.

How can GSA members help? You can continue to support GSA by maintaining your membership, attending meetings, buying publications, donating to the GSA Foundation, serving GSA's Sections and Divisions, and volunteering for GSA committees.

Thank you for your understanding as we go through this challenging financial period.

Jack Hess, *GSA Executive Director*

2010 Birdsall-Dreiss Distinguished Lecturer: Susan S. Hubbard

Susan S. Hubbard

Susan S. Hubbard is the 32nd GSA Birdsall-Dreiss Lecturer selected by GSA's Hydrogeology Division and the first from a National Laboratory. Hubbard is a staff scientist at Lawrence Berkeley National Laboratory, where she leads the Environmental Remediation and Water Resources Program. She earned a B.A. in geology from the University of California (UC) at Santa Barbara, an M.S. in geophysics from Virginia Tech, and a Ph.D. in engineering from UC-Berkeley. She has also worked for the U.S. Geological Survey and the petroleum industry.

Hubbard's research focuses on advancing the use of geophysical methods for shallow subsurface characterization and monitoring, with a particular emphasis on development of data integration methods and application of those methods to water resource and environmental-remediation problems. She co-edited the first book on hydrogeophysics and has published over 60 papers on this topic. Hubbard serves on several scientific advisory boards, as the associate director for the Berkeley Water Center, as a co-editor for the *Vadose Zone Journal*, and as an associate editor for the *Journal of Hydrology*.

At the request of interested institutions,
Susan will present one of the following two lectures.

More information and a lecture request form are online at
http://susanhubbard.lbl.gov/birdsall.html.

Toward X-Ray Vision: Geophysical Signatures of Complex Subsurface Processes

Developing a predictive understanding of water and contaminant fate and transport is complicated by natural heterogeneity, as well as by the disparity of scales across which hydrological, geochemical, and microbiological processes dominate. Because some geophysical attributes are sensitive to hydrological and biogeochemical properties that govern flow and transport, geophysical methods hold potential for minimally invasive subsurface characterization and monitoring. This presentation will describe recent hydrogeophysical and biogeophysical advances obtained using laboratory experiments; radar, seismic, and complex electrical field datasets; and stochastic integration methods. This seminar is intended for engineering, hydrogeology, and earth-science audiences who are interested in advanced approaches to explore complex subsurface systems as is needed to guide environmental remediation and water resources management.

Waves and Wine: Geophysical Characterization to Guide Precision Viticulture

Precision viticulture strategies that focus on promoting uniformly high wine grape quality throughout vineyard blocks require information about the nature and interaction of the factors that impact grape quality, such as soil moisture, canopy density, and micrometeorological properties. Although advanced ground-based and airborne geophysical datasets are now available to provide information about soil variability and vegetation, the wine industry is still at an early stage in using these approaches to guide viticulture. This presentation discusses advances in precision viticulture that have been realized at several California vineyards through experimentation and interpretation of geophysical attributes (electrical, ground-penetrating radar, and remote sensing) in terms of soil and canopy properties and the use of such data within statistical and water-balance numerical models to explore vineyard variability. The overall objective of this research is to use advanced approaches to delineate and guide the management of vineyards based on natural site variability. Such approaches are expected to lead to more uniform vegetation and wine grape characteristics within vineyard blocks, while potentially reducing water, fertilizer, and energy use. This lecture is intended for those interested in the practical use of advanced datasets to guide precision agriculture.

2010 Jahns Distinguished Lecturer: Paul Marinos

Paul Marinos received a mining engineering degree from the School of Mines of the National Technical University of Athens, Greece, in 1966; a postgraduate degree in applied geology from the University of Grenoble, France; and a doctorate in engineering geology from the same university in 1969. Marinos worked for French and Greek design and construction companies until 1977, when he was elected as a professor at Democritus University in Northern Greece. Since 1988, Marinos has been a professor of engineering geology in the School of Civil Engineering in the National Technical University of Athens and has served as head of the school's geotechnical section for several years. From 2001 to 2004 and from 2006 to 2008 Marinos was director of a graduate course in tunneling and underground construction. He was a visiting professor in the geology department of the University of Grenoble in 1987 and of the School of Mines in Paris in 2003.

Marinos is a GSA member as well as a member of the Association of Environmental & Engineering Geologists (AEG) and fellow of the Geological Society of London. He is a past president of the International Association of Engineering Geology and the Environment (IAEG), immediate past president of the Geological Society of Greece, and honorary member of the International Association of Hydrogeologists (IAH).

Awards received by Marinos include the IAEG Hans Cloos Medal and the Andre Dumont Medal of the Geological Society of Belgium. Marinos has also given several named lectures, including the 6th Glossop Lecture in London (2002), the 19th Rocha Lecture in Lisbon (2002), the 33rd Cross Canada Lectures Tour (2005), and the Rock Mechanics Annual Lecture in Madrid (2006).

Marinos and his team conduct research on a variety of applications of geology to engineering, mainly rock mass characterization and weak rock properties and behavior, with special emphasis on tunnel design. His work also covers landslides, dam geology, and engineering in karstic terrain, and Marinos has a significant interest in the protection of historic monuments and archeological sites. Marinos has authored or co-authored over 300 papers, and he has been a key or invited lecturer at more than 40 conferences or special events. He has also served as editor for proceedings published by international publishers and is an editorial board member for a number of prominent journals, including *Engineering Geology*, *Bulletin of the International Association of Geology*, *Landslides*, *Environmental Geology*, *Rock Mechanics*, and *Environmental and Engineering Geosciences*.

Marinos has extensive industrial experience, having served as consultant, independent reviewer, and member of consulting boards or expert panels on major civil engineering projects in Greece, France, India, Iran, Jordan, Morocco, Portugal, Saudi Arabia, Southeast Asia, Spain, Sweden, and Turkey.

Lectures

Lecture abstracts are online at http://users.civil.ntua.gr/marinos/. Requests for lectures should be directed to Paul Marinos at marinos@central.ntua.gr. The Jahns Lectures begin January 2010 and run through June 2010, while Marinos is on sabbatical leave in the United States. Some lectures can also be accommodated a week before each of the annual meetings of AEG and GSA in the fall of 2010.

University and college lectures can be arranged as one- or two-hour presentations. Lecture content will be adjusted according to the field of study of students—geology, civil, mining—and whether they attend an applied geology program.

Paul Marinos

Lecture Titles

- Ongoing challenges in engineering geology for tunneling in difficult ground;
- Geological constraints and geotechnical issues in mechanized tunneling;
- Tunneling through karstic rocks—How engineering geology needs hydrogeologic input and logic;
- Rock mass characterization; a vehicle to translate geology into the design of engineering structures;
- Geology in dam engineering—An evolving contribution of engineering geology for safety and efficiency; and
- Geology of Athens, Greece—A case of urban geology for land use, construction of major engineering structures, hazard assessment, and sustainable development.

About the Lectureship

The Association of Environmental & Engineering Geologists (AEG) and the Engineering Geology Division of the Geological Society of America (GSA) jointly established the Richard H. Jahns Distinguished Lectureship in 1988 to commemorate Jahns and to promote student awareness of engineering geology through a series of lectures offered at various locations around the United States. Richard H. Jahns (1915–1983) was an engineering geologist who had a diverse and distinguished career in academia, consulting, and government.

UPCOMING AWARD, RECOGNITION & GRANT DEADLINES

For details on the following awards and grants, see the October *GSA Today* or go to **www.geosociety.org/awards/nominations.htm.**
Information and nomination forms can also be obtained from GSA Grants, Awards, and Recognition, P.O. Box 9140, 3300 Penrose Place, Boulder, CO 80301-9140, USA, +1-303-357-1028, awards@geosociety.org.

2010 GSA MEDALS AND AWARDS

- Penrose Medal
- Day Medal
- Young Scientist Award (Donath Medal)
- GSA Public Service Award
- The Bromery Award for the Minorities
- GSA Distinguished Service Award
- Subaru Outstanding Woman in Science Award

Nomination deadline: 1 February 2010.

GSA FELLOWSHIP

Elevation to GSA Fellowship is an honor bestowed on the best of our profession at each spring GSA Council meeting. **GSA Fellows** may support two nominees each year but only one as a primary nominator, and **GSA members** who are not Fellows may be secondary nominators for up to two nominees. **Nomination deadline:** 1 February 2010.

AGI MEDAL IN MEMORY OF IAN CAMPBELL

The AGI Medal in Memory of Ian Campbell recognizes singular performance in and contribution to the profession of geology. To submit a nomination, go to www.agiweb.org/direct/awards.html. **Nomination deadline:** 1 February 2010.

2010 NATIONAL AWARDS

- **William T. Pecora Award:** http://remotesensing.usgs.gov/pecora.php.
- **National Medal of Science:** www.nsf.gov/od/nms/medal.jsp.
- **Vannevar Bush Award:** www.nsf.gov/nsb/awards/bush.jsp.
- **Alan T. Waterman Award:** www.nsf.gov/od/waterman/waterman.jsp.
- **G.K. Warren Prize:** www.nasonline.org/site/PageServer?pagename=AWARDS_warren.

Nomination deadline: 1 February 2010.

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

In cooperation with the Association of American State Geologists and supported by endowment income from the GSA Foundation's John C. Frye Memorial Fund, GSA makes an annual award for the best paper on environmental geology published either by GSA or by a state geological survey. **Nomination deadline:** 31 March 2010.

2010 STUDENT RESEARCH GRANTS

Applications will be accepted online beginning early December. Paper applications or letters will not be accepted. **Submission deadline:** 1 February 2010 at 11:59 p.m. (MST) to www.geosociety.org/grants/gradgrants.htm.

2010 POST-DOCTORAL RESEARCH AWARDS

The following post-doc research awards are managed by the GSA Foundation. Learn more at www.geosociety.org/grants/postdoc.htm.

- The **Gladys W. Cole Memorial Research Award** for research on the geomorphology of semiarid and arid terrains in the United States and Mexico is awarded annually to a GSA member or Fellow between 30 and 65 years of age who has published one ore more significant papers on geomorphology.
- The **W. Storrs Cole Memorial Research Award** for research on invertebrate micropaleontology is awarded annually to a GSA member or Fellow between 30 and 65 years of age who has published one or more significant papers on micropaleontology.

Application deadline: 1 February 2010.

Section Meeting
MENTOR PROGRAMS

STUDENTS — *Interested in a career in the applied geosciences?*

We hope you'll plan to attend a **Roy J. Shlemon Mentor Program in Applied Geoscience** and/or a **John Mann Mentors in Applied Hydrogeology Program** at your 2010 Section Meeting. These are great opportunities for you to chat one-on-one with practicing geoscientists, who will answer your questions and share insights on how to get a job after graduation.

PROFESSIONALS — *Interested in talking to students about your applied geoscience career?*

Being a mentor is a rewarding experience—if you'd like to learn more, please contact Jennifer Nocerino, jnocerino@geosociety.org.

CALL FOR APPLICATIONS

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Congressional Science Fellowship

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Deadline for application: 1 February 2010

The GSA-USGS Congressional Science Fellowship provides a rare opportunity for a unique individual. Prospective candidates are GSA Members with a broad geoscience background and excellent written and oral communication skills. Minimum requirements are a master's degree with at least five years professional experience or a Ph.D. at time of appointment. This fellowship is open only to U.S. citizens or permanent U.S. residents.

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JOINT MEETING

**44th Annual Meeting,
North-Central Section, GSA
44th Annual Meeting, South-Central Section, GSA
Branson, Missouri, USA**

11–13 April 2010

Table Rock Lake, Missouri, USA. Photo courtesy of Branson/Lakes Area Convention and Visitors Bureau.

On behalf of GSA's North-Central and South-Central Sections, Missouri State University and Emporia State University are pleased to host the 2010 joint meeting in Branson, Missouri, USA. In the heart of the Ozarks, Branson is surrounded by spectacular geology, including numerous caves, springs, lakes, and glades. The meeting will be held at the new Hilton Convention Center at Branson Landing, on the shore of Lake Taneycomo.

CALL FOR PAPERS

Abstract deadline: 19 January 2010

Submit online at www.geosociety.org/meetings/

Submission fee: US$10

Contact Nancy Wright, +1-303-357-1061, nwright@geosociety.org, if you cannot submit via the online system.

TECHNICAL PROGRAM

Symposia

1. **They Say That "Breaking Up Is Hard To Do": Geological, Geophysical, and Remote Sensing Investigations of Continental Rifts.** Mohamed Abdelsalam, abdelsam@mst.edu, Missouri University of Science and Technology (MS&T); John Hogan, jhogan@mst.edu, MS&T; Kelly H. Liu, liukh@mst.edu, MS&T.
2. **Advances in the Chronology, Correlation, and Stratigraphy of Pre-Wisconsinan Glacigenic Sediments.** Charles Rovey, Missouri State University, charlesrovey@missouristate.edu; Greg Balco, Berkeley Geochronology Center, balcs@bgc.org.
3. **Geological Aspects of the Civil War.** Sherman Lundy, BMC Aggregates, sherml@bmcaggregates.com; George Davis, Missouri Dept. of Transportation, George.Davis@modot.mo.gov; Joseph T. Hannibal, Cleveland Museum Natural History, hannibal@cmnh.org.
4. **Sedimentary Geology of the North American Craton and its Southern Margin.** *Cosponsored by Great Lakes Section, SEPM.* John Groves, University of Northern Iowa, john.groves@uni.edu.
5. **Cultural Geology: Archaeological and Historic Building Stones, Sites, and Materials; Terrain, Terroir, and More.** Joseph T. Hannibal, Cleveland Museum of Natural History, hannibal@cmnh.org; Andrew Bauer, University of Chicago, bauer@uchicago.edu.
6. **Geology and Public Policy Forum—Reclamation in the Tri-State Lead-Zinc Mining District: A Trans-Boundary Effort.** *Cosponsored by the GSA Geology and Society Division.* Moderators: Rex Buchanan, rex@kgs.ku.edu; Marcia Schulmeister, mschulme@emporia.edu. Panelists: David Drake, U.S. EPA Region 7; Paul Baumgarten, U.S. EPA Region 6; Rebecca Jim, Local Environmental Action Demanded; Cheryl Seeger, Missouri Division of Geology and Land Survey.

