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Vestiges of a Beginning: Clues to the Emergent Biosphere Recorded in the Oldest Known Sedimentary Rocks

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Figure 1. Environment of Hadean (>3800 Ma) Earth was more similar to than different from Earth of today. Liquid water and cycling of elements between geochemical reservoirs had already been established by 3.9 Ga. (Artwork by Don Dixon.)

ABSTRACT

Recent explorations of the oldest known rocks of marine sedimentary origin from the southwestern coast of Greenland suggest that they preserve a biogeochemical record of early life. On the basis of the age of these rocks, the emergence of the biosphere appears to overlap with a period of intense global bombardment. This finding could also be consistent with evidence from molecular biology that places the ancestry of primitive bacteria living in extreme thermal environments near the last common ancestor of all known life. To make new advances in understanding the physical, chemical, and biological states of early environments for life through this unique Greenland record, we must fully exploit the spectrum of biosignatures available; these efforts must also be coupled with an understanding of the complex geologic history of the rocks hosting these signatures. The new methods employed here will eventually become applicable to other worlds when samples become available for study early in the 21st century.

INTRODUCTION

If the presence of a stable liquid water veneer on Earth is necessary for the origin, evolution, and propagation of life (Fig. 1), then the best sources of information to understand this phenomenon are water-laid sediments preserved in the geologic record. Ancient (>3800 Ma) water-sculpted terrains have been recognized on Mars, and liquid water appears to exist beneath the icy crust of Jupiter's moon Europa. As long as liquid water, energy sources, and organic building blocks were present, life could have emerged on these worlds as well. The discovery of terrestrial marine sediments approaching 4 b.y. in age (Nutman et al., 1996) provides a remarkable opportunity to investigate possible environments from which life arose. Complicating this opportunity is their protracted metamorphic history; the oldest known sediments have been recrystallized under high-grade metamorphism (Griffin et al., 1980) and do not contain recognizable microfossils (Bridgwater et al., 1981). However, stable isotope fractionations of the bioessential elements (e.g., C, N, and S) produced by different metabolic styles can be preserved in ancient sediments (Schidlowski et al., 1983). This permits understanding of the development of early life inferred from chemical and isotopic information, rather than solely on interpretation of microfossil-like shapes (e.g., Schopf, 1993; McKay et al., 1996) (Fig. 2).

EARLY EARTH—SURFACE STATE

Early Earth was likely dominated by markedly different hydrospheric (e.g., lower pH, much higher $[Fe^{2+}]_{aq}$) and atmospheric (e.g., much lower p_{O_2}, much higher p_{CO_2}) conditions (Holland, 1984) and a tectonic style reflecting higher heat flow through the crust than at present. Several factors were unique to the early Archean surface, including a higher ultraviolet flux from a Sun 30% less luminous at 3800 Ma than today (Kuhn et al., 1989) and impact rates from asteroids and comets many orders of magnitude greater. Together, these conditions would presumably have restricted the number of suitable environments for life to emerge. The minimum ages of some of the oldest Greenland rocks (Nutman et al., 1996, 1997) appear to overlap in time with a period of intense impacts peaking at 3850 ± 100 Ma as recorded on the Moon (Ryder, 1990). Thermal and shock effects associated with the Late Heavy Bombardment era (Tera et al., 1974) are presumed to have rendered early Earth unsuitable for the emergence of life until after the massive bombardments ceased (e.g., Maher and Stevenson, 1988). During this bombardment era, conditions may have favored the survival of certain bacteria that survive (and even thrive) in environmental extremes of temperature, pressure, and pH before diversifying into wider ecological niches throughout the planet. Phylogenetic studies using highly conservative

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ribosomal RNA sequences reveal that the deepest branches of life derive from "heat-loving," or thermophilic, bacteria (Pace, 1997). Such organisms could have survived thermal assaults from giant impacts, especially if sequestered deep in the oceans or in rocks away from a destructive surface zone bathed both in the intense ultraviolet radiation of the early Sun and a rain of extraterrestrial debris ~4 b.y. ago. To better understand this early era, we have to unravel the timing of events from a heavily modified early Archean rock record.

EARLY ARCHEAN (>3500 Ma) HISTORY OF WEST GREENLAND

The diverse rock types present in the Isua district of West Greenland are all contained within extensive early Archean (3600–3900 Ma) gneisses dominantly of tonalitic-granodioritic composition (Black et al., 1971; Nutman et al., 1996) (Fig. 3). This multiply metamorphosed terrane, termed the Itsaq Gneiss Complex (Nutman et al., 1996), contains <10% volcano-sedimentary enclaves in the gneisses. The identification of water-laid rocks, such as banded iron-formation (BIF), metamorphosed chert, metapelites, rare graywackes, and pillow lava basalts, attests to a hydrosphere with an already mature cycling of sediments by ~3900 Ma. The paleogeography of this sedimentary system remains poorly understood (e.g., oceanic arc–back-arc basin or deep abyssal basins), but the apparent lack of continentally derived sediment (Nutman et al., 1984) mitigates against the widespread presence of nearby exposed continental crust at the time of deposition.

Vestiges *continued on p. 3*

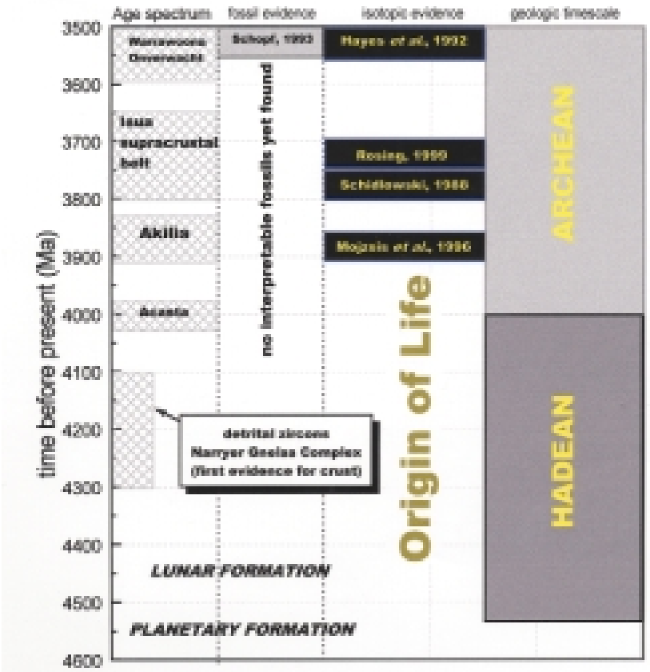

Figure 2. Timeline of early Earth history and recent advances made in investigating oldest biogeochemical records. Listed are ages for oldest rock sequences, and of isotopic evidence for life in oldest sediments.

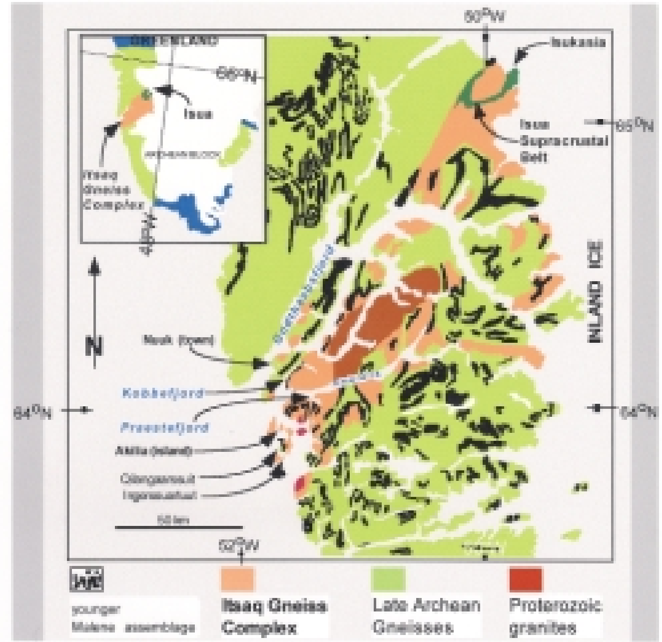

Figure 3. Generalized geologic map showing extent of early Archean (3770–3900 Ma) Itsaq Gneiss Complex in southern West Greenland (adapted from Nutman et al., 1984, 1996). Oldest sedimentary rocks and associated gneisses are along coast, represented by island of Akilia, and are intruded in places by Proterozoic Qorqut granites (Fig. 4).

Vestiges *continued from p. 2*

Banded Iron-Formation >3850 Ma on Akilia Island

The oldest known sediment (Nutman et al., 1997), and the oldest known rock with evidence of biological processes active during time of deposition (Mojzsis et al., 1996), is a layer ~3 m thick of BIF within a body of amphibolite on the southern tip of Akilia island, West Greenland (Fig. 4). This BIF on Akilia was chosen as the type locality for the Akilia association, a term used for volcano-sedimentary enclaves found throughout the Itsaq Gneiss Complex that are not part of the larger and better preserved Isua supracrustal belt (McGregor and Mason, 1977). More detailed field studies through the 1980s and 1990s, combined with geochronological work on the intruding gneisses in the coastal regions of southern West Greenland, demonstrated that the rocks around Godthåbsfjord (in the southwestern coastal area), including those of the Akilia association, contain older components (Kinny, 1986) than most rocks in the Isua district, 150 km distant.

On Akilia island itself, gneissic sheets crosscut the amphibolite enclave containing BIF and yield U-Pb zircon ages as old as ca. 3850 Ma, interpreted as the age of crystallization of the magmatic protolith by Nutman et al. (1996, 1997). If this interpretation is correct, then the BIF is at least as old as 3850 Ma. Carbon isotopic evidence of bio-organic activity during deposition of the BIF sediments (Mojzsis et al., 1996) would then suggest that the emergence of life on this planet occurred much earlier than previously thought (Hayes, 1996; Holland, 1997). This age for the Akilia island sediments is also significant because it would place their deposition simultaneous with the Late Heavy Bombardment of the Moon at 3800–3900 Ma, and coeval with the presence of abundant liquid water on the surface of Mars.