Theme Sessions

Tectonics, Regional Geology, and Precambrian Geology

1. **Lithospheric Structure of the Mid-Continent Region: What We Know, What We Need to Know, and What EarthScope Can Tell Us.** *Cosponsored by the GSA Geophysics Division.* G.R. Keller, University of Oklahoma, grkeller@ou.edu; Kevin Mickus, Missouri State University, kevinmickus@missouristate.edu.
2. **Geological Evolution of the Sierra Madre Oriental, Mexico.** José Guadalupe Lopez Oliva, Universidad Autónoma de Nuevo León, joseglop@ccr.dsi.uanl.mx, Juan Alonso Ramírez Fernández, Universidad Autónoma de Nuevo León, juanaram@prodigy.net.mx.
3. **Precambrian Geology of the Midcontinent: Celebrating the Career of W.R. Van Schmus.** Renee Rohs, Northwest Missouri State University, RROHS@nwmissouri.edu.

4. **Geology of the Ozark Plateaus.** Mark R. Hudson, USGS, mhudson@usgs.gov; Angela Chandler, Arkansas Geological Survey, angela.chandler@arkansas.gov.

Paleontology, Stratigraphy, and Sedimentology

5. **Current Conodont Research: A Pander Society Session in Honor of Raymond Ethington, Tom Thompson, and Jim Miller.** *Cosponsored by the Pander Society.* Darwin Boardman, Oklahoma State University, darwin.boardman@okstate.edu; Damon Bassett, Missouri State University, damonbassett@missouristate.edu; John Repetski, USGS, jrepetski@usgs.gov.
6. **Ichnofossils: The Marriage of Sedimentology and Ecology.** *Cosponsored by the Paleontological Society.* Katherine Bulinski, Bellarmine University, kbulinski@bellarmine.edu; Karen Koy, Missouri Western State University, kkoy@missouriwestern.edu.
7. **Paleoecology: Variation in Fossil Communities through Space and Time.** *Cosponsored by the Paleontological Society.* Benjamin Dattilo, Indiana University-Purdue University–Fort Wayne, ben.dattilo@gmail.com; Katherine Bulinski, Bellarmine University, kbulinsk@bellarmine.edu.
8. **Mid-Continent Paleontology.** Michael Morales, Emporia State University, mmorales@emporia.edu.
9. **Pennsylvanian and Permian Cyclothems of Midcontinent North America.** John Pope, Northwest Missouri State University, jppope@nwmissouri.edu; Tom Marshall, Iowa Geological Survey, Thomas.Marshall@dnr.iowa.gov.
10. **Developments in Early Paleozoic Stratigraphy in the U.S. Midcontinent.** Robert L. Ripperdan, Saint Louis University, ripperdan@eas.slu.edu; James D. Loch, University of Central Missouri, loch@ucmo.edu.

Engineering and Environmental Geology

11. **Environmental Microbiology: Intersections between the Biosphere and the Geosphere.** Melissa Lenczewski, Northern Illinois University, lenczewski@niu.edu.
12. **Is Mother Nature out to Get You? Medical Geology Issues in the Mid-Continent.** Robert B. Finkelman, University of Texas-Dallas, bobf@utdallas.edu; Syed E. Hasan, University of Missouri, hasans@umkc.edu.
13. **The 2005 Taum Sauk Reservoir Breach: Failure Mechanisms, Flood Effects, Bedrock Exposures, and Current Remediation Efforts.** Cheryl Seeger, Missouri Dept. of Natural Resources, cheryl.seeger@dnr.mo.gov; David J. Wronkiewicz, Missouri University of Science and Technology, wronk@mst.edu.
14. **Carbon Sequestration: Research, Deployment, and Commercialization.** Sallie Greenberg, Illinois State Geological Survey, Greenberg@isgs.illinois.edu.
15. **Water-Rock-CO_2 Interactions during Carbon Sequestering Activities.** David Wronkiewicz, Missouri University of Science and Technology, wronk@mst.edu; Melida Gutierrez, Missouri State University, mgutierrez@missouristate.edu.
16. **The Tri-State Mining District, a Decades-Long Project: Progress, Challenges, and Revelations.** Gina Manders, Emporia State University, mgblues@sbcglobal.net; Rebecca Jim, Local Environmental Action Demanded Agency, rjim@neok.com.

Energy and Economic Geology

17. **Devonian and Mississippian Strata of the Midcontinent North America: Sequence Stratigraphy, Paleontology, and Hydrocarbon Potential (Gas Shales, Carbonates, Cherts).** Darwin R. Boardman II, Oklahoma State University, darwin.boardman@okstate.edu; Salvatore J. Mazzullo, Wichita State University, salvatore.mazzullo@wichita.edu; Brian Wilhite, Woolsey Operating Co., bwilhite@woolseyco.com; Jim Puckette, Oklahoma State University, jpucket@okstate.edu.
18. **Ore Deposits of the Central U.S.: Origin, Mining, and Environmental Remediation.** Martin Appold, University of Missouri–Columbia, appoldm@missouri.edu; Kevin Shelton, University of Missouri–Columbia, sheltonkl@missouri.edu.

Geoscience Education

19. **Issues in Geoscience Education.** *Cosponsored by National Association of Geoscience Teachers–Central Section.* Kathleen Bower, Eastern Illinois University, kmbower@eiu.edu.
20. **Arts Integration in K–16 Geoscience Education.** *Cosponsored by National Association of Geoscience Teachers.* P. Allen Macfarlane, Kansas Geological Survey, dowser@kgs.ku.edu; Gary Rosenberg, Indiana University–Purdue University, grosenbe@iupui.edu.
21. **Teaching Sustainability.** *Cosponsored by National Association of Geoscience Teachers.* David H. Voorhees, Waubonsee Community College, dvoorhees@waubonsee.edu.
22. **Easy-to-Incorporate Inquiry-Based Activities for the K–16 Classroom.** *Cosponsored by National Association of Geoscience Teachers–Central Section.* Carrie Wright, University of Southern Indiana, clwright@usi.edu.

Hydrogeology

23. **Water Resources Sustainability in the Deep Carbonate Aquifers of the Ozark and Midwest Regions: Will We Have Enough?** P. Allen Macfarlane, Kansas Geological Survey, dowser@kgs.ku.edu; John B. Czarnecki, USGS, jczarnec@usgs.gov.
24. **Karst Hydrogeologic Systems of the Central United States.** *Cosponsored by the GSA Hydrogeology Division.* Gary Marcus, Zara Environmental, marcus@zaraenvironmental.com; Benjamin Schwartz, Texas State University–San Marcos, bs37@txstate.edu.
25. **Aquifer Management Challenges: Unsustainable, Unbounded, Undefined, or Unregulated.** Susan Stover, Kansas Water Office, susan.stover@kwo.ks.gov; Robert Mace, Texas Water Development Board, robert.mace@twdb.state.tx.us.
26. **Tracers in the Environment: Tried and True or Something New—Identifying Issues with the Hydrogeologic System.** Margaret Townsend, Kansas Geological Survey, mtown@ku.edu; Ralph Davis, University of Arkansas, ralphd@uark.edu.

JOINT MEETING *continued on p. 18*

JOINT MEETING *continued from p. 17*

27. **Innovative Approaches to Characterization and Remediation of Contaminated, Unconsolidated Aquifers.** *Cosponsored by the GSA Hydrogeology Division.* Marcia Schulmeister, Emporia State University, mschulme@emporia.edu; Joseph Dom, Kansas Dept. of Health & Environment, jdom@kdheks.gov; Robert Weber, U.S. EPA, Robert.Weber@epamail.epa.gov.

Surficial Geology

28. **Reservoir Science: Sediment and Water-Quality Studies for Effective Management.** Kyle Juracek, USGS, kjuracek@usgs.gov.
29. **Speleogenesis, Processes and Records in Karst Systems.** Kevin Stafford, Stephen F. Austin State University, staffordk@sfasu.edu; Matt Covington, University of Minnesota, covin039@umn.edu.
30. **Human Impacts on Fluvial Systems.** Robert Pavlowsky, Missouri State University, bobpavlowsky@missouristate.edu; Marc Owen, Missouri State University, mowen@missouristate.edu.
31. **Urbanization Influences on Stream Geomorphology, Hydrology, and Sediment Transport.** Faith A. Fitzpatrick, USGS, fafitzpa@usgs.gov; Jordan Clayton, Georgia State University, jclayton@gsu.edu.

Other Sessions

32. **Undergraduate Research (Posters).** *Cosponsored by the Council on Undergraduate Research–Geosciences Division.* Jeanette Pope, DePauw University, jpope@depauw.edu.

FIELD TRIPS

For further information, please contact field trip leaders directly. Field trip coordinators: James S. Aber, jaber@emporia.edu; Kevin R. Evans, kevinevans@missouristate.edu.

Before the Meeting

1. **High-Resolution Sequence Stratigraphy of Upper Devonian and Mississippian Strata of the Ozark Region with Reference to Subsurface Kansas, Oklahoma, and Arkansas.** Wed.–Fri., 7–9 April. Darwin R. Boardman II, Oklahoma State University, darwin.boardman@okstate.edu; S.J. Mazzullo; Brian Wilhite; Jim Puckette; Thomas L. Thompson.
2. **Geology of Route 66 in Southwestern Missouri, Southeastern Kansas, and Northeastern Oklahoma: Legacy of the Tri-State Mining District.** Sat.–Sun., 10–11 April. James S. Aber, Emporia State University, jaber@emporia.edu; Susan W. Aber; Gina Manders; Aaron Johnson.
3. **Civil War and Cultural Geology of Southwestern Missouri, Part 1: The Geology of Wilson's Creek Battlefield and the History of Stone Quarrying.** Sat., 10 April. Joseph T. Hannibal, Cleveland Museum of Natural History, hannibal@cmnh.org; George H. Davis; Sherman Lundy; Kevin R. Evans.
4. **Innovative Stormwater Management Practices.** Sat., 10 April. Holly D. Neil, James River Basin Partnership, hneil@missouristate.edu; Robert T. Pavlowsky.
5. **Introduction to Karst Land scape Development–Ozark Underground Laboratory.** Sun., 11 April. Tom Aley; Douglas Gouzie, douglasgouzie@missouristate.edu.
6. **Civil War and Cultural Geology of Southwestern Missouri, Part 2: Geologic Influences on the Battle of Forsyth, Guerilla Activities, and Post-War Vigilantism.** Sun., 11 April. Kevin R. Evans, Missouri State University, kevinevans@missouristate.edu; George H. Davis.

After the Meeting

7. **Geomorphology and Paleontology of Riverbluff Cave, Springfield, Missouri.** Tues., 13 April. Matt Forir; Charles W. Rovey II, Missouri State University, charlesrovey@missouristate.edu; Greg Balco.
8. **Rift-Related Volcanism and Karst Geohydrology of the Southern Ozark Dome; Montauk to Big Spring—Geologic Framework of the Upper Current River Region.** Tues.–Thurs., 13–15 April. Gary R. Lowell, University of Texas at Arlington, lowell@uta.edu; Richard W. Harrison; David J. Weary; Randall C. Orndorff; John E. Repetski.
9. **Geology of Weaubleau and Decaturville Impact Structures, Missouri.** Tues.–Wed., 13–14 April. James F. Miller, Missouri State University, jimmiller@missouristate.edu; Kevin R. Evans.
10. **Geology of the Taum Sauk Reservoir Scour.** Tues.–Wed., 13–14 April. Cheryl M. Seeger, Missouri Division of Geology and Land Survey, cheryl.seeger@dnr.mo.gov; David Wronkowicz.
11. **Geology and Karst Landscapes of Buffalo National River, Northern Arkansas.** Wed., 14 April. Mark Hudson, USGS, mhudson@usgs.gov; Kenzie J. Turner; Chuck Bitting.

REGISTRATION

Early registration deadline:
8 March 2010

Cancellation deadline: 15 March 2010

www.geosociety.org/meetings/

Call for Papers

2010 GSA Section Meetings

13–16 March
Northeastern-Southeastern Joint Meeting, Baltimore, Maryland, USA.
Abstract submission opens
1 Oct.; deadline: 8 Dec. 2009.

11–13 April
North-Central–South-Central Joint Meeting, Branson, Missouri, USA.
Abstract submission opens
1 Nov.; deadline: 19 Jan. 2010.

21–23 April
Rocky Mountain, Rapid City, South Dakota, USA.
Abstract submission opens
1 Nov.; deadline: 26 Jan. 2010.

27–29 May
Cordilleran, Anaheim, California, USA.
Abstract submission opens
1 Dec.; deadline: 9 Mar. 2010.

Donna L. Russell, *Director of Operations*

GSA Foundation Fiscal Year '09 Highlights

Established in 1980 as an independent nonprofit corporation, the GSA Foundation's mission is to raise contribution revenue from all sources in order to provide funding for GSA programs and projects.

Despite the economic turmoil during fiscal year 2009 (FY09), the GSA Foundation was able to raise US$2,419,329 in contributions from 5,382 donors. A large portion of the dollars raised were from five bequests—GSA members planning ahead for the future of GSA.

The Foundation transferred a total of US$645,475 in FY09 to help fund several GSA programs and projects.

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**Term expires at GSA Foundation Trustees October 2009 meeting*

FY09 FOUNDATION BALANCE SHEET	
Assets	
Cash & Investments	$8,607,686
Pledge Receivables	$148,858
Unitrust Receivable	$311,538
Gifts in Kind	$2,881
Accounts Receivable	$4,485
Inventory—Medals/Software	$3,938
Total Assets	**$9,079,385**
Liabilities	
Due to GSA—Award & Programs	$109,269
Other Misc. Liabilities	$36,348
Total Liabilities	**$145,617**
Net Assets	
Unrestricted	$1,778,911
Temporary	$3,524,760
Permanent	$3,630,097
Total Net Assets	**$8,933,768**

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5. **Find opportunities for leadership, mentoring, and service.**
6. **Serve as a resource when GSA is called upon by the media for geosciences expertise or comment.**
7. **Divisions have a strong voice in the governance of the Society and help with strategic planning.**
8. **Divisions have a major role in the life and history of The Geological Society of America, starting with the first Division formed in 1947 (Engineering Geology).**
9. **Divisions build and shape the scientific exchange that moves the geoscience profession forward.**
10. **Division dues are low.**

DIVISIONS OVERVIEW

■ **Archaeological Geology,** est. 1977; 577 members. The Archaeological Geology Division provides a forum for the presentation and discussion of papers on archaeological geology in order to stimulate and promote research and teaching in this field. Division awards include the Rip Rapp Archaeological Geology Award, the Richard Hay Student Paper/Poster Award, and the Claude C. Albritton, Jr., Award memorial fund.