Several of the Akilia gneisses that cut the BIF generally contain three zircon age populations: ca. 3850, 3650, and 2700 Ma (Fig. 5) (Mojzsis and Harrison, 1999; Whitehouse et al., 1999). One possible explanation for this zircon age distribution is that the ~2700 Ma grains are metamorphic in origin, the ~3650 Ma grains are igneous, and the oldest grains are xenocrysts inherited from an older rock. In the latter interpretation, the actual intrusive age of the tonalitic protolith of the gneiss would be only 3650 Ma. For example, Kamber and Moorbath (1998) and Whitehouse et al. (1999) argued that the ca. 3850 Ma ages were assimilated at about 750 °C from adjacent, zircon-bearing rocks. However, there is no identified candidate rock for the assimilant in the whole of the Itsaq Gneiss Complex. The granitoid protolith of the orthogneisses is characterized by relatively low Zr contents (~120 ppm) and high crystallization temperatures (>900 °C). The likelihood of strongly zircon undersaturated tonalitic-granodioritic melts (Harrison and Watson, 1983) intruding into zircon-poor rocks and preserving widespread inherited zircon is low (Watson, 1996). Kamber and Moorbath (1998) argued that the lack of 3850 Ma Pb-Pb ages in feldspars from

Figure 4. Aerial photograph of BIF locality on Akilia, looking east; sediments are bounded by amphibolites and intruded by gneissic sheets up to 3850 m.y. old (Fig. 5).

Vestiges *continued from p. 3*

gneisses collected throughout southern West Greenland specifically preclude a 3850 Ma protolith age for any rocks in West Greenland. However, their conclusion overstates the clarity of interpretations that can be drawn from Pb isotopes in feldspars. Peak metamorphism experienced by these rocks at 3650 Ma occurred under conditions (Griffin et al., 1980) that could permit exchange of primitive Pb isotopes in feldspar (Cherniak, 1992) with radiogenic Pb released from U-rich phases. McGregor (2000) pointed out that the petrologically unrelated samples analyzed by Kamber and Moorbath (1998) are dominated by relatively late phases of the gneiss complex that underwent partial melting under granulite facies metamorphism, and thus their data "do not preclude the existence of very old (≥3800 Ma) rocks" on Akilia island.

Existing evidence points to a 3850 Ma age for granitoids intruding BIF on Akilia island, but the great significance of this age for early terrestrial evolution leads us to continue our geochronological investigations in more detail. We are testing more directly the hypothesis that the 3850 Ma zircon ages are the result of xenocrystic contamination by determining in situ U-Pb ages of zircons included in preserved, early-crystallizing phases of the tonalite protolith. Also, the three-dimensional distribution of Pb/U revealed by isotopic depth profiling (e.g., Grove and Harrison, 1999) and applied to the oldest zircons helps us address whether zircon overgrowths reflect magmatic or metamorphic processes. If these rocks indeed provide a glimpse into pre–3800 Ma Hadean Earth, then the time of the emergence of the biosphere appears to have coincided with a period of intense bombardment in the inner solar system, as recorded on the Moon.

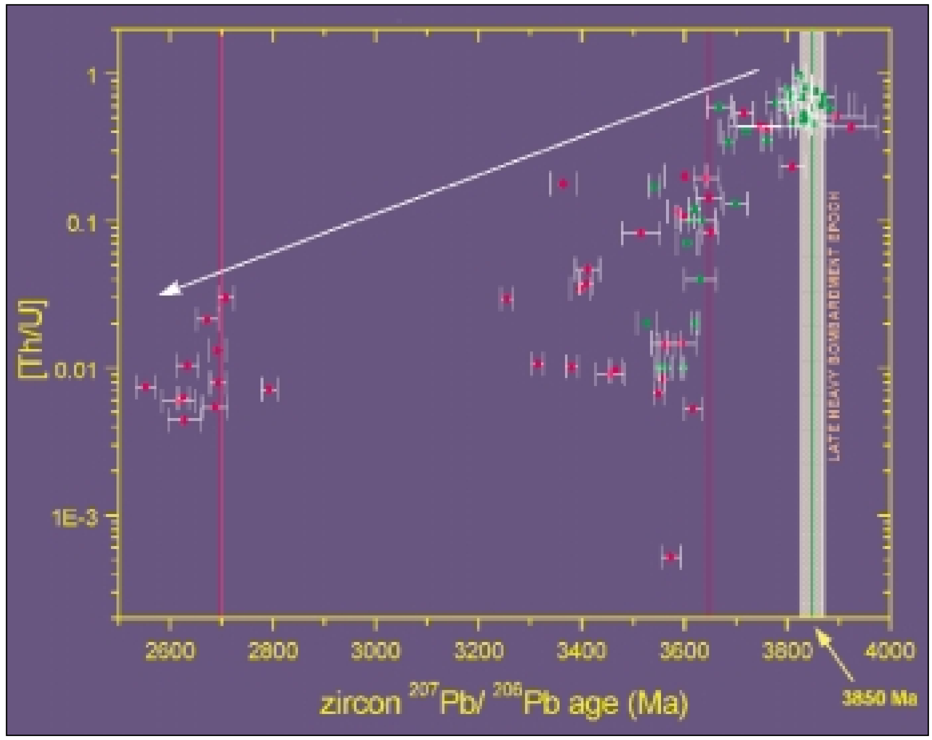

Figure 5. $^{207}Pb/^{206}Pb$ ion microprobe ages of zircons from tonalitic gneiss intruding amphibolite + banded iron-formation on Akilia island, West Greenland. What we interpret as the magmatic zircon population in these rocks (top right) has highest Th/U values and tightest spectrum of ages at 3850 ± 10 Ma (data in green from Nutman et al., 1997; data in red from Mojzsis and Harrison, 1999). All other ages are for lower Th/U metamorphic zircons (arrow) that correlate with well-known metamorphic events in West Greenland at 3650 Ma and 2700 Ma (Baadsgaard et al., 1976; Griffin et al., 1980).

LATE HEAVY BOMBARDMENT OF THE MOON AND EARTH AT CA. 3850 MA

The surface of the Moon displays evidence of an intense bombardment that took place at some time between original crust formation and the outpourings of lava that form the dark mare plains. The oldest of the lunar mare are dated at ~3800 Ma (see review in McDougall and Harrison, 1999). Breccias from the lunar highlands generally yield radiometric ages between 3800 and 3900 Ma that are interpreted as reflecting impact resetting (Dalrymple and Ryder, 1996). The narrow distribution of ages and rapid transition from older, impact-dominated landforms to volcanic plains has generally been attributed to a cataclysmic spike in impacts at 3800–3900 Ma (Tera et al., 1974; Ryder, 1990). The present evidence is consistent with an abrupt termination of this intense activity coinciding with nearly simultaneous creation of the large Imbrium, Orientale (Fig. 6), and Schrödinger basins at 3850 Ma, or even as early as 3870 Ma (G. Ryder, personal communication). These timing details are important for at least two reasons: An age of 3850 Ma closely corresponds to that of the oldest sediments in West Greenland cited above, and that age has been taken as a temporal marker horizon for estimating the age of heavily cratered crust on Mars and Mercury.

Consequences of Bombardments to Early Life

Highly energetic impacts would have been deleterious for near-surface emergent ecosystems as conceptualized in the classic "Darwin Pond" hypothesis of the origin of life. Impact "erosion" of planetary atmospheres and wholesale destruction of hydrosphere and crust from the most massive infalling bodies are some of the effects postulated to have rendered the surface zone truly Hadean in character before 3800 Ma (Sleep et al., 1989). However, if life originated in deep marine or crustal nurseries (Shock et al., 1995) and continued to reside there until bombardment ceased, events at the surface might have had little immediate consequence to survivability of the biosphere.

To search for evidence of impacts in the geologic record, workers have taken advantage of the geochemistry of iridium. Earth's crust is highly depleted in Ir and other platinum-group metals relative to its mantle, which is itself depleted relative to chondritic meteorites by partitioning of Ir into the core. Iridium content of sediments is therefore used as a sensitive indicator of the presence of extraterrestrial debris (e.g., Alvarez et al., 1980). Sources of Ir in ancient sediments might represent interplanetary dust particles, micrometeorites, local- to world-spanning impacts, airbursts, and products of asteroid or comet showers. If depositional rates can be estimated, measurements of Ir in sediments can provide information on the accretion of extraterrestrial material during the time of deposition. On the basis of timing of the lunar bombardment and age of the oldest terrestrial sediments, the Akilia rocks might therefore be expected to preserve a signal of markedly higher flux according to their precise age correlation with the lunar bombardment record.

However, unless sedimentation rates were anomalously rapid (»1 mm/yr), thereby diluting a signal of intense impacts, the Ir contents for all West Greenland samples studied thus far are lower than that expected from simple models for the Late Heavy Bombardment (Anbar et al., 1999). This observation may be explained by the fact that the bombardment was not an era of continuous massive impacts. It was most likely dominated by quiet conditions punctuated by relatively infrequent episodes of extreme thermal shocks, none of which could have erased a deep-seated biosphere already in place. Furthermore, evidence for life from carbon isotopic distributions in rocks from the early Archean of Greenland would appear to indicate that life withstood the Late Heavy Bombardment, whatever its intensity, relatively unscathed.