■ **Coal Geology,** est. 1954; 282 members. The Coal Geology Division encourages coal research and dissemination of coal geology information by actively participating in thought-provoking symposia and technical sessions at GSA's meetings and through scientifically pertinent publications. The Division sponsors a major award for outstanding contributions to the field of coal geology, the Gilbert H. Cady Award, and also recognizes the volunteered contributions of its members through its Distinguished Service Award. For students, the Division offers both the Antoinette Lierman Medlin Scholarship and a best student paper award.

■ **Engineering Geology,** est. 1947 (GSA's first Division!); 785 members. The Engineering Geology Division promotes education, research, outreach, and application of engineering geologic knowledge to the betterment of human society by adopting sound design of buildings, structures, and facilities that assure public safety and a healthy environment. Each year, this Division honors geologists with the E.B. Burwell, Jr., Award and, along with the Association of Environmental and Engineering Geologists, commissions the Richard H. Jahns Distinguished Lecturer. Other Division awards include the Meritorious Service Award, the Distinguished Practice Award, and Roy J. Shlemon Scholarship and Meeting Awards.

■ **Geobiology & Geomicrobiology,** est. 2001; 354 members. The Geobiology & Geomicrobiology Division brings together scientists working at the interface of biology and geology and integrates these disciplines by simultaneously promoting both the broad scope and the detailed, disciplined work demanded of rigorous interdisciplinary research. Fields currently represented within this Division include biogeochemistry, biomineralogy, geochemical ecology, paleontology, micropaleontology, origins of life and coevolution of planets and life, paleobiology and paleoecology, molecular paleontology and ecology, systems modeling and informatics, and astrobiology. This Division sponsors a best student poster award.

Learn more and sign up at **www.geosociety.org/sectdiv/divisions.htm.**

■ **Geoinformatics,** est. 2006; 200 members. The mission of the Geoinformatics Division is to advance "Data to Knowledge"—providing GSA members with an opportunity to participate in the emerging field of cyberinfrastructure. The Division actively promotes and sponsors short courses, symposia, and books that emphasize information technology–supported discovery and integration of geoscience data leading to a more comprehensive understanding of Earth and the planets as complex systems.

■ **Geology and Health,** est. 2005; 250 members. The Geology and Health Division focuses on the intersection of natural or anthropogenic geological conditions with health, disease, pathology, and death in fossil and modern humans, animals, and plants. This Division fosters communication and collaboration among scientists and health practitioners with an emphasis on the interdisciplinary relationship of geology with medicine, biology, chemistry, and related sciences.

■ **Geology and Society,** est. 2003; 373 members. The motto of the Geology and Society Division is "geology working for society." By increasing the geoscience community's knowledge of societal issues and improving the community's overall communication skills, this Division works to ensure accurate and intelligent dissemination of geologic information to society as a whole. This Division sponsors a best student paper award.

■ **Geophysics,** est. 1971; 542 members. The Geophysics Division facilitates the presentation and discussion of the challenges and ideas of scientists interested in geophysics, fosters communication among geophysicists and other earth scientists, and promotes research and publication. This Division sponsors the George P. Woollard Award and lecture for outstanding contributions to geology through the application of the principles and techniques of geophysics. For students, the Division offers the Allan V. Cox Student Research Award and the GSA Geophysics Division Student Research Award.

■ **Geoscience Education,** est. 1991; 1,087 members. The purpose of the Geoscience Education Division is to foster the active participation of GSA members in all aspects of earth-science education. The Division complements and expands on the contributions of GSA's Education & Outreach group, the National Earth Science Teachers Association (NESTA), the National Association of Geoscience Teachers (NAGT), the National Science Teachers Association (NSTA), and other similar organizations. This Division sponsors the Biggs Earth Science Teaching Award.

■ **History of Geology,** est. 1976; 408 members. GSA's History of Geology Division encourages the study and communication of the history of geology. The Division sponsors technical sessions at GSA meetings and honors geologists for their research, writing, and historical work through the Mary C. Rabbitt History of Geology Award, the Gerald M. and Sue T. Friedman Distinguished Service Award, and the History of Geology Student Award. The Division manages the *GSA Today* "Rock Stars" article series, which highlights the life and work of "giants in geology."

■ **Hydrogeology,** est. 1959; 1,483 members. The Hydrogeology Division focuses on the geologic aspects of hydrogeology, the role of geology in the hydrologic cycle, and the importance of hydrogeology to society and science. The Division has a well-established mentor program for students looking at careers in hydrology or hydrogeology: the John Mann Mentors in Applied Hydrogeology Program. The Birdsall-Dreiss Distinguished Lecturer honorees are named by this Division, along with the O.E. Meinzer Award, the Division's Distinguished Service Award, and the Hydrogeology Division Student Research Grant Awards.

■ **Limnogeology,** est. 2002; 234 members. The Limnogeology Division centers on the study of both ancient and modern lakes around the world, encourages interdisciplinary collaboration, and fosters student research and careers in lake studies. The Division sponsors the Kerry Kelts Research Awards for students and in 2010 will present its inaugural Israel C. Russell Award.

■ **Planetary Geology,** est. 1981; 605 members. The Planetary Geology Division is the GSA Division "with the biggest field area!" Awards sponsored by this Division include the G.K. Gilbert Award, the Eugene M. Shoemaker Impact Cratering Award for students, the Stephen E. Dwornik Student Research Paper Award, and (jointly with the Meteoritical Society) the Pellas-Ryder Award for the best student paper in planetary science.

■ **Quaternary Geology and Geomorphology,** est. 1955; 1,630 members. The Quaternary Geology and Geomorphology Division facilitates communication among scientists in these fields and the presentation of their research and ideas to the wider scientific community. Several awards are given by this Division: the Distinguished Career Award, the Farouk El-Baz Award for Desert Research, the Don J. Easterbrook Distinguished Scientist Award, and the J. Hoover Mackin, Arthur D. Howard, and Marie Morisawa student research awards.

■ **Sedimentary Geology,** est. 1985; 1,334 members. The Sedimentary Geology Division works to ensure the presentation of sedimentary-related topics and sessions at GSA meetings and actively nurtures the work of students by offering the Sedimentary Geology Division Student Research Grant Award, student travel and poster awards, and financial aid for students to attend Division-sponsored short courses and field trips. The Laurence L. Sloss Award for outstanding accomplishments in sedimentary geology and contributions to GSA is also sponsored by this Division.

■ **Structural Geology and Tectonics,** est. 1980; 1,907 members. The Structural Geology and Tectonics Division focuses on the geometry and mechanisms of natural and experimental deformation at all scales and works to promote research in these fields and to facilitate communication and discussion at all levels of the earth sciences. This Division offers a Career Contribution Award for advancement of the science of structural geology and tectonics, a Best Paper Award, and a Division Research Grant Award.

Learn more and sign up at **www.geosociety.org/sectdiv/divisions.htm.**

Thank You 2009 GeoCorps™

Constantin Platon, paleontologist, BLM Gunnison Gorge National Conservation Area.

GeoCorps™ America places geoscientists of all levels—university students, teachers, professionals, and retirees—in short-term geoscience projects on public lands throughout the United States. These projects, hosted by the National Park Service (NPS), the U.S. Dept. of Agriculture (USDA) Forest Service, and the Bureau of Land Management (BLM), range from geology, hydrology, and paleontology, to mapping, GIS, soils, geohazards, and interpretation.

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Positions for Summer 2010 will be posted 1 December
www.geosociety.org/geocorps/

PARTICIPANTS

Allison Barnes, Craters of the Moon National Monument and Preserve

Andrew King, BLM Old Spanish National Historic Trail

Andrew Tveter, Craters of the Moon National Monument and Preserve

Ashley Shockley, Guadalupe Mountains National Park

Ashley Snider, BLM Royal Gorge Field Office

Ashley Van Dyne, Sequoia and Kings Canyon National Parks

Brett Carr, Yellowstone National Park

Brian Dempsey, Mount Rainier National Park

Brian Tarpinian, BLM National Landscape Conservation System

Bryant Platt, Sierra National Forest

Cara Shonsey, Sierra National Forest

Chelsea Feeney, Yellowstone National Park

Chris McGarrity, BLM Grand Staircase–Escalante National Monument

Christopher Colabaugh, Delaware Water Gap National Recreation Area

Emily Reinsel, hydrogeologist, Fraser Experimental Forest, Arapahoe-Roosevelt National Forests.

Constantin Platon, BLM Gunnison Gorge National Conservation Area & Wilderness

David Risberg, Coronado National Forest

Dennis Eck, BLM Nevada Winnemucca District

Drew Downs, Custer National Forest

Dylan Linet, Tongass National Forest

Elena Evans, NPS Geologic Resources Division

Emerald Shirley, BLM Craters of the Moon National Monument

Emily Gurney, Glacier Bay National Park and Preserve

Emily Reinsel, Fraser Experimental Forest, Arapahoe-Roosevelt National Forests

Emmett Weatherford, Pipestone National Monument

Erica Clites, NPS Center for Urban Ecology, National Capital Region

Erik Arnesen, Inyo National Forest

Erin Tainer, Mount Rainier National Park

Gilbert Garcia, NPS Geologic Resources Division

Graham Messe, Grand Canyon National Park (North Rim)

Gregory Flum, Badlands National Park

Heather Hintz, Oregon Caves National Monument

Heather Rogers, Yosemite National Park

James Donnelly, Hagerman Fossil Beds National Monument

Jamie Fearon, Florissant Fossil Beds National Monument

Jason Dally, Dinosaur National Monument

Jens-Erik Lund Snee, Idaho Panhandle National Forest

John Neff, Denali National Park

Jonathan Harvey, Lake Clark National Park and Preserve

Erin Tainer, geomorphologist, Mount Rainier National Park.

Josh Heise, NPS Geologic Resources Division

Justin Tweet, NPS Geologic Resources Division

Katie Stehli, NPS Geologic Resources Division

Kelly Hokanson, Inyo National Forest

Kristin Frederick, Great Sand Dunes National Park and Preserve

Lauren Schaefer, Mount Rainier National Park

Leah Vazquez, BLM Price Field Office

Leigh Heath, Gila National Forest

Participants continued on p. 24

Rebecca Port, geology education specialist, Rocky Mountain National Park.

GeoCorp participants continued from p. 23

Leslie Cox, Mammoth Cave National Park
Lisa Fay, NPS Geologic Resources Division
Lucas Carrington, NPS Geologic Resources Division
Marissa Kelly, Sequoia and Kings Canyon National Parks
Matthew Dettinger, Coronado National Monument
Megan Tessmer, BLM Arizona Strip District
Melanie Stevens, Shasta Trinity National Forest
Melissa Lindholm, Denali National Park
Nathan Lyons, Great Smoky Mountains National Park
Nathan Rossman, Lewis and Clark National Historic Trail
Nicholas Chamberlain, Antietam National Battlefield
Nicholas Kopiasz, NPS Geologic Resources Division
Nicole Ortiz, Delaware Water Gap National Recreation Area
Nicolle Anderson, Dinosaur National Monument
Olivia Miller, Grand Teton National Park
Patrice Cobin, Grand Teton National Park
Paul Doss, Huron-Manistee National Forest
Philip Reiker, NPS Geologic Resources Division
Rebecca Hammer-Lester, U.S. Forest Service Northern Region
Rebecca Port, Rocky Mountain National Park
Rebecca Roberts, Tongass National Forest
Robin Canavan, BLM Upper Missouri River Breaks National Monument Interpretation Center
Ryan Sincavage, Fraser Experimental Forest, Arapahoe-Roosevelt National Forests
Sarah Friedman, Devils Tower National Monument
Sarah Glancy, Oregon Caves National Monument
Sarah Slotznick, Glacier National Park
Sarah Weeks, BLM Jarbidge Field Office National Landscape Conservation System Units
Scott Rohlf, Bryce Canyon National Park
Steven Dafler, BLM Fairbanks District Office
Steven Louis-Prescott, Grand Mesa–Uncompahgre–Gunnison National Forests
Ted Fremd, NPS Geologic Resources Division
Thomas Key, Klamath National Forest
Tim Moloney, Yellowstone National Park
Zachary Arno, Guadalupe Mountains National Park
Zachary Zeis, BLM Nevada Winnemucca District

First Announcement and Call for Papers

THE GEOLOGICAL SOCIETY OF AMERICA®

ROCKY MOUNTAIN

62nd Annual Meeting
Rapid City, South Dakota, USA

21–23 April 2010

The 62nd Annual Meeting of GSA's Rocky Mountain Section will take place at the Rushmore Plaza Civic Center in Rapid City, South Dakota, USA.

CALL FOR PAPERS
Abstract deadline: 26 January 2010

Submit online at www.geosociety.org/sectdiv/sections.htm

Submission fee: US$10

Contact Beth Engle, +1-303-357-1006, bengle@geosociety.org, if you cannot submit via the online system.

REGISTRATION
Early registration deadline: 22 March 2010

Summit of Harney Peak, Black Hills, Pennington County, South Dakota, USA. Sitting in this 12 Aug. 1897 photo are J.A. Holmes, C.D. Walcott, and Henry Gannett. Courtesy USGS; photo ID: Walcott, C.D. 424; http://libraryphoto.cr.usgs.gov/htmllib/btch391/btch391j/btch391z/wcd00424.jpg.

Classified Rates—2009

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Classification	Per Line for 1st month	Per line each addt'l month (same ad)
Positions Open	$8.50	$8.25
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First 25 lines	$0.00	$4.50
Additional lines	$4.50	$4.50
Fellowship Opportunities	$8.50	$8.25

Positions Open

ASSISTANT PROFESSOR, UINTAH BASIN

The Dept. of Geology at Utah State University-Regional and Distance Education Campus is accepting applications for a nine-month, tenure track position located at the USU Uintah Basin Regional Campus in Vernal, Utah. Responsibilities include teaching (graduate & undergraduate courses), research, and service duties. Ph.D. in geology or a closely associated field is required. See http://jobs.usu.edu (req. ID 051862) for more information and to apply online. AA/EOE.

CHAIR
DEPT. OF OCEAN, EARTH & ATMOSPHERIC SCIENCES, OLD DOMINION UNIVERSITY

Old Dominion University invites applications and nominations for the position of Chair, Dept. of Ocean, Earth and Atmospheric Sciences (OEAS) in the College of Sciences. We seek an outstanding scholar in Ocean, Earth, or Atmospheric Science, or a related discipline, with demonstrated excellence in research, international recognition, consistent peer-reviewed research grant funding, and a strong commitment to educational programs. The successful candidate will provide leadership to further enhance the department's excellent research and educational programs and will have a strong commitment to teaching and mentoring of junior faculty, post-doctoral fellows, and graduate and undergraduate students. The appointment will be at the rank of professor with tenure, with a competitive salary. The position will be available in May 2010.

The OEAS Dept. is nationally ranked and currently includes 22 full-time faculty, 5 research faculty, and 13 staff members. The Dept. has graduate and undergraduate programs of high quality, granting a Ph.D. degree in Oceanography and M.S. and B.S. degrees in Ocean and Earth Sciences. The Dept. receives substantial state support and is well funded by extensive peer-reviewed grants from federal agencies. An endowment of approximately $16 million provides additional support for programs within the department. The Department of OEAS includes two research centers, the Center for Quantitative Fisheries Ecology and the Center for Coastal Physical Oceanography, and maintains a 55-foot research vessel, the R/V Slover. More information on the Dept. can be found at http://sci.odu.edu/oceanography.

Located in Norfolk, Virginia, Old Dominion University (www.odu.edu) is a state supported, research intensive institution enrolling more than 23,000 students, of which 6,000 are graduate students. Norfolk is a culturally rich, historic city and a major international maritime center in a metropolitan area of over 1.5 million people. Norfolk is one of the seven cities comprising Hampton Roads, located on the Chesapeake Bay, one of the world's largest estuarine systems. It is a center of research development in marine science, ship design and construction, and other areas of advanced technology.

Interested candidates should submit curriculum vitae, a statement of research and teaching interests, and contact information for four references to Dr. Gail Dodge, Chair of the OEAS Search Committee, Dept. of Physics, Old Dominion University, Norfolk, VA 23529, or electronically to OEASChair@odu.edu. The review of applications will begin 1 Dec. 2009 and continue until the position is filled.

Old Dominion University is an affirmative action/equal opportunity institution and requires compliance with the Immigration Reform and Control Act of 1986.

TERM LABORATORY INSTRUCTOR POSITION GEOLOGY, UNIV. OF TENNESSEE AT MARTIN

The Dept. of Agriculture, Geosciences, and Natural Resources, University of Tennessee at Martin, seeks applicants for a non tenure-track, term position as a Geology Lab Instructor. The candidate must demonstrate an ability to teach intro-level physical and environmental geology labs; oversee laboratory function and preparedness on a weekly basis; assist faculty with lectures, labs, and fieldtrips. The full position announcement can be found at: www.utm.edu/departments/caas/agnr/pdf/LabInstructor.pdf

Review of applications begins immediately and continues until the position is filled. The University of Tennessee at Martin is EEO/AA/Title VI/Title IX/Section 504/ADA/ADEA employer. The University seeks to diversify its work force. Therefore, all qualified applicants, regardless of race, color, national origin, religion, gender, age, disability or Vietnam veteran status, are strongly encouraged to apply.

FACULTY OPENINGS: ECONOMIC GEOLOGY, STRUCTURAL GEOLOGY, TECTONICS, GEOLOGIC HAZARDS, GEOTHERMAL ENERGY, ENVIRONMENTAL GEOLOGY RESEARCH ASSISTANT PROFESSORS UNIVERSITY OF NEVADA, RENO

The Nevada Bureau of Mines and Geology (NBMG), University of Nevada, Reno (UNR), seeks applicants for two tenure-track, Research Assistant Professor faculty positions beginning on or after 1 July 2010. One position is for a Research Assistant Professor with interest in field-based, 4-D geologic framework studies related to mineral and energy resources of Nevada. The second position is for a Research Assistant Professor with interest in innovative studies that can be applied to a wide variety of geologic topics of societal relevance in Nevada, including geologic hazards, geothermal energy, and environmental geology. Nevada geology provides an exciting venue for basic and applied research on the tectonic history of western North America; fundamental Earth processes and applications in exploration, mining, and environmental stewardship; renewable energy; active tectonics; and water resources. For complete position descriptions and requirements, view the position announcements at www.nbmg.unr.edu and http://jobs.unr.edu/ or contact Geoscience Search, NBMG, Mail Stop 0178, UNR, Reno, NV 89557-0178. Applications received through http://jobs.unr.edu/ by 31 January 2010 will receive full consideration. EEO/AA. Women and under-represented groups are encouraged to apply.

POSTDOCTORAL RESEARCH POSITION IN SEISMOLOGY AT YALE UNIVERSITY

The Dept. of Geology and Geophysics at Yale University invites applications for a postdoctoral researcher in seismology at Yale University. The successful candidate will carry out research in observational seismology and mantle dynamics in the research group of Professor Maureen Long. Resources available at Yale include access to high-performance computing clusters and a pool of 20 portable broadband seismometers for temporary field deployments.

The successful applicant will have completed a Ph.D. in geophysics or a closely related field and demonstrated scientific achievement at the time of appointment. The initial appointment will be for one year, with the possibility of renewal for a second year. Review of applications will begin on 1 December 2009. The position will be available beginning in January 2010, but the start date is negotiable.

Applicants should submit a CV, list of publications, and a statement of research interests, and should arrange for three letters of reference to be sent directly to the department. All application materials should be sent by e-mail (maureen.long@yale.edu) or by post to Professor Maureen Long, Yale University, Dept. of Geology and Geophysics, PO Box 208109, New Haven, CT, 06520. Yale University is an affirmative action/equal opportunity employer; applications from women and minority scientists are strongly encouraged.

PETROLOGY/MINERALOGY WESTERN CAROLINA UNIVERSITY

The Geosciences Program at Western Carolina University (WCU) invites applications for a tenure-track position at the Assistant Professor level to begin August 2010; Associate rank will be considered for exceptional candidates. We seek a geologist with expertise in igneous-metamorphic petrology/mineralogy or related expertise with significant field experience. The applicant should have a strong commitment to excellence in teaching and research at the undergraduate level. The successful candidate is expected to contribute to the department's vibrant undergraduate research program, develop a research program that includes some focus on the Southern Appalachians, and seek external funding to help support our mission. Teaching duties will include courses in mineralogy, petrology and introductory courses that are part of university's liberal studies program.

WCU is part of the University of North Carolina system and is located in Cullowhee in the heart of the Blue Ridge Mountains. WCU is committed to the Boyer model of scholarship, stewardship of place, integrated learning, and engagement. All requirements for a Ph.D. in geology or related field must be complete by time of appointment. For complete information and to apply, go to https://jobs.wcu.edu (position 306). For more information or questions, go to gnr.wcu.edu or contact Dr. Mark Lord (mlord@wcu.edu; +1-828-227-7367). Review of applications will begin 4 December 2009 and continue until the search is complete. WCU is an AA/EOE employer that conducts background checks. Official transcripts and proper documentation of identity and employability are required at the time of employment.

CLUSTER HIRE AT THE NICHOLAS SCHOOL OF THE ENVIRONMENT AT THE INTERSECTION BETWEEN ECOLOGY AND HYDROLOGY DUKE UNIVERSITY

The Nicholas School of the Environment (NSOE) at Duke University (DU) will make four tenure-track appointments at junior- or senior-levels as part of a cluster-hire in eco-hydrology (see http://nicholas.duke.edu/application). This new initiative builds on DU's strengths in ecological and hydrological sciences and seeks to attract outstanding faculty who will engage in and facilitate multidisciplinary interactions across the NSOE and other units on campus such as Biology, Civil and Environmental Engineering, and the Global Health Institute on research at the interface between ecosystem function and hydrological processes. Candidates will contribute to the NSOE's curriculum at the undergraduate, professional master's, and doctoral level.

Consideration of applications will begin immediately and continue until all positions are filled. Applications should include a full CV, statement of research and teaching goals and arrange for three letters of reference to be forwarded to http://nicholas.duke.edu/application.

The Nicholas School and Duke University are committed to equal opportunity in employment. Applications are strongly encouraged from members of underrepresented populations.

TENURE TRACK FACULTY POSITION GEOSCIENCE EDUCATION OR LOW-TEMPERATURE GEOCHEMISTRY, GEORGIA SOUTHERN UNIVERSITY

Georgia Southern University's Dept. of Geology and Geography invites applications for a second tenure-track position as Assistant Professor of Geology with expertise in geoscience education or low-temperature geochemistry. The full text advertisement is available at http://cost.georgiasouthern.edu/geo/. Screening of applications begins 20 November 2009 and continues until the position is filled. Georgia Southern seeks to recruit individuals who are committed to excellence in teaching, scholarship, and professional service within the University and beyond and who are committed to working in diverse academic and professional communities. Finalists will be required to submit to a background investigation. Georgia is an open records state. Georgia Southern is an AA/EO institution. Individuals who need reasonable accommodations under the ADA to participate in the search process should contact the Associate Provost.

ASSISTANT PROFESSOR STRUCTURAL GEOLOGY BOONE PICKENS SCHOOL OF GEOLOGY OKLAHOMA STATE UNIVERSITY (OSU)

The Boone Pickens School of Geology at Oklahoma State University (OSU) seeks applications for a tenure-track faculty position in the broad area of structural geology. We are particularly interested in someone with interest in one or more of the following research areas: structural analysis of petroleum reservoirs, basin evolution, continental tectonics, neotectonics. The appointment will be at the assistant professor level and effective August 2010. The applicant is required to have a Ph.D. degree in geology or related field at the time of appointment. The applicant must show promise of an outstanding research program and be committed to excellence in teaching. The successful candidate will be expected to supervise M.S. and Ph.D. level graduate students

and develop courses in her or his specialty. In addition she/he will participate in teaching introductory geology courses and teach a core geology curriculum course in structural geology.

The successful candidate will join a faculty of eleven geoscientists and will be part of the sedimentary geology, petroleum geology, and tectonics research groups that include six other faculty and has close ties to the petroleum industry. In addition to other research facilities the School of Geology has the Devon Teaching and Research Laboratory, which contains state-of-the-art 3-D image processing facilities.

Candidates should submit a letter of application, including a discussion of research interests and approach to teaching, along with a curriculum vitae and the names, addresses, e-mail addresses, and phone numbers of three references to: Assistant Professor Position Search, Boone Pickens School of Geology, 105 Noble Research Center, Oklahoma State University, Stillwater, Oklahoma 74078-3031, Phone: +1-405-744-6358, Fax: +1-405-744-7841. Inquires about this position may be directed to Dr. Todd Halihan (todd.halihan@okstate.edu) or Dr. Jay Gregg (jay.gregg@okstate.edu) at the above address. Screening of candidates will begin 31 December 2009 and continue until the position is filled. Filling of this position will be dependant on the availability of funding.

More information on OSU and the Boone Pickens School of Geology can be found on the web http://osu.okstate.edu and http://geology.okstate.edu respectively. Committed to health and safety Oklahoma State University maintains a tobacco free work environment. Oklahoma State University is an Affirmative Action/Equal Opportunity/E-Verify employer committed to diversity.

TENURE-TRACK ASSISTANT PROFESSOR, GEOLOGY
UNIVERSITY OF TENNESSEE AT MARTIN

The Dept. of Agriculture, Geosciences, and Natural Resources, University of Tennessee at Martin, seeks applicants for a tenure-track, Assistant Professor of Geology position. The candidate must demonstrate an ability to teach intro-level undergraduate geology courses as well as courses in mineralogy, petrology, structural geology, and geologic field methods. The full position announcement can be downloaded at www.utm.edu/departments/caas/agnr/pdf/Assistant Professor of Geology (1).pdf. Review of applications begins 16 November 2009 and continues until the position is filled. The University of Tennessee at Martin is EEO/AA/Title VI/Title IX/Section 504/ADA/ADEA employer. The University seeks to diversify its work force. Therefore, all qualified applicants, regardless of race, color, national origin, religion, gender, age, disability or Vietnam veteran status, are strongly encouraged to apply.

DEPARTMENT CHAIR
DEPARTMENT OF GEOLOGICAL & ENVIRONMENTAL
SCIENCES, YOUNGSTOWN STATE UNIVERSITY

The Dept. of Geological & Environmental Sciences at Youngstown State University invites applications for the position of Department Chair to be appointed at the Associate or Full Professor level, available summer 2010. The successful candidate should qualify for tenure based on prior experience, and is expected to maintain a vigorous research program involving undergraduate and MS students A Ph.D. in the area of Environmental Science, Environmental Geology, Soil Science, or related fields is required. In addition to leading the Department, the successful candidate will be expected to lead an interdisciplinary team of Environmental Studies faculty into full recognition as a Center of Excellence at YSU. Application details may be found at: http://cfweb.cc.ysu.edu/hr/Position_Announcements.htm.

YSU is an affirmative action/equal opportunity employer.

POSITION OPENING
GEOCHEMIST, OAK RIDGE NATIONAL LABORATORY

The Geochemistry and Interfacial Science Group in the Chemical Sciences Division at Oak Ridge National Laboratory, www.ornl.gov/sci/csd/Research_areas/gis_group.html, is seeking an early to mid-career Geochemist to fill a new position in the area of water-rock interactions. The primary focus areas of this research group involve coupling macroscopic laboratory experiments, neutron scattering and advanced spectroscopies and microscopies with multiscale theoretical modeling and simulation. Research is directed at elucidating the molecular-level origins of the properties of bulk minerals and fluids, mineral dissolution and precipitation processes, elemental and stable isotope partitioning, and the evolution through time and space of reactive interfaces in simple to complex geological environments. Our interests span the temperature, pressure and compositional ranges encountered at the Earth's surface and within the Crust and Upper Mantle.

The Group is equipped with a wide array of experimental facilities including four rocking autoclaves, nine cold-seal pressure systems, a piston cylinder, an internally-heated pressure vessel, numerous small-volume autoclave systems, high temperature pH-monitoring cells, vibrating tube densimeters, a high temperature Calvet calorimeter, an isopiestic apparatus, and a large volume custom gas adsorption system. Analytical facilities include two Finnigan MAT 252 isotope ratio mass spectrometers, a Quantachrome BET, two Dionex ion chromatographs, graphite furnace and flame atomic absorption spectrometers, and a 16-node computer cluster. The Group's facilities will relocate into the new state-of-the-art Chemical and Materials Sciences building in 2011. Additionally the group has access to world-class user facilities at ORNL, www.ornl.gov, which include the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR) both for neutron scattering studies, the High Temperature Materials Laboratory (HTML), the Advanced Microscopy Laboratory with unique z-contrast aberration corrected electron microscopes, the Center for Nanophase Materials Sciences (CNMS) and the National Center for Computational Sciences (CCS), which houses the world's most powerful open science computers.