CHEMICAL AND ISOTOPIC FOSSILS OF EARLY LIFE

On a global scale, kinetic isotope fractionations during enzymatic activity produce distinctive variations in stable isotope ratios of bioessential elements (e.g., carbon, nitrogen, and sulfur) in various reservoirs. A record of these fractionations can be obtained by measuring the isotopic ratios of these elements in bio-organic materials preserved in sediments. It has long been recognized (e.g., Thode et al., 1949; Wickman, 1952; Craig, 1953) that life systematically and significantly affects the isotopic composition of the biologically important elements and that these distinctive biosignatures can be preserved during diagenesis and moderate-grade metamorphism. After more than 50 years of investigations, geochemists now agree that postdepositional processes tend to obscure the original carbon isotopic signal of bio-organic material, but only toward values characteristic of inorganic carbon (Schidlowski, 1988; Kitchen and Valley, 1995; Des Marais, 1997). If this isotope record can survive very high grade metamorphism, then it becomes possible to analyze the oldest sediments for evidence of life (e.g., Mojzsis et al., 1996).

Carbon Isotopes

The primary metabolism of organisms on Earth that manufacture their own food (autotrophs) imposes a kinetic isotope fractionation that discriminates against ^{13}C in the fixation of atmospheric CO_2 ($\delta^{13}C_{PDB}$ = –7.9‰) and dissolved marine HCO_3^-($\delta^{13}C$ = 0 ± 1‰). Because of the intrinsic lower reactivity of ^{13}C vs. ^{12}C, enzymatic processes discriminate against CO_2 during carbon fixation (by the enzyme ribulose bisphosphate carboxylase in cyanobacteria and plants; Park and Epstein, 1960). These mechanisms induce up to 5% differences in isotopic composition of bio-organic carbon with respect to inorganic carbon sources in the atmosphere and hydrosphere. The average isotopic composition of Phanerozoic bio-organic matter ($\delta^{13}C$ = –27‰) is far away from the inorganic field. While Horita and Berndt (1999) postulated that the inorganic production of CH_4 from serpentinization could create a carbon isotope fractionation of similar magnitude, subsequent work suggests that the evolved methane in these experiments derives exclusively from bio-organic contaminants in the reactant olivine (McCollom and Seewald, 1999). No known abiotic process mimics the large carbon isotopic signal of life in sediments.

Microbial methanogenesis is a widespread phenomenon whereby organic matter decomposes in anaerobic sediments and in the intestinal tracts of ruminants. The acetyl-CoA pathway—a metabolic system utilized by methanogens—is responsible for carbon isotope fractionations up to –40‰ from inorganic carbon (Preuß et al., 1989). Methanogens are a group of chemosynthetic (rather than photosynthetic) microbes that are among the most primitive life forms (Woese, 1987). Chemoautotrophes can produce biomass with $\delta^{13}C$ values as low as –60‰ (Summons et al., 1998). The recycling of carbon by these primitive microbes, and the isotopically light ($\delta^{13}C$ = –30‰ to –60‰) composition of their organic remains are considered diagnostic of contemporary microbial habitats characterized by extreme environments. These habitats (e.g., high salinity, high water temperature, or variable pH) are considered analogous to some of the earliest environments for life on Earth.

Analyses of bulk carbonaceous matter trapped within early Archean, Proterozoic, and younger sediments has demonstrated the ubiquity of isotopically light carbon (Schidlowski et al., 1979, 1983; Hayes et al., 1983; Des Marais, 1997; Rosing, 1999). These results are consistent with a bio-organic origin for sedimentary reduced carbon; yet, generalized concerns regarding later contamination or open-system behavior during metamorphism have been raised. While specific criticisms of this kind (e.g., Sano et al., 1999) can be shown to be unwarranted on geologic grounds alone (e.g., Mojzsis et al., 1999a), newly developed isotopic measurements permit textural and mineralogical preservation of the analyzed material and potentially transcend these two issues. Mojzsis et al. (1996) used a high-resolution ion microprobe to analyze extremely small (~10 µm) carbonaceous inclusions locked within mineralogic domains that had remained stable since diagenesis (Mojzsis et al., 1999a). Carbon isotopic values for carbonaceous inclusions in apatite from the ≥3770 Ma Isua sediments ($\delta^{13}C$ = –30‰) and the ≥3850 Ma BIF from Akilia island ($\delta^{13}C$ = –37‰) closely match those for similar rocks from a variety of younger, less metamorphosed rocks.

The simplest interpretation of the carbon isotopic data in Mojzsis et al. (1996) is that the organisms responsible for the light carbon signature in the oldest known terrestrial sediments were metabolically complex, perhaps comprising populations of phosphate-utilizing photoautotrophs and chemoautotrophs. These data may point to the presence of diverse photosynthesizing, methanogenic, and methylotrophic bacteria on Earth before 3850 Ma (Mojzsis and Arrhenius, 1998; Mojzsis et al., 1999b). Not only had life taken firm hold on Earth by the close of the Hadean era, but it also appears to have evolved far enough away from its origin to create an interpretable signature in carbon isotopes.

Our group at the University of California, Los Angeles, has undertaken study of the stable isotope composition of individual microfossils by the techniques described above; these studies indicate the opening of new vistas in the isotopic paleontology of ancient life forms where recognizable fossil microbes are preserved. Furthermore, the utility of sulfur isotope (^{32}S,^{33}S, ^{34}S) measurements of individual sulfide minerals in ancient rocks (Greenwood et al., 1999) potentially provides information not only about primitive metabolic cycling of sulfur in the biosphere, but also of unique atmospheric fractionations and atmosphere-crust interactions early in Earth history.

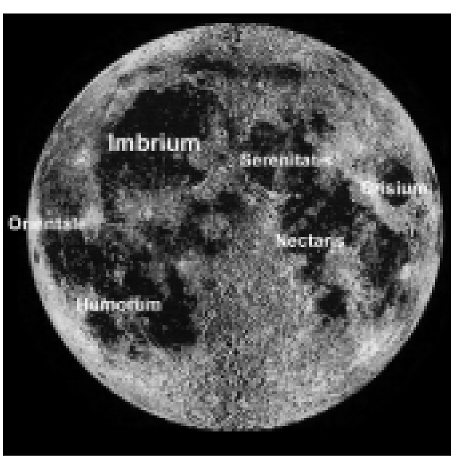

Figure 6. Telescopic mosaic of the front side of Moon shows dark mare basalt plains and much more rugged and heavily cratered highlands of higher albedo and more feldspathic composition. Highlands show ancient impact basins as well as craters.

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Submitting Science Articles

Each month, *GSA Today* features a short science article on current topics of general interest. For guidelines on submitting an article, contact either *GSA Today* Science Editor:

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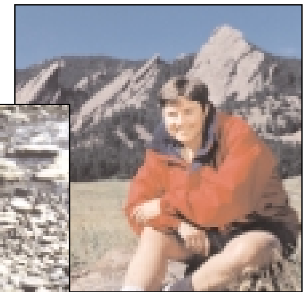
Dialogue

Sara Foland, CEO

> This notion, that "science" is something that belongs in a separate compartment of its own, apart from everyday life, is one that I should like to challenge. We live in a scientific age; yet we assume that knowledge is the prerogative of only a small number of human beings .... This is not true. The materials of science are the materials of life itself. Science is part of the reality of living; it is the what, the how, and the why in everything in our experience.
>
> *—Rachel Carson*



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Above: Sara Foland

Left: Jill Schneiderman

Geoscientists as Stewards of Earth

This month we continue our exploration of GSA's core values of science, stewardship, and service. Joining me is Jill Schneiderman, associate professor of geology, Vassar College. She is editor of *The Earth Around Us: Maintaining a Livable Planet,* published by W. H. Freeman and released this month in time for Earth Day, April 22.

Schneiderman: Rachel Carson's message, delivered as she accepted the National Book Award for *The Sea Around Us,* should motivate all of us scientists to communicate the substance of our work to the public. In the 21st century, science and technology will continue to dominate the events of our daily lives, everything from the mundane to the magnificent.

Foland: That's right. A recent NBC News viewer poll found that science was the #1 topic of interest. Stories that dominate the press today are focused on earth processes, yet we see a limited number of geoscientists as spokespeople in those stories.

Schneiderman: Interesting, isn't it? Rachel Carson validated the role of geoscientists in this endeavor in her most well known work, *Silent Spring.* In warning about the potential hazards of widespread use of herbicides and pesticides, she recognized the need to understand the natural workings of earth processes. She also understood that this knowledge must underlie investigations of environmental hazards and the decisions made regarding them.

Foland: If understanding earth processes is key, then geoscientists by definition are stewards of that knowledge. Beyond that, I'd also venture to say that when we enter this profession, we assume an obligation to be active stewards of Earth.

Schneiderman: In order to be effective stewards, it's important that we make our work more visible. For too long, the media have designated biologists as the spokespeople for our physical environment. As we well know, the biosphere is only one element in the complex Earth system. Who better than earth scientists to speak for the complexity of the whole Earth?

Foland: In today's global community, geoscientists must lead the way in protecting nonrenewable resources. World demand for resources, a function of both lifestyle and increased population, will continue to exert tremendous pressure on the environment.

Schneiderman: In our scientific community at GSA, we have colleagues who embrace Carson's message and take to heart GSA's call to science, stewardship, and service. In contributing essays to *The Earth Around Us,* they've written in plain language for the general public, informing readers of the importance of geoscience in securing a global future that is both sustainable and *worth* sustaining.

Foland: Now that this book, reinforcing Rachel Carson's message, is complete, how do you envision it being used?

Schneiderman: I hope it will serve as a handbook for the public and policymakers—a reminder of what geoscientists can contribute to debates about how humans should interact with this planet, our home. ■

The Earth Around Us: Maintaining a Livable Planet
Jill S. Schneiderman, Editor; W. H. Freeman and Company.
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Engaging "My Neighbor" in the Issue of Sustainability Part IV: Sustainability and Resources

E-an Zen, *University of Maryland, College Park*

Whenever we ponder the future of the human enterprise, questions about material resources come up. Will they run out? Will they replenish themselves? Will the demand for them diminish, or will alternatives be found? Without a good estimate of those resources, we will never be able to predict or improve human welfare. "Malthusians" have a doomsday outlook; "Cornucopians" have a more optimistic view (McCabe, 1998). Yet whichever school of thought seems more persuasive, the fact remains that we live in a materially closed system. Earth's resources are finite, so we must choose how best to use them.