Qualifications: Applicants must possess a Ph.D. in Geochemistry or closely-related fields in Chemical, Materials or Earth Sciences. The ideal candidate would have experience in both low temperature and hydrothermal experimental studies relating the structure and dynamics of interfacial fluids at mineral surfaces and in porous geologic media, with heterogeneous reaction rates and mechanisms, including fluid nanoconfinement effects and mineral/rock alteration processes. We seek an individual capable of independently conceiving and conducting novel experimental studies that can be linked with the array of characterization and computational modeling approaches available at Oak Ridge, and through our extensive external collaborations. Experience in aqueous geochemistry, kinetics, reaction-transport theory and computational modeling, and familiarity with scattering and spectroscopic probes of interfacial phenomena will be beneficial. Excellent oral and written communication skills in English are required. The applicant must have a demonstrated ability to organize a creative, independent research program and have communicated the results in peer-reviewed journals and presentations at scientific meetings. A successful funding track record is desirable, and postgraduate experience is preferred. The applicant must have good organizational and management skills and have the ability to interact effectively with colleagues displaying a broad range of expertise and interests.

Job Expectations: The staff member is expected to conduct and publish high quality-high impact independent research with a focus on fundamental geochemical behavior of mineral (rock)-fluid interactions over a broad range of pressure-temperature-compositions conditions. The development of novel methods and new concepts that permit interrogation over a wide range of length and time scales will be highly encouraged. Establishing scientific collaboration with neutron and computational scientists within the group and within ORNL is also expected. The staff member is expected to participate in as well as lead the development of new programs through the generation of peer review proposals. The researcher will also be responsible for upholding the environmental, safety, and health requirements of the laboratory.

Interested candidates should apply electronically at http://jobs.ornl.gov/ERecruiting.shtml. Select "View Open Positions" then, enter NC50145888 in the "Key Word Search."

ASSISTANT PROFESSOR OF GEOSCIENCES (STRUCTURE, TECTONICS, BASIN ANALYSIS)
UNIVERSITY OF NEBRASKA–LINCOLN

Applications are invited for a tenure track position as Assistant Professor in the Dept. of Geosciences at the University of Nebraska–Lincoln. The successful candidate will be expected to conduct a rigorous, externally funded research program in structural geology, tectonics, and/or sedimentary basin analysis, and to participate in teaching and curricular development of core undergraduate and graduate courses. The successful candidate will teach a course on structural geology and contribute to the growing petroleum geosciences-related teaching and research activities in the Department, which could include teaching exploration geophysics. There is an opportunity for the candidate to teach part of our summer field camp in the Bighorn Basin. The candidate should demonstrate strong potential for research and teaching and must hold a Ph.D. in a geosciences field at the time of appointment. Female and ethnic minority candidates are strongly encouraged to apply.

The Sedimentary Geology and Paleontology program is one of the three primary components of the Geosciences Dept. The department offers B.S. degrees in Geology and Meteorology/Climatology, as well as M.S. and Ph.D. degrees in Geosciences. Find out more about our department at http://geosciences.unl.edu.

To apply, go to http://employment.unl.edu requisition 090488 and complete the "faculty/administrative form." Applicants must attach a cover letter, curriculum vitae, statements of research and teaching interests, and names of at least three references via the above Web site. We will begin to review applications on 11/15/2009, but the position will remain open until it is filled.

The University of Nebraska has an active National Science Foundation ADVANCE gender equity program and is committed to a pluralistic campus community through affirmative action, equal opportunity, work-life balance, and dual careers. Lincoln is a highly livable city with affordable housing and excellent schools. For further information, contact Dr. Mary Anne Holmes, Search Committee Chair at mholmes2@unl.edu; +1-402-472-5211; 214 Bessey Hall, Geosciences Dept., University of Nebraska–Lincoln, Lincoln, NE 68588-0340.

ASSISTANT PROFESSOR, GEOLOGY DEPT.
UNION COLLEGE, SCHENECTADY, NY

The Geology Dept. at Union College (www.union.edu/academic_depts/geology) seeks a dynamic teacher and scholar with a research background in marine geology, oceanography or paleoclimatology to fill a tenure track position to begin August 2010. The successful candidate will be expected to teach courses in their field and to contribute to the Environmental Science and Policy Program (http://minerva.union.edu/env/ES_Home.html). Courses could include oceanography, paleoclimatology, sedimentology, and surface processes.

Union College is a highly selective liberal arts college with a strong tradition of science and engineering at the undergraduate level. The Geology Dept., a member of the Keck Consortium (http://keckgeology.org/), is well equipped with analytical instrumentation, and has a strong record of student-faculty research.

Candidates should submit a letter of application, curriculum vitae, statements of teaching and research interests, and the names and contact information (including e-mail) of three people who may be contacted to provide letters of recommendation. Screening of applications will begin on December 15th and will continue until the position is filled. Application materials should be sent to: D.T. Rodbell, Search Committee Chair, Geology Department, Union College, Schenectady, NY 12308.

Union College is an equal opportunity employer and is strongly committed to student and workforce diversity.

FACULTY FELLOW IN GEOLOGY:
STRUCTURE/GEOPHYSICS, COLBY COLLEGE

The Dept. of Geology invites applications for a one-year visiting Faculty Fellow position in structure/tectonics and geophysics/remote sensing, beginning 1 September 2010. The successful applicant will be expected to teach a 200-level Structural Geology with laboratory and an upper division course of his/her choice for geology majors during the academic year. The upper division course should complement those already offered in the department. The remainder of the teaching assignment will focus on course offerings for potential majors and non-majors. Additionally, the candidate may have the opportunity to direct one or more independent research projects. Colby is a highly selective liberal arts college recognized for excellence in undergraduate education and for close student-faculty interaction. Ph.D. with teaching experience at time of employment preferred; ABDs encouraged to apply. Applicants should submit a letter of application, curriculum vitae, statement of teaching and research Interests, and three letters of reference to Dr. Robert A. Gastaldo, Chair, Dept. of Geology, 5807 Mayflower Hill Drive, Waterville, ME 04901. Review of applications will begin on 23 November 2009 and will continue until the position is filled. Colby is an Equal Opportunity/Affirmative Action employer, committed to excellence through diversity, and strongly encourages applications and nominations of persons of color, women, and members of other under-represented groups. For more information about the College, please visit the Colby Web site: www.colby.edu.

STAFF POSITION IN MASS SPECTROMETRY
BAYLOR UNIVERSITY

The Dept. of Geology at Baylor University is pleased to announce a search for a new staff position for hire beginning on or before January 1, 2010 as Instrumentation Specialist in Stable Isotope Mass Spectrometry. The department currently consists of 15 geoscientists, including geologists, geophysicists and geographers (please see the department Web site at www.baylor.edu/Geology/ for further information).

INSTRUMENTATION SPECIALIST POSITION. The Dept. of Geology at Baylor University invites applications for a staff position managing the new stable isotope mass spectrometry laboratory at Baylor University, beginning as early as August 2010. A Ph.D. in Geology or Geochemistry is required at the time of appointment. The department seeks an individual with a strong background in applications of stable isotope mass spectrometry to geological systems, who will manage a new laboratory containing a Thermo-Electron Delta V Advantage isotope ratio mass spectrometer with the following peripherals: Gas Bench II, combustion EA, TCEA, and a dual inlet. The instrumentation specialist is expected to support ongoing research programs that include geology, biology and environmental sciences. The position carries appointment as 90% staff and 10% research scientist, and we especially encourage collaboration with Geology faculty and students currently engaged in research focusing on terrestrial paleoclimatology. The successful candidate should also be capable of managing use of the instrument by faculty and students, be able to instruct new users, and conduct routine maintenance and repairs, assisted by a Baylor Sciences Building instrumentation Specialist. Baylor University also supports an annual service contract for the instrument.

Send letter of application, including statement of research interests, curriculum vitae, transcripts, and the names and contact information for three references to: Dr. Stephen I. Dworkin, Instrumentation Specialist Search Committee Chair, Dept. of Geology, Baylor University, One Bear Place #97354, Waco, TX 76798-7354 (+1-254-710-2361; Steve_Dworkin@baylor.edu). The review of applications will begin 1 October 2009 and applications will be accepted until the position is filled. To ensure full consideration, application must be completed by 15 December 2009. Baylor is a Baptist university affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Opportunity employer, Baylor encourages minorities, women, veterans and persons with disabilities to apply.

TENURE-TRACK FACULTY POSITION
ORGANIC GEOCHEMISTRY OR
PALEOCLIMATOLOGY
BAYLOR UNIVERSITY

The Dept. of Geology at Baylor University is pleased to announce a search for a new faculty position for hire beginning in August of 2010 in Organic Geochemistry or Paleoclimatology. The department currently consists of 15 geoscientists, including geologists, geophysicists and geographers. Please see the department Web site at www.baylor.edu/Geology/ for further information.

ORGANIC GEOCHEMISTRY/ PALEOCLIMATOLOGY/. The Dept. of Geology at Baylor University invites applications for a tenure-track Assistant or Associate Professor in the general areas of organic geochemistry and/or paleoclimatology, beginning August 2010. A Ph.D. in Geology, Geochemistry or related field is required at the time of appointment. The Geology Dept. seeks an individual with a strong research agenda that possibly includes compound-specific organic geochemistry, paleoclimate modeling, or palynology applied to field and laboratory studies of terrestrial climate records archived within fluvial (river and floodplain), eolian (loess and sand dune), lacustrine (lake), and coastal systems. The individual must be able to communicate and collaborate with a subset of six Geology faculty members that are currently engaged in studies in the general area of paleoclimatology, and to carry out a vigorous externally funded research program that involves both undergraduate and graduate students. A strong commitment to excellence in teaching is essential, with both undergraduate and graduate courses that might include organic geochemistry, paleoclimate modeling or palynology, as well as other courses in his/her area of specialization. Research space for terrestrial paleoclimatology is available in the five-year-old, 500,000 square-foot "state-of-the-art" Baylor Sciences Building, and startup funds associated with this position are highly competitive. Construction of a new stable isotope laboratory was completed in the spring of 2009, which currently includes a new 600 square-foot laboratory containing a Thermo-Electron Delta V Advantage isotope ratio mass spectrometer with the following peripherals: Gas Bench II, combustion EA, TCEA, and a dual inlet, supporting ongoing research programs that include geology, biology and environmental sciences. The laboratory will be managed by a dedicated instrumentation specialist.

Send letter of application, including statement of teaching and research interests, curriculum vitae, transcripts, and the names and contact information for three references to: Dr. Steven G. Driese, Paleoclimatology Search Committee Chair, Dept. of Geology, Baylor University, One Bear Place #97354, Waco, TX 76798-7354 (+1-254-710-2361; applications sent by e-mail to Steven_Driese@baylor.edu). The review of applications will begin 1 December 2009, and applications will be accepted until the position is filled. To ensure full consideration, application must be completed by 15 December 2009. Baylor is a Baptist university affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Opportunity employer, Baylor encourages minorities, women, veterans and persons with disabilities to apply.

EARTH SYSTEM SCIENTIST—GEOCHEMISTRY
TENURE TRACK POSITION
DEPT. OF GEOLOGY & GEOPHYSICS
BOSTON COLLEGE

The Dept. of Geology and Geophysics at Boston College seeks to hire an Assistant Professor in the broad area of Earth System Science with a focus in Geochemistry to start in Fall 2010. Areas of expertise might include (but are not limited to): biogeochemistry, organic geochemistry, isotope geochemistry, and paleoclimatology. The successful candidate will be expected to develop a vigorous externally funded research program integrated with excellence in teaching within the earth and environmental geoscience curriculum at both the undergraduate and graduate levels, including teaching a course related to climate change, an introductory geochemistry or environmental geochemistry course, and upper level electives in the area of the successful candidate's expertise. The appointment is expected to be made

at the Assistant Professor level, but applications from outstanding candidates at a higher level will also be considered. Information on the department, faculty, and research strengths can be viewed at www.bc.edu/geosciences. Applicants should send a curriculum vita, statements of teaching and research interests, and the names and contact information of at least three references as a single PDF-file e-mail attachment to geochem_position@bc.edu. Review of applications will begin on 6 November 2009. Department faculty will be available at the GSA and AGU fall meetings to meet with applicants. Boston College is an academic community whose doors are open to all students and employees without regard to race, religion, age, sex, marital or parental status, national origin, veteran status, or handicap.

Opportunities for Students

Jonathan O. Davis Scholarship, Division of Earth and Ecosystem Sciences, Desert Research Institute. The family and friends of Jonathan O. Davis, a prominent U.S. geologist and geoarchaeologist and a DRI faculty member, have established an endowment that provides a yearly national Jonathan O. Davis Scholarship, as well as a stipend for a University of Nevada–Reno student.

Jonathan was tragically killed in an automobile accident in December 1990. It is the wish of his family and friends to support graduate students working on the Quaternary geology of the Great Basin, research close to Jonathan's heart. The national scholarship is $4,000 and the University of Nevada, Reno stipend is $1,500.

The national scholarship, administered by the Division of Earth and Ecosystem Sciences of the Desert Research Institute, is open to graduate students enrolled in an M.S. or Ph.D. program at any university in the United States. The stipend, also administered by the Division of Earth and Ecosystem Sciences, is open to graduate students enrolled in an M.S. or Ph.D. program at the University of Nevada, Reno. Quaternary geology, as used here, encompasses a wide range of topics normally considered as part of the Quaternary sciences. The research, however, must have a substantial geologic component or demonstrate a strong reliance on geological techniques and must be focused on the Great Basin.

Applications should include:

- A cover letter explaining how the individual qualifies for the award. Please include your social security number and state whether you are applying for the national scholarship or for the UNR stipend.
- A current résumé or vitae.
- A two-page, single spaced description of the thesis/dissertation research, which also clearly documents the geological orientation and research significance. Figures, tables, and references do not count against the two-page limit.
- A short statement on how funding would be used.
- A letter of recommendation from the thesis/dissertation supervisor, which emphasizes the student's ability and potential as a Quaternary scientist.

Applications must be post-marked by 2 February 2010. Proposal reviews will not be returned to applicants. Applications should be addressed to: Executive Director, Division of Earth and Ecosystem Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512.

If you have further questions regarding the awards or the application process, please contact Barbara Jackson at +1-775-673-7454 or bj@dri.edu.

Graduate Assistantship, New Mexico Highlands University. Graduate assistantships are available for students wishing to pursue an MS in Geology beginning Fall 2010 term. The NMHU Environmental Geology Program offers a field-intensive curriculum emphasizing the geologic history of Northern New Mexico and the processes responsible for natural resources development and landscape evolution. Program strengths are in mineralogy, petrology, geochemistry, rock-paleomagnetism, structural geology, volcanology, and collaborative endeavors with the Forestry and the New Mexico Forest and Watershed Restoration Institute. New NSF-Funded Paleomagnetism-Rock Magnetism, Powder X-Ray Diffraction, and Water Chemistry laboratories allow for a variety of research opportunities. The NMHU campus in Las Vegas, NM, is situated at the boundary of the Great Plains and the Sangre de Cristo Mountains and is located within a one to two hours driving distance from Cenozoic volcanic fields, Precambrian rock exposures, glaciated valleys, desert terrains, and several world-renowned geologic features: the Valles Caldera, the Rio Grande Rift, and the Harding Pegmatite. A low student:faculty ratio, state-of-the art laboratory facilities, and committed faculty provide students with a superior learning experience. The graduate assistantship includes a nine-month stipend and tuition waiver per academic year. Application review begins 01/15/10. For more information, contact Dr. Michael Petronis, Environmental Geology, Natural Resource Management Dept., New Mexico Highlands University, Box 9000, Las Vegas, New Mexico 87701, mspetro@nmhu.edu. For disabled access or services call +1-505-454-3513 or TDD# +1-505-454-3003. AA/EOE Employer.

Fellowship Opportunities

TURNER POSTDOCTORAL FELLOWSHIP THE UNIVERSITY OF MICHIGAN

The Dept. of Geological Sciences invites applications for the Turner Postdoctoral Fellowship, a highly competitive two-year research fellowship in any field of the geological sciences. This fellowship also provides travel and research funds in addition to salary and benefits. The department is interested in innovative research with preference for proposals that have a direct connection to the ongoing research of a faculty member. Visit our department Web site for more information on faculty and research (www.lsa.umich.edu/geo). A complete application includes: a curriculum vitae, a research proposal (3–5 pages) and the names and addresses of at least three references. Applications are due by December 31, 2009 and can be submitted to turnerpdf@umich.edu or Turner Postdoctoral Committee, Dept. of Geological Sciences, University of Michigan, 1100 North University Avenue, Ann Arbor, MI 48109-1005.

The University of Michigan is an affirmative action/equal opportunity employer.

INTERDEPARTMENTAL POSTDOCTORAL FELLOWSHIP IN GEOSCIENCES AT YALE UNIVERSITY

The Dept. of Geology and Geophysics at Yale University (www.geology.yale.edu) seeks applicants for a postdoctoral fellowship in research that links geosciences (studies of the solid earth, oceans, atmosphere, climate, and the evolution of life) with other sciences, including, but not limited to, astronomy and astrophysics; environmental studies; physics; chemistry; biology; engineering; anthropology; medical science and public health; economics and political science.

This Postdoctoral Associate position is awarded for two years, contingent on satisfactory progress, and provides a stipend ($49,000/yr) and base research funds ($5,000/yr), plus health care benefits and limited expenses for relocation.

The Interdepartmental Postdoctoral Fellowship will have at least two faculty collaborators: the primary sponsor will be from Geology and Geophysics, while others are from one or more other Yale departments. Interested candidates should first contact a faculty member in Geology and Geophysics to define a research theme and to identify other appropriate faculty collaborators. Applicants should submit a curriculum vita, a list of publications, an interdisciplinary research proposal (2–3 pages, in which the Yale collaborators are identified), and a brief letter of endorsement from each of the Yale faculty collaborators. Applicants should also arrange for three reference letters to be sent directly to the department. The deadline for receipt of all application materials is 15 January 2010, and decisions will be announced by or shortly after 15 March 2010. Successful candidates are expected to begin their program at Yale between 1 July and 31 December 2010.

Application materials and reference letters should be sent by e-mail (interdepartmental.fellowship@geology.yale.edu) or by post: Interdepartmental Postdoctoral Fellowship, Yale University, Dept. of Geology and Geophysics, P.O. Box 208109, New Haven, CT 06520-8109. Yale University is an equal opportunity/affirmative action employer; applications from women and minority scientists are strongly encouraged.

FLINT POSTDOCTORAL FELLOWSHIP IN GEOSCIENCES AT YALE UNIVERSITY

The Dept. of Geology and Geophysics at Yale University (www.geology.yale.edu) announces the 2009 competition for the Richard Foster Flint Postdoctoral Fellowship. We welcome applicants with research interests in climatic processes as well as Cenozoic climatic history. Specific research areas include, but are not limited to, glaciology; climate dynamics; atmospheric and ocean circulation; low-temperature geochemistry; coupling between tectonics, climate and surface processes; paleoclimate; and biological response to climate change. The Postdoctoral Associate position is awarded for two years, providing a stipend ($49,000/yr) and base research funds ($5,000/yr), plus health care benefits and limited expenses for relocation. Applicants should contact a sponsor in the department to identify potential research projects, and then submit a short (2–3 page) statement of research interests and proposed research, a curriculum vita, and list of publications. The sponsor's name should be clearly identified in the research statement. Applicants should also arrange for three reference letters to be sent directly to the department. The deadline for receipt of all application materials is 15 January 2010, and decisions will be announced by or shortly after 15 March 2010. Successful candidates are expected to begin their program at Yale between 1 July 2010 and 31 December 2010.

Application materials and reference letters should be sent by e-mail (flint.fellowship@geology.yale.edu) or by post: Flint Postdoctoral Fellowship, Yale University, Dept. of Geology and Geophysics, P.O. Box 208109, New Haven, CT 06520-8109. Yale University is an equal opportunity/affirmative action employer; applications from women and minority scientists are strongly encouraged.

BATEMAN POSTDOCTORAL FELLOWSHIPS IN GEOSCIENCES AT YALE UNIVERSITY

The Dept. of Geology and Geophysics at Yale University (www.geology.yale.edu) announces an annual competition for one or more Bateman Postdoctoral Fellowships. We welcome applicants with research interests across the full range of disciplines within the Earth Sciences, including studies of the solid earth, oceans, atmosphere, climate dynamics, geochemistry, paleoclimatology, and the evolution of life. Each of these Postdoctoral Associate positions is awarded for two years, providing a stipend ($49,000/yr) and base research funds ($5,000/yr), plus health care benefits and limited expenses for relocation. Applicants should contact a sponsor in the department to identify potential research projects, and then submit a short (2–3 page) statement of research interests and proposed research, a curriculum vita, and list of publications. The sponsor's name should be clearly identified in the research statement. Applicants should also arrange for three reference letters to be sent directly to the department. The deadline for receipt of all application materials is 15 January 2010, and decisions will be announced by or shortly after 15 March 2010. Successful candidates are expected to begin their program at Yale between 1 July and 31 December 2010.

Application materials and reference letters should be sent by e-mail (bateman.fellowship@geology.yale.edu) or by post: Bateman Postdoctoral Fellowship, Yale University, Dept. of Geology and Geophysics, P.O. Box 208109, New Haven, CT 06520-8109. Yale University is an equal opportunity/affirmative action employer; applications from women and minority scientists are strongly encouraged.

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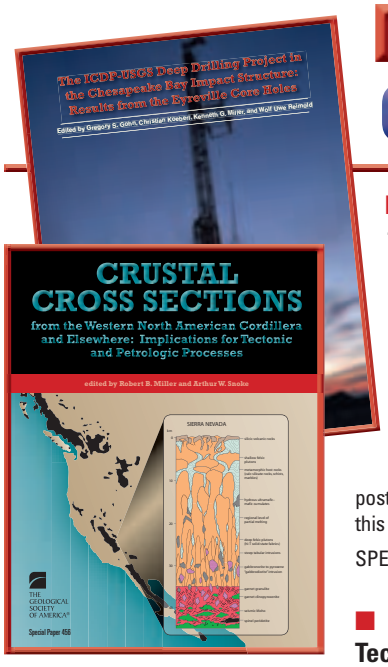


The ICDP-USGS Deep Drilling Project in the Chesapeake Bay Impact Structure: Results from the Eyreville Core Holes

edited by Gregory S. Gohn, Christian Koeberl, Kenneth G. Miller, and Wolf Uwe Reimold, 2009

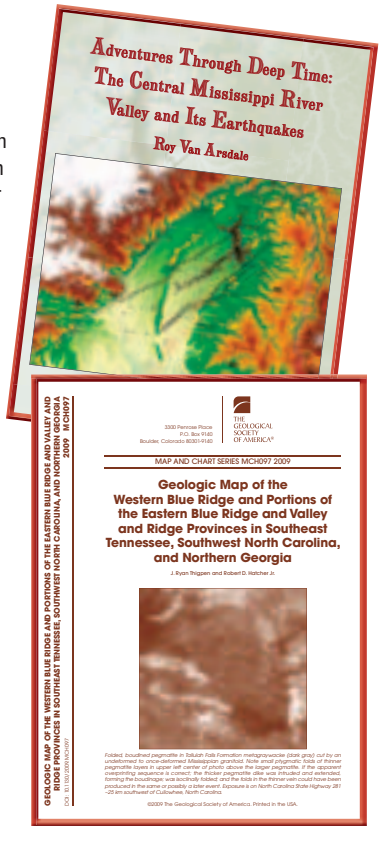
In 2005 and 2006, an international deep drilling project, conceived and organized under the auspices of the International Continental Scientific Drilling Program and the U.S. Geological Survey, continuously cored three boreholes to a total depth of 1.766 km near the center of the Chesapeake Bay impact structure in Northampton County, Virginia. This volume presents the initial results of geologic, petrographic, geochemical, paleontologic, geophysical, hydrologic, and microbiologic analyses of the Eyreville cores, which constitute a step forward in our understanding of the Chesapeake Bay impact structure and marine impact structures in general. The editors have organized this extensive volume into the following sections: geologic columns; borehole geophysical studies; regional geophysical studies; crystalline rocks, impactites, and impact models; sedimentary breccias; post-impact sediments; hydrologic and geothermal studies; and microbiologic studies. The multidisciplinary approach to the study of this impact structure should provide a valuable example for future scientific drilling investigations.

SPE458, 976 p. plus CD-ROM, ISBN 9780813724584 | $135.00 | **member price $95.00**

Crustal Cross Sections from the Western North American Cordillera and Elsewhere: Implications for Tectonic and Petrologic Processes *edited by Robert B. Miller and Arthur W. Snoke, 2009*

Exposed crustal cross sections provide a unique direct view of continental crust, and are a major source of insights into variations in lithologic and geochemical composition, structural style, metamorphism, plutonism, and rheology with progressive depth through the crust. This volume provides a synthesis of crustal cross sections with a special emphasis on Phanerozoic sections from the western North American Cordillera, supplemented by articles on lower- and mid-crustal sections through Proterozoic crust in North America and Australia, and the classic crustal section of Fiordland, New Zealand. Many of the papers describe multidisciplinary research on crustal sections and include data from various combinations of structural analysis, geochemistry, geothermobarometry, geochronology, geophysics, and other disciplines. The volume also discusses common problems for the interpretation of crustal cross sections, including how sections that expose deep-crustal rocks are eventually exhumed, and leading to the conclusion that there is no simple "standard model" for continental crust. This volume will be useful to those interested in structural geology, tectonics, geodynamics, regional geology, petrology, geochemistry/isotope geology, and geophysics.

SPE456, 286 p. plus index, CD-ROM, ISBN 9780813724560 | $90.00 | **member price $63.00**



Adventures Through Deep Time: The Central Mississippi River Valley and Its Earthquakes

by Roy Van Arsdale, 2009

This volume presents the geologic history of the central Mississippi River Valley and the surrounding area from the Precambrian through the Holocene. Its focal point is the New Madrid seismic zone that both threatens and intrigues us. The book begins with a brief presentation of the geologic history of the southeastern United States, and subsequent chapters expand upon particular periods of time, discussing the most important regional geologic events and how those events affected the central Mississippi River Valley. The concluding chapters discuss the geology and seismology of the New Madrid seismic zone. This work is written to engage a wide range of geologists, from beginners to those who are thinking of conducting research in the Mississippi River Valley. The author's casual writing style makes the book a pleasure to read while also updating readers on the geology of the Mississippi Valley and its earthquakes.

SPE455, 107 p. plus CD-ROM, ISBN 9780813724553 | $45.00 | **member price $34.00**

Geologic Map of the Western Blue Ridge and Portions of the Eastern Blue Ridge and Valley and Ridge Provinces in Southeast Tennessee, Southwest North Carolina, and Northern Georgia

compiled by J. Ryan Thigpen and Robert D. Hatcher Jr., 2009

This map represents a synthesis of southern Appalachian Blue Ridge and adjacent Valley and Ridge detailed geologic mapping by numerous authors. The western Blue Ridge in this region, which is bound to the northwest by the Great Smoky and Miller Cove–Cartersville faults, and to the southeast by the Allatoona-Hayesville fault, preserves Neoproterozoic-Ordovician synrift, rift-to-drift, and platform rocks deposited along the southeastern Laurentian margin following the ca. 700 Ma rifting and ca. 565 Ma drifting of Rodinia, and Middle Ordovician clastic wedge rocks (Murphy belt) deposited during the Taconic (Ordovician) orogeny. Southeast of the Allatoona-Hayesville fault, rocks of the central Blue Ridge are dominantly composed of high-grade gneiss, schist, and amphibolite. East of the Chattahoochee–Holland Mountain fault, the eastern Blue Ridge (Tugaloo terrane) consists of the Ashe–Tallulah Falls Formation and Grenville basement in the Toxaway and Tallulah Falls domes. Several Middle Ordovician to Mississippian granitic (granodiorite, some tonalite) plutons are also present. This sequence was originally deformed and metamorphosed ca. 455 Ma during the Taconic and then transported westward during the Alleghanian (Permian) orogeny.