A society needs reliable information on the resources available to it and on the consequences of their use. How it will act on that information will depend on its value system. For example, a society may place a high priority on fair distribution of wealth. We in the developed nations have an opportunity to demonstrate a commitment to use resources in a sustainable way. Do we want to act responsibly toward future generations of our species and toward other life forms as well?

Material resources are whatever a society uses or recognizes as potentially usable. Because that list changes with society's needs and technology, what is useless one day may become vital the next. As recently as a century ago, aluminum, petroleum, and uranium were not significant resources.

Geologists tend to think of "resources" as the stuff we take from the ground: metal ores, coal, petroleum, groundwater, limestone, phosphate, quartz sand, and rock. Earth's resources, however, also include living things that are subject to human exploitation.

Thus, trying to inventory resources for the future is like aiming at a moving target. Yet some statements will remain valid for three reasons: (1) except for energy input from the sun, Earth is a closed system having a fixed quantity of materials; (2) both the extraction and processing of materials and preservation of the environment require energy, itself a resource; and (3) using a material generally changes its state of aggregation and its adaptability for future use. Thus, the processing of materials, including recycling or reaggregating waste material into usable form, causes a thermodynamically inexorable loss of useful energy and/or material. With regard to natural resources, there is no free lunch!

To these factors must be added both an increasing global population (projected to reach about 9 billion people by 2050) and a higher per capita consumption rate reflecting "improved" standards of living. Clearly, resource considerations are crucial for the success of the human enterprise.

Traditionally, resources are grouped as nonrenewable and renewable. Nonrenewable resources (e.g., ores, petroleum, coal) replenish at geological rates that are much too slow to benefit humans. Once consumed, such finite resources are effectively removed from our inventory. New discoveries or more efficient extraction methods merely postpone their inevitable exhaustion.

Renewable resources (e.g., timber, fish stock, groundwater) have rates of natural replenishment commensurate with the time scales of human society. However, consuming such resources faster than they can replenish themselves is like withdrawing funds from a bank account faster than we make deposits; sooner or later that account will run out. We have often been guilty of just such overwithdrawal. Examples include overfishing, poor husbandry of arable and pasturable land, overpumping of aquifers, and destruction of entire ecosystems, such as Russia's Aral Sea. Such local losses can have large systemic effects.

More effective use of substitutes, recycling, and conservation can slow down depletion of a renewable resource (i.e., the amount of consumption that exceeds its renewal by all processes, natural or engineered), but they cannot halt the process. To make a renewable resource truly renewable, the rate of consumption must not exceed the gross rate of renewal. Reaching a sustainable world will demand many changes to our priorities regarding resource utilization.

Some vital resources, such as the environment, are not material objects. A healthy environment is a composite of many other items (e.g., water chemistry and temperature, nutrients and other chemicals in the soil, good habitats for wildlife). A natural place of beauty and wonder is an intangible but valuable resource. A less obvious intangible resource is the future generation's options—i.e., their capability to make real choices. Like the options available to us today, many future options require the availability of material and energy. Even if an Earth material is not dispersed through use, just the processing of it automatically reduces future options for its use.

The results of human exploitation of resources cannot be predicted by looking at one commodity or one social force at a time. Calculation of the effects of use and depletion of materials on the public commons (see Palmer, 2000) must also include human values and cultural habits. Justus von Liebig, a 19th century agricultural chemist, recognized the complexities that arise when humans and natural forces work interactively. Historian Elliott West put von Liebig's view this way: "An organism's limits are set, not by the maximum profusion of necessary things, but by those things' minimum availability .... Look ... for how much is available when vital supplies are the tightest, lowest, stingiest."

What is true for an organism is true for ecosystems. Can we identify the vital supplies, their mutual relations, and their future trends? Can we recognize the factors of minimum availability while there is yet time? Or will they surprise us and perhaps blindside us? We need to be thinking about these issues.

To maintain a society's standard of living requires consumption of resources at some level. In a later installment of this series, we will explore this subject within the sustainability context.

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New Studies Target Future Research Needs

***H. Richard Lane** and **Enriqueta Barrera,** National Science Foundatiom*

The Division of Earth Sciences (EAR) at the National Science Foundation recently commissioned a new National Research Council (NRC) study, chaired by Thomas Jordan, on basic research opportunities in the earth sciences.

The National Academy Press will publish the study committee's final report later this year. Interdisciplinary earth science and the needs of society were among the specific topics given to the committee. To aid deliberations, EAR research programs have been providing input. Five important core research communities of the Geology and Paleontology Program (GE) held small, focused workshops ("Tiger Teams") that produced the following consensus-based white papers about critical research directions and emphases for the coming decades.

Geomorphology and Quaternary Studies, University of Minnesota, February 2–4, 1999; organized by Emi Ito and Robert S. Anderson; *A Vision for Geomorphology and Quaternary Science Beyond 2000.*

Paleontology, Washington D.C., March 6–9, 1999; organized by Karl Flessa; *Dynamic History of the Earth-Life System: A Report to the National Science Foundation on Research Directions in Paleontology.*

Sedimentary Geology, Boulder, Colorado, March 29–31, 1999; organized by Dag Nummedal; *Sedimentary Systems in Space and Time, High Priority National Science Foundation Research Initiatives in Sedimentary Geology.*

Low-Temperature Geochemistry, Boston, Massachusetts, June 5–6, 1999; organized by W. Crawford Elliott; *Directions and Priorities in Low-Temperature Geochemistry for the Year 2000 and the Next Decade.*

Coastal Geology, Honolulu, Hawaii, November 9–11, 1999; organized by Charles (Chip) Fletcher; *Research in the Sedimentary Geology of the Coastal Zone and Inner Shelf.*

The results of these workshops may be of interest to the broader geological community and condensed versions will be published in *GSA Today.* Organizers hope that these white papers will form a basis for continuing discussion within the geological community concerning future research directions and emphases within and outside EAR, and they welcome communications concerning these reports.

The full versions of these white papers can be found online at www.geo.nsf.gov/ear/gepage.html or www4.nationalacademics.org/cger/besr/nsf. ■

National Research Council Studies Have Profound Effect

***H. Richard Lane** and **Enriqueta Barrera,** National Science Foundation*

The Division of Earth Sciences (EAR) at the National Science Foundation periodically commissions studies by the National Research Council (NRC) on the directions of future earth and environmental geosciences research obtaining advice from the earth science community on EAR's research, and programs and the development of new research initiatives. The NRC independently assembles a committee of widely recognized scientists from academia, government, and industry to perform the study.

In 1983, a committee chaired by William Dickinson (a GSA Fellow and former president) completed the last such review, producing a final report, Opportunities for Research in the Geological Sciences (NRC, 1983). This report (p. 2) suggested that the overarching goal for the Division of Earth Sciences, "... should be directed at obtaining a new level of understanding of the structure, composition, energetics, and evolutionary history of the earth with emphasis on the continental lithosphere and its margins." Specific requirements for addressing this goal included increasing funding for standard research grants by a factor of two or more, and for laboratory instrumentation in general, placing expensive equipment such as ion microprobes and accelerator-based mass spectrometers in several regional centers with support staffs; and establishing the following major new experimental projects and facilities: an initiative on arrays of portable digital seismographs to define heterogeneity in the lithosphere; a program of continental scientific drilling; a global digital seismograph network in combination with upgrades to the global system of permanent seismographs; and enhanced data management efforts and state-of-the-art computing facilities.

These recommendations had a profound effect as a planning guide for EAR. Specific results included establishment of the Instrumentation and Facilities Program, Continental Dynamics Program, Southern California Earthquake Center (SCEC), Center for High Pressure Research (CHiPR), Incorporated Research for Seismology (IRIS), Cooperative Studies of Earth's Deep Interior (CSEDI), Fundamental Earthquake Studies of the National Earthquake Hazard Reduction Program (NEHERP), and USArray, among others.

In the 17 years since the 1983 report, significant changes have occurred in both science and its societal context. Scientific emphasis has become increasingly directed toward relevance for human and societal needs; computer technology has surged, producing dramatically expanded database and analytical capabilities; and much of the traditional industry and government monetary support for shallow crustal and surficial processes research has evaporated.

In response to these realities, a new NRC study was recently commissioned by EAR (see "New Studies Target Future Research Needs").

GSA Education: New Directions and Strategies for Excellence

Education, in its broadest and most encompassing sense, provides the foundation and mechanism upon which the Geological Society of America pursues its highest aspirations. Education, in this inclusive sense, is woven throughout GSA's mission to advance the geosciences, to enhance the professional growth of its members, and to promote the geosciences in the service of humankind. Geoscience education is a foremost function to which the Society reaffirms its commitment and support.

The needs of the geoscience education community have undergone remarkable evolution in the past decade. GSA contributed substantially to educational reform efforts and was at the vanguard of advocacy and outreach activities. Today, many more geoscientists are engaged in all facets of geoscience education. Accordingly, the Society must assume a different role of leadership for the growing cadre of geoscience educators.

GSA Education comprises programmatic efforts that will develop, promote, and support geoscience education via, and on behalf of, GSA members. Such endeavors provide focus and purpose to GSA's relationships with donors and sponsors. Organizationally, GSA Education aligns with other programs to uphold member values and fulfill our profession's contract with society. We recommend that GSA Education itself be administered by a director.