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THE GEOLOGICAL SOCIETY OF AMERICA®

Special Commentary
A LOST ART: Geological Illustrations

Daniel Francis Merriam, *University of Kansas, 1930 Constant Avenue, Campus West, Lawrence, Kansas 66047, USA, dmerriam@ku.edu*

> And what anatomy is to the figure painter such is geology to a landscape artist.
> —Miss Lizzie J. Williams (1872)

In pre-computer days, if you can remember, illustrations for scientific papers were often prepared by the author either as sketches, line drawings, or in some other art form, such as watercolors or oil paintings. Natural scientists recorded their findings as sketches in the field or from photographs of perspectives of features they wished to convey to their audience. In this manner they could emphasize special features or landscapes as needed to make their point; these illustrations are a form of communication. Geologist's field notebooks, for example, could be full of sketches of field relations, measured stratigraphic sections, or fossils—many works of art. Some of these scientists were naturally talented artistically, and some could have made their living as commercial artists (Merriam et al., 2005, 2006; Merriam and Charlton, 2007; Merriam, 2007a) (Fig. 1).

> A study of the conceptual uses of visual images in an early nineteenth century [pre-computer] science may help in a small way to counter the common but intellectually arrogant assumption that visual modes of communication are either a sop to the less intelligent or a way of pandering to a generation soaked in television.
> —Martin J.S. Rudwick (1976)

Field conditions in the early days were usually stressful at best, and transportation was by foot, horseback (Fig. 2), or horse-drawn vehicles. Living outdoors was in make-shift accommodations, as pictured by Sir William E. Logan (1798–1875), first director of the Canadian Geological Survey (Fig. 3), or in none at all. Shipboard accommodations were crude and often very uncomfortable. These hardy souls made the best of the situation and recorded their findings as they went along.

Line drawings or sketches were and are the usual way of recording field observations by natural scientists, almost always accompanied by detailed field notes. These field or laboratory renditions, then, could be used for publication either directly from notes or redrawn for clarity. Those who were artistically challenged relied on artistic relatives or scientific illustrators to do their bidding. Later, some geologists, who were pressed for time, developed a technique of inking on photographs and

Figure 1. Wiley cartoon reproduced with permission.

Figure 2. W.H. Holmes' panoramic view of the Green River, which included in Peale's report in the U.S. Geological Survey Monograph of 1879.

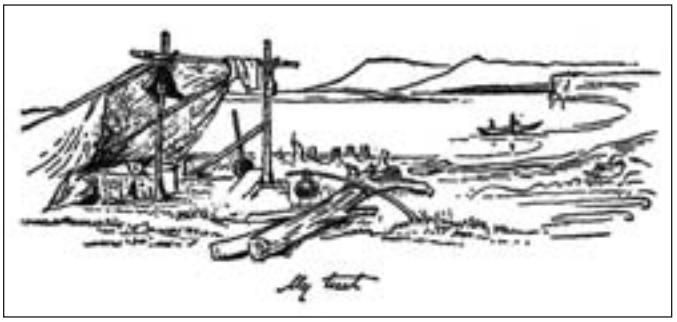

Figure 3. William Logan's field lean-to tent (Fenton and Fenton, 1945).

then bleaching the photo, or drawing on a photograph that had not been fixed, and the image naturally faded, leaving the line drawing.

Louis Agassiz (1807–1873), the Swiss Alpine geologist who immigrated to the United States, had a variation on the identifying features on his drawings. Instead of making the identification on his good sketch, he would make an outline accompanying sketch with all the features named and identified (1840; Fig. 4).

For many of the geologists, the talent for art came naturally; for others, it was developed. It should be remembered that pre-computer geology was mainly a historical science—qualitative, not quantitative. Artistic ability was a talent that gave a researcher extra and special benefits. There were no typewriters, no whiteout, no clear tape, no Xerox. Who were some of these multi-talented, now well-known scientists?

Carolus Linnaeus (1707–1778), the Swedish naturalist, is a good example of a scientist who took copious field notes with accompanying illustrations. True, other than his portrayal of plants, his drawings were crude, but served as reminders of adventures and sights (Blunt, 1971). Alexander von Humboldt (1769–1859), the German world traveler, kept a log on his extensive travels that included illustrations of flora, fauna, and places of interest (Botting, 1973; Fig. 5). Likewise, Charles Darwin (1809–1882), the English biologist/geologist, kept a journal on his round-the-world journey on the *Beagle* with hand-drawn illustrations (Moorehead, 1969; Fig. 6).

The way of scientific illustrating, however, changed with the introduction of the camera. Multiple records could be made easily and quickly almost anywhere a camera could be transported. Photography developed from glass-slide negatives taken with large cameras and equipment to digital instant photographs with pocket-sized cameras. With the introduction of computer graphics, hand-drawn illustrations have all but disappeared, although some representations, say of the three-dimensional (3-D) block diagrams, cannot be captured on camera. Nevertheless, the fashion of hand-drawn illustration has carried over into the twentieth and twenty-first centuries by a few outstanding scientists, and the literature still contains a few excellent scattered examples.

Figure 4. Agassiz's "Glacier de Viesch" (1840) with notations.

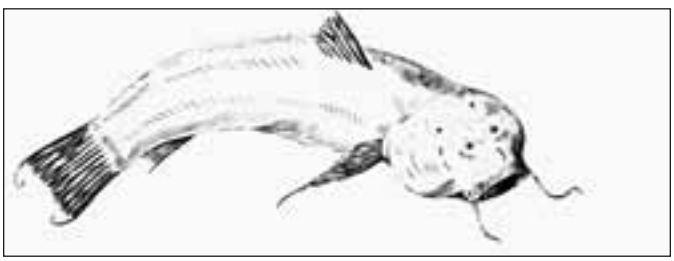

Figure 5. Alexander von Humboldt's fish illustration (Botting, 1973).

Figure 6. Charles Darwin's South American geology map (Herbert, 2005).

Early explorations in the American West were often made under difficult conditions and in areas of hostile Indians. Early reports of the U.S. Geological and Geographical Surveys of the Territories (popularly known as the King, Hayden, and Powell surveys) of the nineteenth century contain a multitude of beautifully hand-drawn sketches, maps, and cross sections (Fig. 7).

Many of these renditions were by William H. Holmes (1846–1933), the noted geologist/artist. Holmes illustrated Grand Canyon panoramas as "...marvelously accurate in their geology, [making] the atlas that accompanies Dutton's memoir perhaps the most beautiful American geology book ever published" (Faul and Faul, 1983, p. 204) (Fig. 8). The Dutton (Clarence E. Dutton, 1841–1912) reference is to his 1882 report on "The Tertiary History of the Grand Canyon District," for the U.S. Geological Survey.

William Morris Davis (1850–1934), the American geomorphologist and founder of the American school of physiography, constructed beautiful 3-D block diagrams to illustrate a progression of topographic landforms of an area through time.

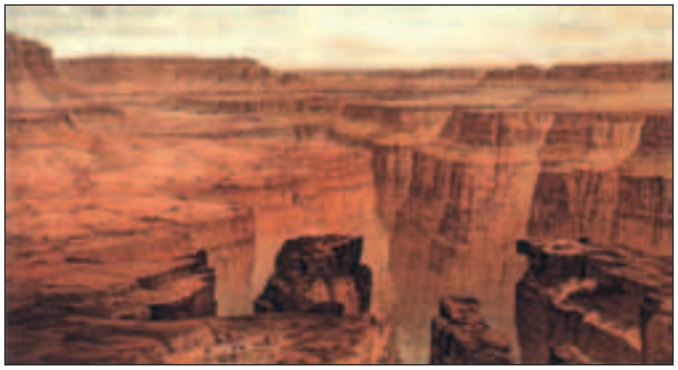

Figure 7. W.H. Holmes' Grand Canyon; a version was reproduced by A. Geike in his widely used textbook (1882).

Figure 8. W.H. Holmes' Grand Canyon in C.E. Dutton's monograph (1882).

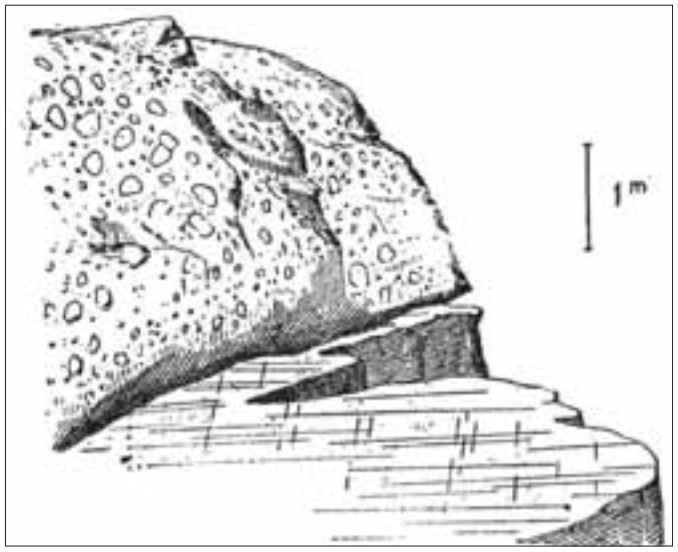

Figure 9. Amadeus Grabau's conglomerate outcrop (1920).

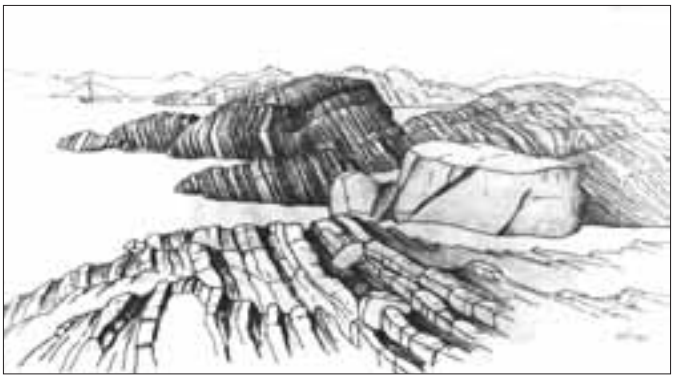

Figure 10. Hans Cloos, upturned beds (1953).

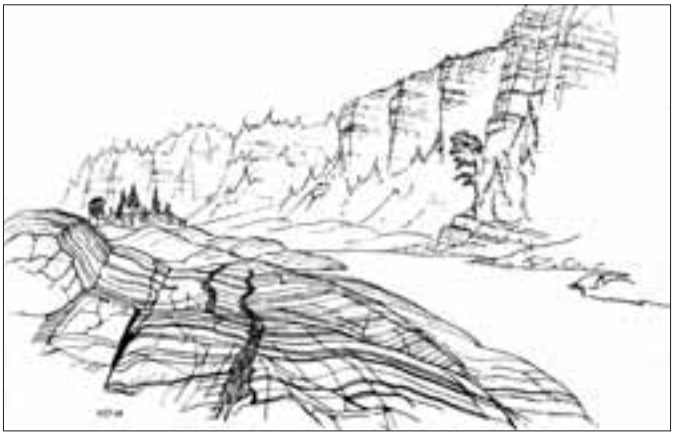

Figure 11. Hans Cloos, river (1953).

Figure 12. Hans Cloos, sand dune (1953).

Amadeus Grabau (1870–1946), a former professor at Columbia University and long-time professor at the Government University of Peking (China), illustrated his *Textbook of Geology* (1920) with drawings from a variety of sources (Fig. 9).

One of the more masterly works of art is in Hans Cloos' (1885–1951) autobiography (1953), which is profusely illustrated with beautiful hand-drawn 3-D block diagrams and hand-lettered maps and cross sections (Figs. 10–12). The illustrations accompanying his text show that "he had a keen source for aesthetic harmony and symmetry of form. His hand-drawn sketches resemble those of Albert Heim (1849–1937), the great Swiss Alpine geologist, in many ways, and in his writings, he must have had a desire to maintain classical simplicity and elegance" (Balk, 1953, p. 91). Another beautifully illustrated book is by the Dutch geographer/historian Henrik Willem van Loon (1932). The features van Loon (1882–1944) discusses throughout the book are illustrated by maps, cross sections, and 3-D scenic views, some reproduced in color (Fig. 13). It is almost the ultimate for what can be produced by an artistic scientist.

Some more recent scientists preferred to augment their works with their own illustrations. Two good examples are the work of American Philip B. King (1903–1989) in his 1977 book on structural geology (Fig. 14), and Jean Goguel (1908–1987), the French geologist/engineer, produced wonderful sketches in his book on tectonics in 1962 (Fig. 15).

Figure 13. Henrik van Loon's book color illustration (1932).

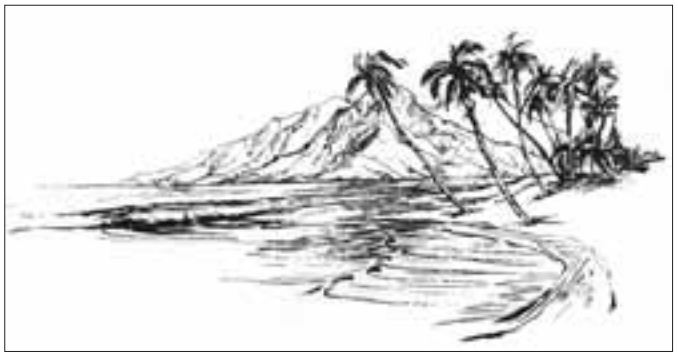

Figure 14. Philip B. King's south seas (1977).

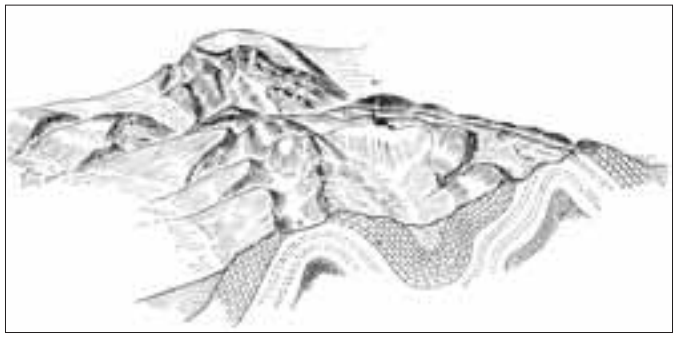

Figure 15. Jean Goguel's geologic structure (1962).

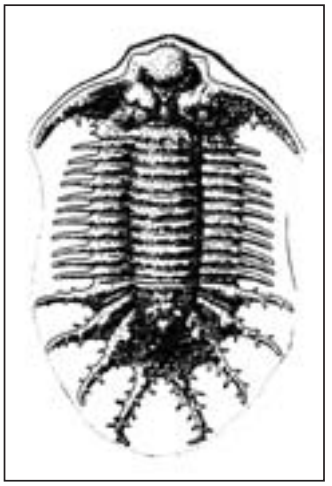

Figure 16. The trilobite *Teratespis* by R.C. Moore (Moore et al., 1952).

Figure 17. R.C. Moore's reconstruction of an ancient swamp (Moore and Merriam, 1959).

Figure 18. R.C. Moore's reconstruction of an ancient landscape (from author's personal collection).

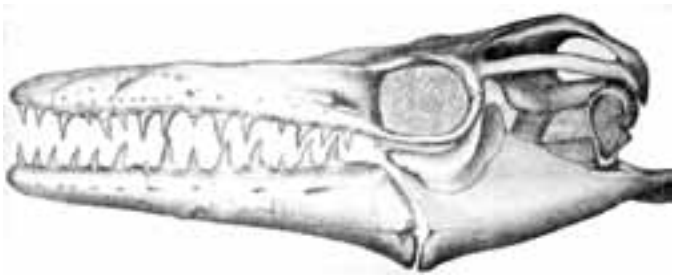

Figure 19. A mosasaur, *Mosasaurus,* by S.W. Williston (Shor, 1971).

The American paleontologist Raymond C. Moore (1892–1974) not only drew paleontological illustrations for his publications (e.g., Moore et al., 1952; Fig. 16) and field sketches, but crafted masterfully artistic restorations (Merriam, 2007b; Figs. 17–18). Samuel Wendell Williston, the famous paleontologist/biologist who taught at both the University of Kansas and University of Chicago, also drew his own illustrations of fossils and reconstructions of their living environments. Williston "never had a hired illustrator working for him, but, thanks to his own background in anatomy and competence in drawing, he could do all his own illustrations" (Shor, 1971, p. 178; Fig. 19). These geologists probably could have been successful commercial artists.

Some, if they did not have the talent or the time, had a relative produce the illustrations. Edwin H. Colbert (1905–2001), an American vertebrate paleontologist, had his professional artist wife, Margaret Colbert, produce superb illustrations, and Erasmus Haworth (1855–1932), state geologist and director of the Kansas Geological Survey at the University of Kansas, had his sister-in-law, Harriet (Hattie) M. Huntsman of Lawrence, prepare many of his illustrations for publication.

There is something satisfying to the reader about illustrations prepared by the author—it gives some insight into the scientist's thinking and ability. This artwork, like music, transcends national, subject, and scientific interest and can be appreciated by all. In days of yore, the scientist took time to study the subject in depth and to render it as seen through his or her eyes and so noted. The examples given here are only a small sample of the fine artistic workmanship that can be found in the older literature. Look, read, and enjoy!

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GROUNDWORK
Furthering the Influence of Earth Science

Facing major challenges in carbon capture and sequestration

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INTRODUCTION

Anthropogenic emission of greenhouse gases, notably CO_2, contributes significantly to global warming (IPCC, 2007). Economic growth in developing countries, increasing reliance on non-conventional oil, and use of coal as a power source are all leading to increased emissions of CO_2 (Kerr, 2008). Carbon Capture and Sequestration (CCS) is often viewed as a panacea. The U.S. Department of Energy (DOE) has made $3.4 billion available for fossil fuel research, a significant fraction for CCS (Charles, 2009), and DOE supports a number of trial projects for CO_2 sequestration (Litynski et al., 2008).

Injecting CO_2 in the subsurface has an out-of-sight, out-of-mind appeal because injecting the waste makes the problem "go away." This approach is, however, not without its drawbacks, and research needs to focus on making CCS effective both technically and economically on the scale needed to mitigate anthropogenic contributions to global warming. In order to assess this issue, it is essential to look at the numbers involved in CCS.

HOW MUCH CO_2 DO WE NEED TO SEQUESTER IN ORDER FOR CCS TO HAVE A SIGNIFICANT EFFECT?

Pacala and Socolow (2004) studied what steps can be taken to cap the CO_2 concentration at 550 ppm, this is twice the pre-industrial level of CO_2. They propose to select seven steps from fifteen possible options that include increased energy efficiency and conservation, more nuclear energy, increasing the use of renewable energy, more efficient forest and land use, and CCS. The amount of CO_2 to be sequestered worldwide as one of these seven actions is 3 Gt CO_2/year. To put this amount into perspective, this is about one-eighth of the current global CO_2 production. It is about the same mass as the total annual global oil production (http://www.eia.doe.gov/neic/infosheets/crudeproduction.html). To sequester such an amount in the subsurface may require an infrastructure that is comparable to the one used now for petroleum production worldwide.

Currently, CO_2 is injected at a number of pilot projects in countries that include Canada (Weyburn), Norway (Sleipner), and Algeria (In Salah). Through these projects, and the new ones planned by DOE in the continental U.S., typically ~1 Mt CO_2/year is to be injected. Therefore, the pilot-project technology currently used must be replicated or upscaled by a factor of 1000 to be effective for mitigating global climate change. The current cost of CCS is between $40 and $70 per ton CO_2 (Metz et al., 2005). The annual cost of sequestering 3 Gt CO_2/year at a cost of $50 per ton CO_2 is $150 billion per year. Even though this is not a large amount compared to the global expenditure for energy, one may question whether society is willing to cover an expense of this magnitude in order to mitigate climate change. Moreover, the recent McKinsey report, *Reducing U.S. greenhouse emissions: How much at what cost?* (McKinsey&Company, 2007), showed that the United States can avoid ~40% of its CO_2 emissions by taking actions such as driving more efficient cars and trucks and implementing combined heat and power generation. Most of the actions proposed in the report are cheaper than CCS and actually pay for themselves in the long term. Over the time scale of several hundred years, CO_2 has the potential to react with the host rock in some geologic formations and to become permanently stored in the subsurface (Metz et al., 2005). In order for CCS to be effective, CO_2 must be sequestered for several hundred years. Losing 0.5% of the CO_2 per year over 200 years due to leakage amounts to a total loss of 64%. This means that in order to ensure that CCS is effective, one must be able to contain the CO_2 and to predict and measure extremely low leakage rates.

IN ORDER FOR CCS TO BE A VIABLE OPTION, IT IS ESSENTIAL THAT THE FOLLOWING QUESTIONS BE ANSWERED

1. How do we reduce the cost of CCS? Currently, CCS is not financially competitive with other options for avoiding CO_2 emissions (McKinsey&Company, 2007), many of which also save energy. The current cost of CCS (between $40 and $70 per ton of CO_2) (Metz et al., 2005) makes it unlikely for this technology to be used at a scale that will make a difference in curbing global warming.
2. How do we upscale current technology by a factor of 1000? If pilot studies demonstrate the successful sequestration of 1 Mt CO_2/year with current technology, how do we upscale the technology so that it is feasible to inject several Gt CO_2 per year? Perhaps we simply need a thousand times as many injection sites, but is this the optimal way to implement CCS?

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3. How can we predict and monitor extremely low leakage rates? In order for CCS to be effective, leakage rates of a fraction of a percent per year must be predicted and monitored. Monitoring such low leakage rates is beyond our current capability (Wells et al., 2006).

It is essential that CCS research addresses these questions. If not, CCS projects and related research may serve to provide valuable insights and develop useful expertise but ultimately fall short of cost-effective implementation on the scale needed to significantly reduce greenhouse gas emissions. Because CCS is among the most expensive options for avoiding CO_2 emissions compared to alternative approaches that actually save energy and pay for themselves (McKinsey&Company, 2007), we may run the risk of repeating a mistake from the 1970s in the diversification of our energy portfolio; that is, developing technical solutions that are not economically viable and therefore in the long run do not succeed. A critical evaluation of the various options for avoiding CO_2 emissions is essential for formulating and implementing a holistic policy that is successful not only in reducing CO_2 emissions, but also in saving energy and creating jobs in the economy of the twenty-first century. By using appropriate CCS appropriately, but not placing too much emphasis on "injecting ourselves" out of the climate change problem, we will avoid being lulled into a sense of complacency that may prevent us from starting to work on additional approaches to reduce CO_2 emissions that may cost less and also save energy.

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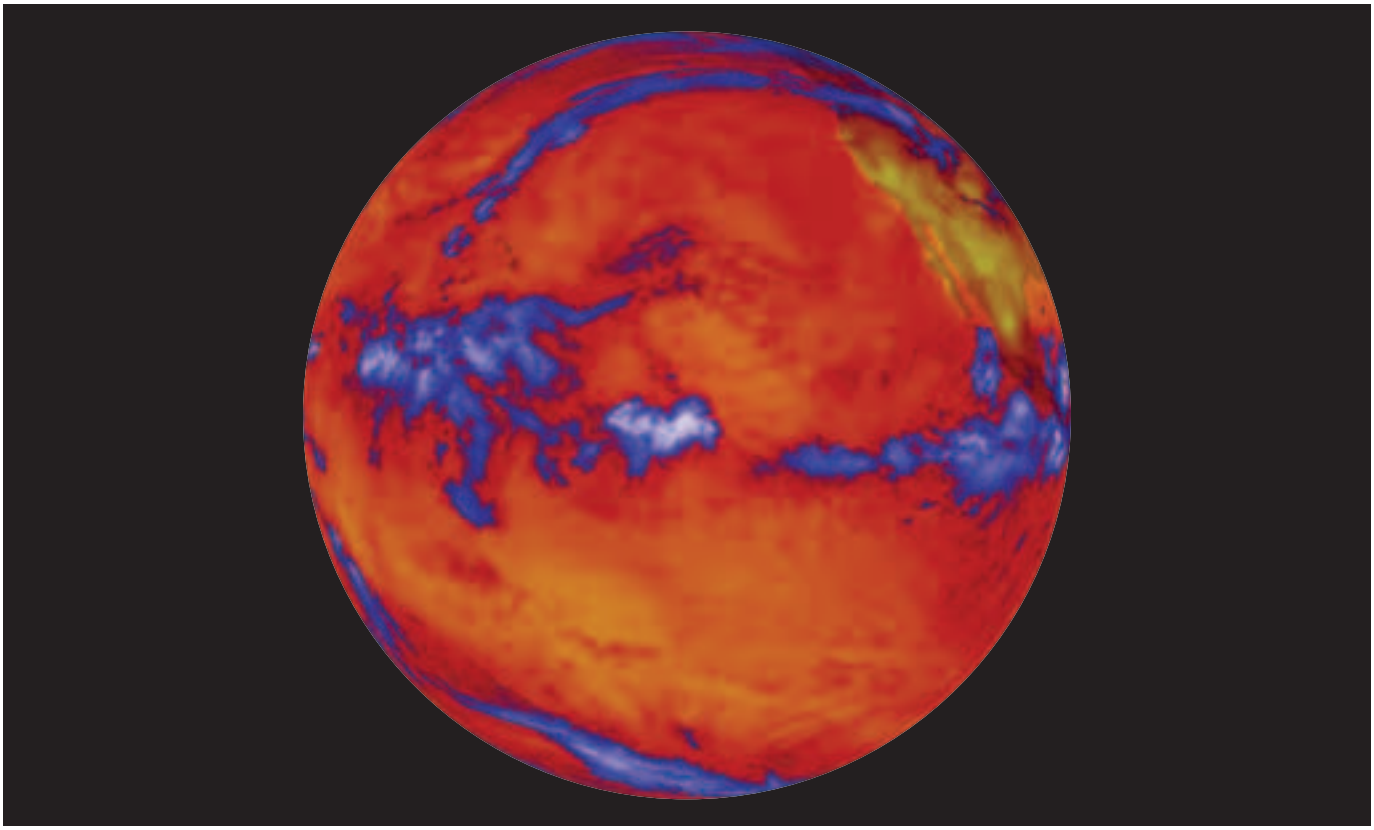

"Watching the World Rev its Heat Engine." This false-color image of Earth was produced 30 Sept. 2001 by the Clouds and the Earth's Radiant Energy System (CERES) instrument flying aboard NASA's *Terra* spacecraft. The image shows where more or less heat, in the form of longwave radiation, is emanating from the top of Earth's atmosphere. Image courtesy Barbara Summey, NASA Goddard Visualization Analysis Lab, based upon data processed by Takmeng Wong, CERES Science Team, NASA Langley Research Center (http://visibleearth.nasa.gov/view_rec.php?vev1id=11546).

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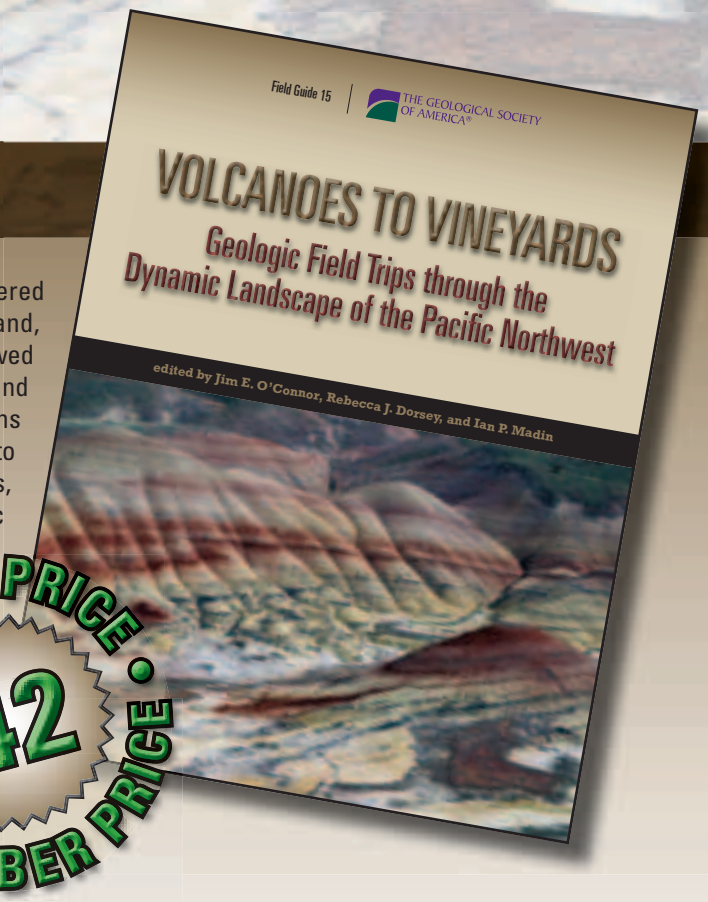
edited by Jim E. O'Connor, Rebecca J. Dorsey, and Ian P. Madin



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