In assembling our collective recommendations for GSA Education we were guided by our individual appraisals of the needs and requirements of the program. We submitted "one pagers" about the requirements of geoscience education at GSA—what they have been and what they should be—as well as our thoughts about the responsibilities, roles, and expectations of the educational leadership position at GSA. Understandably, issues and suggestions came from several perspectives: as a member of GSA, as a member of an affiliated association, from a national and public science literacy need, and from the Society's organizational requirements. Although appraisals were drawn from various vantage points, the thoughts expressed were fresh, forward looking, and very helpful. Recurring themes in these submissions gave our recommendations cohesion and focus. It is our view that excellence in GSA Education will require staying informed and competent regarding rapid developments in information technology, assessing the implications of new understandings in cognitive science, and assisting in and developing the wide-scale adoption of curriculum reform efforts. These requisite moves must merge, with purpose and will, into an intangible, irrepressible force as strong as tides. To this end, the Education Task Force and Search Committee offer to Council and management the following recommendations.

GSA Education should be oriented toward providing leadership. Dynamic societies provide direct and obvious opportunities for professional development, both internally for members and externally for society at large. It is the role of all scientists to transmit their knowledge—that is, to educate. In its new leadership role, GSA Education will identify both successful models that support geosocience education and impediments to its advancement. GSA Education will act as a catalyst to engage members, associated societies, and other public and private organizations in a coordinated effort to build mechanisms to disseminate successful models and find solutions to impediments. GSA seminars, workshops, and publications will be important components of this strategy.

GSA Education should have programs that are based on the inherent strength of the Society and on assessment of new opportunities in a changing educational environment. This recommendation calls for one indispensable principle recommended for programmatic change and one that may require immensely strong will. To grow in quality during a time of boundless educational interest, requests, and opportunities requires the principle of restraint. Education programs within professional societies need to develop their programs in better coordination with one another. GSA's involvement in educational activities will require scrutiny, rational selection and assessment of how new opportunities support and contribute to member needs and to the enhancement of the Society's mission. A myriad of activities can fall under the aegis of geoscience education. Most, if not all, are worthwhile activities that help advance and broadly promote geoscience understanding. Yet each of these initiatives requires investment of time, talent, and resources. Strategic planning, or the rational selection of courses of action that are most likely to bring success in the future, is required. The touchstone of programmatic appropriateness needs to be the extent to which an activity visibly and tangibly contributes to fundamental and durable change. If that criterion cannot be established, or at best is tangential to programmatic goals and objectives, then it might be better to help direct the activity to a more appropriate organization or to leave it alone.

As an example, it might be argued that helping to establish geological awareness in the development of a park's new visitor center or new interpretive trail is a worthwhile endeavor, because a large sector of the public will benefit. Yet, it must also be recognized that the benefit is, at best, a second derivative, one that might have a limited contribution to professional development and other established societal programmatic goals. For a contrasting example, a geoscience education effort directed toward enabling faculty to establish programs to help geology majors obtain teacher certification in conjunction with their geoscience degrees can be shown to provide direct benefits to a much larger sector of societal members. Preparation of competent earth science teachers attracts students, contributes to departmental growth, and develops a cadre of professionals who can further contribute to the mission of the Society. This second initiative also contributes to an expressed national need.

Finally, if knowledge acquisition and transfer of information is the core business of the world today, an initiative that brings greater attention to teaching and learning clearly provides dividends throughout all programmatic areas of the Society. Reorientation of GSA Education in the new millennium may not be a zero-sum game, but the overwhelming amount of time on any task will almost always, unavoidably, be derived from internal realignments. Therefore, it is important to assess a project's potential contribution and impact right from the start.

GSA Education should support and publicize the educational activities of member organizations, but it should avoid redundancy. The Society is fortunate in that several associated societies also have long and active involvement in geoscience education. The National Association of Geoscience Teachers should be viewed, fostered, and developed to be more of a direct "working arm" of GSA Education because it has a large congruent membership and a long period of advancing geoscience education. Other associated societies, such as the National Earth Science Teachers Association, and related professional organizations, such as the American Geological Institute and the American Geophysical Union, have active offices of education and contribute significantly to geoscience education. GSA Education must maintain positive and mutually cooperative relationships with each of these organizations (and with some that are outside the direct geoscience sphere, such as the National Science Teachers Association).

GSA Education efforts must be considered in relationship to established priorities and the activities of associated societies and related organizations. Each associated society brings with it a certain constituency of interest and competency. In the myriad of educational levels represented and activities addressed, it is necessary to mutually determine areas of focus for each society. Enhancement of geoscience education at all levels will largely be determined by the extent to which societies can identify and mutually support each other's areas of educational interest, activity, and influence. In this regard, GSA Education should facilitate discussions helping to identify, support, and respect societal spheres of educational interest and influence.

GSA Education should establish affiliated academic centers for geoscience excellence. GSA Education, in its new leadership role, should work to establish academic partnerships in which the research and development activities of geoscience education take place at academic institutions.

At a time when extraordinary developments are occurring in information transfer, a more integrated perspective is also bringing significant contextual change in geoscience education. Earth system science is contributing to important understandings of the interactions among the atmosphere, hydrosphere, biosphere, and solid Earth. As research moves toward an integrated Earth system approach, so too should our educational efforts. We stand at a potentially unprecedented juncture of content and pedagogical reform. Geoscience education's fundamental objective of fostering the development of an informed and geoscience-aware public is inherently linked to our ability to unite the elements of content, information acquisition, and educational practice.

Education's unique contribution lies in understanding the mental operations that underlie learning and the processes of knowledge acquisition. Therefore, GSA Education must be able to link the science of learning and cognition with the development of technologies for teaching and learning. What individuals show enhanced development of cognitive facilities when presented with various modes of learning? Why do they show that development? For the long-term success and contribution of geoscience education, it is important that we consider how data acquisition, analysis, and visualization technology have beneficial effects on students' problem-solving skills and on their ability to transfer these skills to new situations. GSA Education should work to find more effective means of addressing the needs of diverse populations in diverse cultural settings. GSA does not have—nor should it have—the depth of personnel resources required for such research and development. The work of affiliated academic centers can provide important benefits to the Society and many of its members. Recent collaborative initiatives by the physics community could provide a possible model for GSA. Some forward-thinking departments are making important moves in this direction, and it would be mutually beneficial to them as well as to the Society to have such formal partnerships. In turn, establishing such affiliated centers will send a powerful signal to other academic departments throughout the nation. Such an initiative by GSA Education would be transforming leadership at its finest.

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CALL FOR NOMINATIONS

To reward and encourage **teaching excellence** in beginning professors of earth science at the college level, the Geological Society of America announces:

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Eligibility: All earth science instructors and faculty at 2- and 4-year colleges who have been teaching full time for 10 years or less. (Part-time teaching is not counted in the 10 years.)

Award Amount: An award of $750 is made possible as a result of support from the Donald and Carolyn Biggs Fund. The GSA Geoscience Education Division provides up to $500 in travel funds to attend the award presentation at the GSA annual meeting.

Nomination Procedure: For nomination forms, contact Leah Carter, Science, Education, & Outreach, Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140, lcarter@geosociety.org, or visit our Web site at www.geosociety.org.

Deadline: Nominations and support materials for the 2000 Biggs Earth Science Teaching Award must be received by May 1, 2000.

About People

GSA Member Kenneth A. Farley, California Institute of Technology, will receive the National Academy of Science Award for Initiatives in Research.

Fellow Richard E. Gray, GAI Consultants, Monroeville, Pennsylvania, has been elected vice-president for North America by the International Association for Engineering Geology and the Environment.

Fellow Siegfried Muessig, Crystal Exploration Inc., Pasadena, California, has been appointed to a life term as a member of the Board of Governors of the National Mining Hall of Fame (Leadville, Colorado).

GSA on the Web

Visit the GSA Web site at www.geosociety.org.

From our home page you can link to many information resources.

Read about Critical Issues such as Evolution vs. Creationism in the classroom. You can find this information in the Geoscience Initiatives area of the Web site.

Be sure to stop in the Online Bookstore to see the selection of new GSA books.

BOOK REVIEW

Kinetic Theory in the Earth Sciences. *By A.C. Lasaga. Princeton University Press, Princeton, New Jersey, 1998, 811 p., $99.50*

Thermodynamics determines the direction and equilibrium state of a reaction and process, but only at the mercy of kinetics. For example, although thermodynamics tells us that diamond is unstable at room temperature and pressure, both kinetics and experience tell us that diamond persists for a long time, billions of years, and does not convert to graphite, nor to carbon dioxide at room temperature and pressure. In the past 30 years, geochemists have learned a great deal about the kinetics of geochemical processes, ranging from development of geospeedometers to bubble growth that powers violent gas-driven eruptions and to mineral reactions at the surface which control weathering processes. Much of that knowledge is scattered in the literature, and there has been a dire need for good texts for both geochemistry students and professionals.

Therefore, the publication of this new book by one of the leaders of geochemical kinetics was much anticipated. The book is a rigorous and thorough treatise of geochemical kinetics and includes many practical examples from Lasaga's own research. It is also self-contained, providing the necessary mathematics and physics background. The structure is similar to that of Volume 8 of Reviews in Mineralogy. It starts with rate laws of chemical reactions (both homogeneous and heterogeneous). It then delves into the details of the transition state theory. Two chapters on transport theory and diffusion follow. A chapter on irreversible thermodynamics unifies the treatment of all the kinetic processes in the first four chapters. The book ends with two chapters on theories of nucleation and crystal growth. This book may become a classic, for such sections as the simple discussion of closure temperature and the presentation of the difficult materials of irreversible thermodynamics.

As with every book, there is room for improvement. Readers would appreciate more tables of various kinetic data. In a few places, I would have organized the book differently. For example, I would have included Ostwald ripening and the Avrami equation in the chapter on crystal growth, instead of in the chapter on nucleation. Lasaga mixes the kinetics of homogeneous reactions (reactions in a single phase) and heterogeneous reactions (reactions involving two or more phases) in the first chapter. Such mixing is confusing or even incorrect, because reaction rate laws are applicable only to homogeneous reactions, whereas heterogeneous reactions at phase boundaries must be discussed in terms of nucleation, interface reaction (grain size plays a role), and transfer of mass and heat. Because geochemical kinetics has developed into an extremely broad field, it is understandable that a kinetics book reflects the background of the author. This book is written from the view of both a chemist and a geochemist. For example, the extensive and excellent coverage of the transition state theory is, in my opinion, not necessary. There are some applications (such as flow and reaction models) to low-temperature geochemistry, but geospeedometry, an important application, is discussed only briefly. From my high-temperature bias, one of the main differences between chemical and geochemical kinetics is that geochemists (at least high-temperature geochemists) are much more interested in kinetic processes under cooling and the inverse, geospeedometry. This kind of bias is not a real problem, but it indicates the extreme breadth of the subject.

Despite some minor shortcomings, this is an excellent reference book for graduate students and professionals interested in geochemical kinetics, especially for low-temperature geochemists. For those working in high-temperature kinetics, the book is useful for learning the basics but is not enough to prepare the reader for research.

Youxue Zhang
University of Michigan
Ann Arbor, MI 48109-2143

Nominate Someone Else or Volunteer Yourself

Technical Program Chair Wanted for the 2002 GSA Annual Meeting

To give more people the opportunity to organize a GSA Annual Meeting Technical Program, the chair is now selected after a national search. The search for the chair for the 2002 GSA Annual Meeting, in Denver, has begun.

The Technical Program Chair has the final responsibility for the entire technical program, including review and acceptance of keynote and topical session proposals (January–February) and the scheduling (July–early August) of all sessions for the GSA Annual Meeting, in conjunction with the Joint Technical Program Committee (JTPC) representatives. The chair also participates actively for three years on the Annual Program Committee, which meets twice a year (usually March and August).

The Technical Program Chair must have a broad perspective on the geological sciences and must be efficient, organized, fair-minded, flexible, and committed to organizing a dynamic meeting. Some experience with technical program scheduling is helpful, especially membership on the GSA JTPC within the past five years, but is not required. In addition, the Technical Program Chair must be able to work regularly and interactively on the Web and via the Internet, and must be a GSA member.

If you know of someone who would be an effective Technical Program Chair, or are interested yourself, please contact the GSA Meetings Department for a nomination form: (303) 447-2020 ext. 239, ajimenez@geosociety.org. *Nominations are due July 15, 2000.*

2000 GSA SECTION MEETINGS

South-Central Section — April 3–4, 2000, Fayetteville, Arkansas, Center for Continuing Education, University of Arkansas. Information: Doy L. Zachry, Jr., Dept. of Geosciences, 118 Ozark Hall, University of Arkansas, Fayetteville, AR 72701-1201, (501) 575-3355, dzachry@comp.uark.edu. *Preregistration deadline was February 18, 2000.*

North-Central Section — April 6–7, 2000, Indianapolis, Indiana, Government Center and Marriott Courtyard Downtown. Information: Robert D. Hall, Indiana University–Purdue University, 723 W. Michigan Street, Indianapolis, IN 46202-5132, (317) 274-7484, rhall@iupui.edu. *Preregistration deadline was February 25, 2000.*

Rocky Mountain Section — April 17–18, 2000, Missoula, Montana, Missoula Community Theater. Information: Donald W. Hyndman, Dept. of Geology, University of Montana, Missoula, MT 59812-1019, (406) 243-2241, dhyndman@selway.umt.edu. *Preregistration deadline was March 10, 2000.*

Cordilleran Section — April 27–29, 2000, Vancouver, British Columbia, Canada, Robson Square Conference Center. Information: Peter S. Mustard, Dept. of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6, (604) 291-5389, pmustard@sfu.ca. *Preregistration deadline was March 17, 2000.*

2001 ♦ Boston

2001 GSA Annual Meeting
Boston, Massachusetts
November 5–8, 2001
John B. Hynes Veterans Memorial Convention Center

GENERAL CHAIR
Christopher Hepburn
Boston College

TECHNICAL PROGRAM CHAIR
Robert S. Young
Western Carolina University

DUE DATE FOR PARDEE KEYNOTE SYMPOSIA AND TOPICAL PROPOSALS:
January 9, 2001

FOR MORE INFORMATION:
Call: (303) 447-2020 or 1-800-472-1988
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Web site: www.geosociety.org

CALL FOR FIELD TRIP PROPOSALS
We are interested in proposals for half-day, single-day, and multi-day field trips, beginning or ending in Boston and dealing with all aspects of the geosciences.

PLEASE CONTACT FIELD TRIP CO-CHAIRS
David P. West, Jr.
Department of Geology
Earlham College
Richmond, IN 47374
(765) 983-1231, fax 765-983-1497
westd@earlham.edu

Richard (Dick) Bailey
Department of Geology
Northeastern University
Boston, MA 02115
(617) 373-3181, fax 617-373-4378
r.bailey@nunet.neu.edu

FUTURE GSA MEETING: 2003—Seattle, Washington, November 2–5

Donna Russell, *Director of Annual Giving*

Four Distinguished Scientists Appointed to Board of Trustees

Farouk El-Baz, Susan Landon, Anthony Reso, and Robert Weimer will lend their experience and expertise to the GSA Foundation Board of Trustees for the next five years.

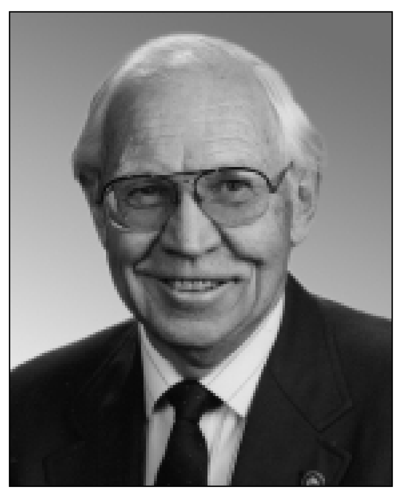
The four were selected and appointed by the board from a list of candidates approved by the GSA Council. Two replace Claire Davidson and Carel Otte, whose terms ended in 1999, and two expand the board to 12 trustees.

Farouk El-Baz is research professor and director of the Center for Remote Sensing at Boston University. He earned his B.Sc. from Ain Shams University in Cairo, his M.S. from the Missouri School of Mines and Metallurgy in Rolla, and his Ph.D. from the University of Missouri. A member of GSA since 1960 (Fellow since 1972), El-Baz worked extensively in the U.S. Apollo program, including training astronauts and selecting lunar landing sites. He established and directed the Center for Earth and Planetary Studies at the National Air and Space Museum of the Smithsonian Institution in Washington, D.C. He has served on committees addressing arid and semi-arid research needs, extraterrestrial features, and lunar nomenclature. He coordinated the first visit by U.S. scientists to the desert regions of northwestern China and served as science advisor to Egyptian President Anwar Sadat. He is a Fellow of the Third World Academy of Sciences and represents the academy at the Non-Governmental Organization Unit of the United Nations Economic and Social Council. He also serves as president of the Arab Society of Desert Research.

Farouk El-Baz

Susan Landon

Anthony Reso



Robert Weimer

El-Baz is known for pioneering work in the applications of space photography to the understanding of arid terrain, particularly the location of groundwater resources. His recommendations have resulted in the discovery of groundwater resources in the Sinai Peninsula, the Western Desert of Egypt, and arid terrains in Somalia and eastern Sudan. Honors accorded to him include several NASA Apollo awards, the University of Missouri Alumni Achievement Award for Extraordinary Scientific Accomplishments, the American Association for the Advancement of Science Award for Public Understanding of Science and Technology, the Award for Outstanding Contributions to Science and Space Technology of the American-Arab Anti-Discrimination Committee, and the Order of Merit—First Class of the Arab Republic of Egypt.

Susan Landon, an independent petroleum geologist associated with Thomasson Partner Associates in Denver, is actively involved in petroleum exploration and production in the United States and teaches industry courses worldwide. She earned her bachelor's from Knox College and her master's from the State University of New York at Binghamton. Her early career included exploration throughout the Rocky Mountains, Alaska, and the midcontinent United States for Amoco Production Company. She joined GSA in 1997 and was elected a Fellow in 1999.

Landon has served two terms on the Board of Earth Sciences and Resources of the National Research Council and is currently chair of the Committee on Earth Resources. She served on the Advisory Committee of the Colorado Geological Survey from 1991 to 1998 and is currently an appointee to the National Cooperative Mapping Advisory Committee. She has been president of the American Institute of Professional Geologists, treasurer of the American Association of Petroleum Geologists, and president of the American Geological Institute. Currently, she is president-elect of the Rocky Mountain Association of Geologists.

Landon has received the Distinguished Service Award and the Honorary Membership Award from AAPG and the Martin Van Couvering Award from AIPG.

Anthony Reso, vice-president of Peak Production Company in Houston, has worked as a geologist for ARCO and for Tenneco Oil Company, as well as teaching at Amherst College and Rice University. He received A.B. and M.A. degrees from Columbia University and his Ph.D. from Rice University. He has been a member of GSA since 1955 and a Fellow since 1965.

Reso's expertise includes exploration for and economic evaluation of oil, gas, and mineral resources worldwide and the relationship of strategic economic resources to national security and international conflict and trade. He has been president of the Houston Geological Society, treasurer of the American Association of Petroleum Geologists, and chair of the GSA Committee on Investments; currently, he is treasurer of the SEPM Foundation and an AAPG Foundation Trustee Associate.

Reso has received the Houston Geological Society Distinguished Service Award, the AAPG Distinguished Service Award, and the GSA Distinguished Service Award.

Robert Weimer has taught courses in stratigraphy, regional and field geology, and energy resource exploration and development for 43 years. He earned B.A. and M.A. degrees from the University of Wyoming and his Ph.D. from Stanford University. He joined GSA in 1954 and became a Fellow in 1961. He has been a visiting professor at universities in Calgary, Canada; Adelaide, Australia; and Bandung, Indonesia. He is currently professor emeritus, Colorado School of Mines.

Weimer has been honored for teaching excellence, blending basic and applied research, national and international continuing education, and service to scientific societies and to state and national boards. Among his many awards are the American Association of Petroleum Geologists Sidney Powers Medal, the American Institute of Professional Geologists Ben H. Parker Medal, the Mines Medal (Colorado School of Mines), and the University of Wyoming Distinguished Alumni Award.

Weimer has served as a trustee of the Colorado School of Mines Foundation, president of SEPM, the Colorado Scientific Society, the Rocky Mountain Association of Geologists, and the American Association of Petroleum Geologists. He was elected to the National Academy of Engineering for application of stratigraphic principles to exploration and for promoting continuing professional education. Pursuing his civic interests, he serves as president of Northwoodside, Inc., a conservancy foundation, and is on the board of directors of the Foothills Art Center in Golden, Colorado.

Farouk El-Baz, Susan Landon, Anthony Reso, and Robert Weimer bring an eclectic mix of experience in research, applied science, and support of geoscience work. They join the GSA Foundation Board of Trustees at a time of unprecedented growth as the Foundation seeks new resources to support vital GSA programs and initiatives. ■

Donors to the Foundation, January 2000

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Digging Up the Past

Most memorable early geologic experience:

"I found three huge dinosaur ribs and several large segments of a leg bone while doing field work near Paradox Valley in Colorado"

—*Linus R. Litsey*

GSA Foundation

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2000 GeoVentures

GeoTrip

Giant Steps Through Time

Dublin, Ireland • September 16–October 1, 2000

Cliffs of Moher. Photo by Jay Gregg.

Scientific Leaders:

John Morris, Barry Long, Brian McConnell, Conor MacDermot, and Pat O'Connor, Geological Survey of Ireland, Dublin; Patrick McKeever, Ian Mitchell, and Terry Johnston, Geological Survey of Northern Ireland. Coordinators: Enda Gallagher, Geological Survey of Ireland, gallaghe@tec.irlgov.ie; Jay M. Gregg, Dept. of Geology and Geophysics, University of Missouri—Rolla, greggjay@umr.edu

This cooperative trip between the Geological Surveys of Ireland and Northern Ireland will be led by eight professional geologists. All are experienced field trip leaders and acknowledged as leading experts in their respective fields within Irish geology.

Description

Participants will be introduced to the wonderful diversity of Ireland's geology, contained within a surprisingly small area. To examine the same assortment of geological localities in the United States would require a considerable trek—perhaps from coast to coast. Not only is Ireland's geology diverse, it also contains numerous classic geologic localities, many of which we will visit during this trip. Participants will see the rocks that neptunists and vulcanists argued over, including Ireland's geologic jewel—the Giant's Causeway in Antrim. Equally impressive are the classic igneous ring complexes and volcanic centers of counties Louth, Armagh, and Down, including Slieve Gullion and Carlingford, which were among the first such features described anywhere in the world. The granites of counties Donegal and Galway exhibit a variety of granite emplacement mechanisms and include the localities where granitization was first proposed. How exactly does an orogeny work? The story of the Grampian orogeny can be read in rocks from Antrim in the northeast across to Galway on the west coast. Ireland's west coast, from Donegal to Clare, reveals many other geologic treasures, including a prograding deltaic sequence, exceptional fossil preservation, and karstic features. All these features are contained in a spectacular glaciated landscape, which, when combined with Ireland's unique culture, history, and folklore, adds a delightful extra dimension to the trip.

Fees and Payment

$4,300 for GSA Members; $4,400 for nonmembers. A $300 deposit is due with your reservation and is refundable through July 1, less $50 processing fee. The total balance is due August 1, 2000. FIRM minimum: 20; maximum: 25. Included: Round-trip airfare from Atlanta to Dublin; guidebook; ground transportation; lodging for 14 nights, based on double occupancy; and meals for 14 days. For registration, contact Edna Collis, ecollis@geosociety.org.

GeoTrip

Deformation, Dinosaurs, and Darwin

Photo by James H. Reynolds.

Salta, Argentina
July 24–August 13, 2000
21 days, 20 nights

Scientific Leaders:

James Reynolds, Magstrat, LLC, Webster, North Carolina, and Brevard College, Brevard, North Carolina; Dorothy L. Stout, Cypress College, Cypress, California

Fees: $3,900 for GSA members; $4,000 for nonmembers

GeoHostel

Valley of Fire in Southern Nevada, Toroweap Valley of the Grand Canyon, Zion & Bryce Canyon National Parks of Southern Utah

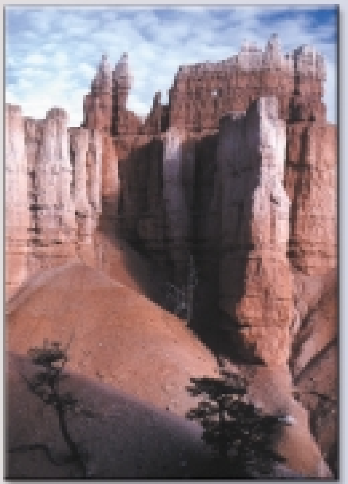


Photo by Martin Miller.

Dixie College,
St. George, Utah
June 10–15, 2000
5 days, 6 nights

Scientific Leaders:

Spence Reber, Chevron USA (retired); Janice Higgins, Dixie College, St. George, Utah

Fees: $800 for GSA members; $900 for nonmembers

For more information, see March *GSA Today* or www.geosociety.org/meetings/gv/index.htm.

Do You Have Some Outstanding Photos?

The Geological Society of America is publishing a new anthology of text and photographs, "Encounters with Earth" (a working title), edited by Eldridge Moores and Lauret Savoy. GSA invites submissions of photographic images, in various photographic media, that examine physical features of Earth for this interdisciplinary anthology. This book will illustrate some of the scope and range of the Earth-human experience to a broad audience by interweaving literary and visual narratives. It will feature current as well as historical photos of a variety of Earth subjects. The photos will be used in combination with writings from a range of fields in addition to the geosciences.

The editors will select original photographs that reflect social, scientific, and cultural themes related to Earth. These selections will also reflect a range of perspectives, time periods, nationalities, and ethnicities. The focus will be how Earth, with its landscapes, environments, topography, and resources, has influenced human activities and perception, and how, conversely, human action has modified or shaped the land.

The editors particularly want images of regions outside of North America, especially Africa, Latin America, and Asia. They prefer photographs that make a visual narrative on their own, rather than simply illustrating accompanying texts.

SUBMISSION REQUIREMENTS

Photographers may submit individual images or a body of work of 10 to 25 images. Images may be submitted either as (1) black-and-white prints (8" × 10" on smooth, nonglossy paper), or (2) color slides. Orientation and name must be clearly marked on each slide or print. The descriptive text for each image should be brief (two or three sentences) and written in language understandable by nonscientists. The text should include the location, type of feature(s), scale, and any other important information. Please provide this text in hard copy and on computer disk. On the disk label, note the computer type (Mac or PC), software text program and version used, document name, and your name. Be sure to include any specific identification for each image with the text. Also, if you are aware of authors (of any discipline or genre) who have written about the regions or features in your photographs, please include this information (author, title of work, date, and place of publication).

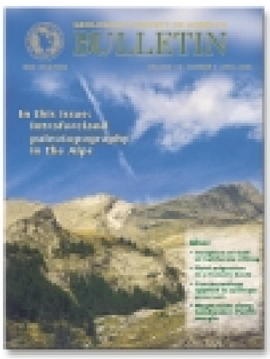
Send submissions as soon as possible, but no later than *June 1, 2000.* We cannot guarantee that they will be considered if received after that date. Your materials will not be returned unless accompanied by a stamped, self-addressed envelope.

Send submissions to:
Lauret Savoy (Encounters Photos)
Dept. of Earth and Environment
Mount Holyoke College
South Hadley, MA 01075

For further information, contact Lauret Savoy at lsavoy@mtholyoke.edu or (413) 538-2125. ■

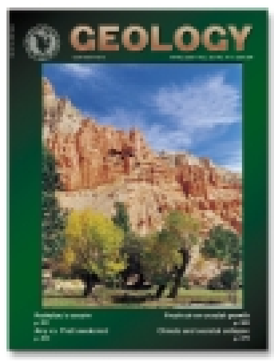
April *Bulletin* and *Geology* Highlights

Because *Bulletin* and *Geology* are now online (www.geosociety.org) as well as in print, their contents listings will no longer appear in *GSA Today,* but here are April *Bulletin* and *Geology* highlights:



In April *Bulletin* —

- Intraforeland paleotopography in the Alps
- Inception of Gulf of California rifting
- Fluid migration in a forearc basin
- Geochronology applied to geologic processes
- Magmatism along Gondwana's Pacific margin

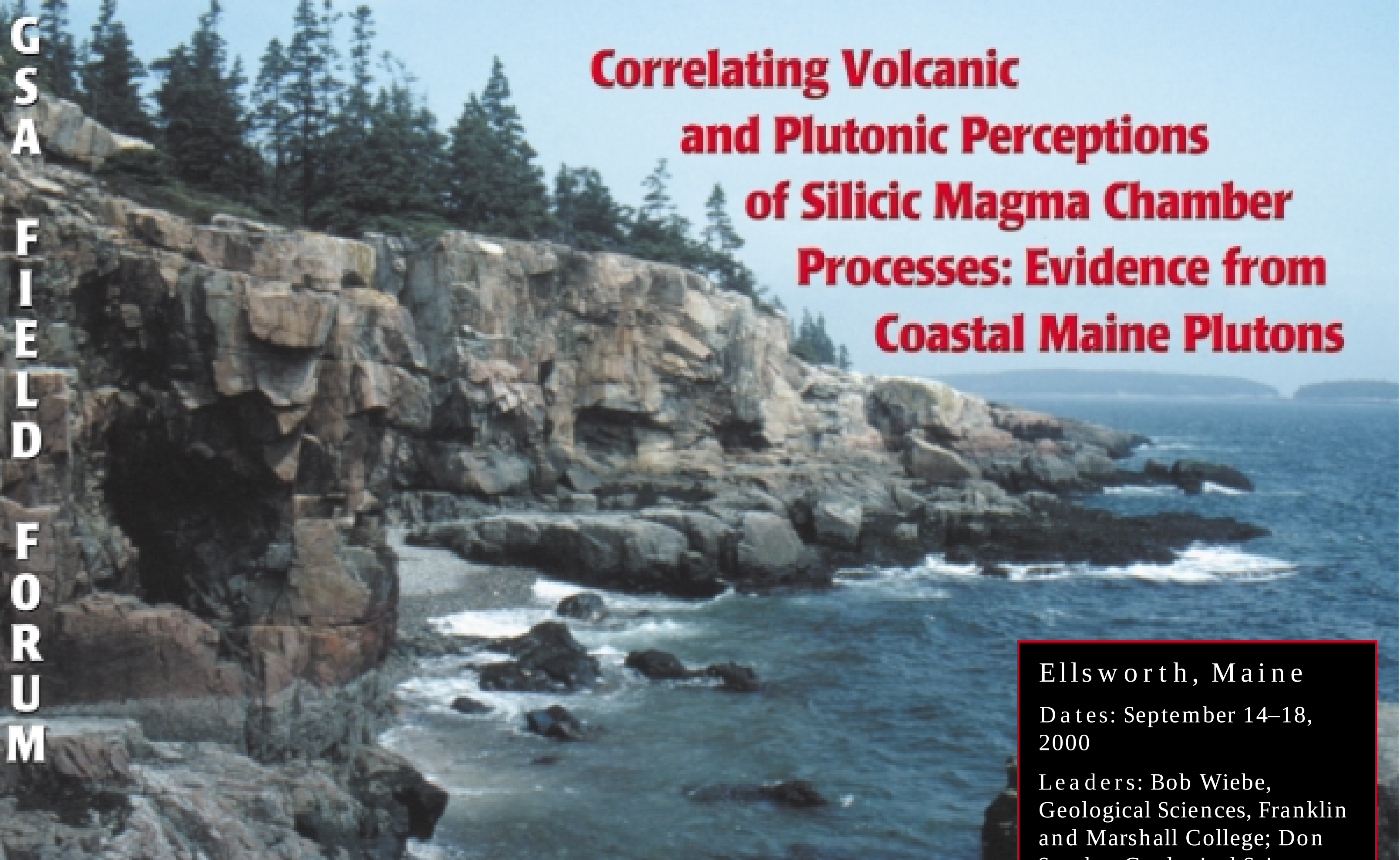


In April *Geology*—

- Krakatau's cousin
- Airy vs. Pratt awakened
- Fresh air on crustal growth
- Climate and societal collapse

For subscription information, call toll-free 1-888-443-4472, or e-mail member@geosociety.org.

GSA FIELD FORUM



Correlating Volcanic and Plutonic Perceptions of Silicic Magma Chamber Processes: Evidence from Coastal Maine Plutons

Ellsworth, Maine

Dates: September 14–18, 2000

Leaders: Bob Wiebe, Geological Sciences, Franklin and Marshall College; Don Snyder, Geological Sciences, University of Michigan; David Hawkins, Department of Geology and Geography, Denison University; Tod Waight, Danish Lithosphere Centre

Photo: Coastal exposures of the Gouldsboro granite in Acadia National Park, Maine. Large silicic enclaves have been deeply eroded by wave action into the prominent caves above the high tide mark. Photo by Bob Wiebe.

This forum will concentrate on the evidence for silicic magma chamber processes in the exceptional coastal exposures of shallow granitic plutons located in Maine. Parts of these plutons contain sections up to several kilometers thick that provide stratigraphic records of crystal accumulation and periodic injection of mafic magma and preserve spectacular magma mingling relations.

These relations appear to be the plutonic record of mafic replenishment events so widely inferred from the study of silicic eruptive systems. While it is becoming increasingly recognized that comparable features are widespread in granitic plutons of all ages and tectonic settings, most petrologists are unaware of the potential impact of these magma chamber processes on the compositions of silicic volcanic and plutonic rocks. The forum will explore the implications of these stratigraphic sequences for the mineralogical and geochemical evolution of silicic magma chambers and the possible impact of the magma chamber processes on the chemical and mineralogical evolution of silicic volcanic rocks and granitic plutons. A diverse group of scientists interested in field, geochemical, experimental, and theoretical aspects of silicic plutonic and volcanic systems will include volcanologists and fluid dynamicists, as well as the more traditional workers on silicic plutonic rocks—those who focus on field, structural, petrographic, geochemical, and isotopic studies of granites.

Some basic questions we plan to address are:

- Is it possible to recognize the signature of a volcanic event in a plutonic system (and vice-versa)?
- How do silicic magmas differentiate?
- How do injections of basic magma interact, both physically and chemically, with silicic magmas?
- What are the factors that influence the geochemical and isotopic signatures of silicic magmas?
- What do the field relations and structures in granitic plutons tell us about the emplacement of granitic magma and the solidification of silicic magma chambers?

Itinerary

Thursday, September 14. Participants should attempt to fly into Bangor, Maine, before 6:00 p.m., in time for dinner and orientation. Vans will provide transport from the airport to the White Birches Motel.

Friday, September 15. The entire day will be spent on Mount Desert Island (Acadia National Park), examining the Cadillac Mountain intrusive complex, which exposes both the base and upper levels of a composite pluton with gabbro, diorite, and granite. We will examine (1) mafic-silicic layered rocks in the gabbro-diorite unit, near the base of the complex (mafic replenishments into a silicic magma chamber), (2) the “shatter zone” (possible evidence for roof collapse during an explosive eruption), and (3) intermediate and silicic enclaves in the high-level Cadillac Mountain granite (are these disrupted samples of hybrid magmas from the base of the chamber?).

Saturday, September 16. Although dominantly gabbroic in composition, the Pleasant Bay layered intrusion contains many layers of granitic and intermediate (hybrid) rocks, which demonstrate that it formed by extensive injections of basaltic magma into a silicic magma chamber. Four stops are designed to show the widest range of interactions between resident granitic material and mafic replenishments, including (1) hybrid layers that grade upward from chilled basaltic magma to granite, (2) mafic layers pierced by granitic pipes fed from underlying crystal mush, and (3) extensive networks of composite dikes consisting of chilled mafic magma in a granite host.

Sunday, September 17. In contrast to the first two intrusions, mafic input into the Gouldsboro granite-gabbro complex has produced little obvious hybridization; gabbro is present only at the base of the intrusion and consists of discrete chilled pillows and sheets. We will examine (1) the transition between interlayered granite-gabbro and the overlying massive granite, (2) the abundant, large silicic enclaves at the highest exposed levels of the granite, and (3) several examples of composite dikes with mafic margins and silicic interiors. These dikes appear to have formed when a basaltic dike penetrated the active silicic chamber, permitting escape of viscous silicic magma from along the margins of the chamber.

Monday, September 18. In the Corea rapakivi granite, including minor gabbroic rocks near the base of the pluton, we will examine (1) interactions between mafic replenishments and granitic magma with large K-feldspar crystals, (2) a higher-level contact of the granite with metavolcanic rocks where rapakivi textures are absent at the contact and become common toward the center of the granite, (3) depositional features and hybrid enclaves within the granite.

Tuesday, September 19. Transport to airport.

Logistics, Participants and Costs

Each day we will have breakfast at 7:00 a.m. and attempt to leave no later than 8:00 a.m. White Birches Motel will provide substantial box lunches and drinks. We anticipate dinners at about 7:00 p.m. and opportunities for discussion and informal presentations afterward, in a room provided with slide and overhead projectors. Hiking is not strenuous, and participants in reasonably good physical condition will be able to visit all localities. Participants must make their own travel arrangements to and from Bangor, Maine. A registration fee of $630 will cover all meals, lodging, field trip transportation, and park fees.

The forum is limited to 30 participants in order to permit easy access to outcrops and opportunities for discussion by all. Participation of graduate students is encouraged. Those interested should send a letter of application to Bob Wiebe. Selection of participants will be made by the field forum leaders; notification of acceptance will be no later than June 15, 2000. To reserve a place, the registration fee is due by *August 1, 2000.*

For Information, Application, and Registration

Contact Bob Wiebe, Dept. of Geological Sciences, Franklin and Marshall College, Lancaster, PA 17604-3003, (717) 291-3820, fax 717-291-4186, r_wiebe@acad.fandm.edu. ■

CALENDAR

Only new or changed information is published in *GSA Today*. A complete listing can be found in the Calendar section on the Internet: **www.geosociety.org.**

2000

August

August 3–5, **History of Geologic Pioneers,** Troy, New York. Information: Gerald M. Friedman, Rensselaer Center of Applied Geology, (c/o Brooklyn College of the City University of New York), 15 Third Street, P.O. Box 746, Troy, NY 12181-0746, fax 518-273-3249, gmfriedman@juno.com.

September

September 8–10, **National Association of Geoscience Teachers Far-Western Section,** Blairsden, California. Information: Elwood Brooks, Dept. of Geological Sciences, California State University, Hayward, CA 94542, (530) 862-0415, ebrooks@csuhayward.edu.

November

November 12–15, **Sixth International Conference on Seismic Zonation,** Palm Springs, California. Information: EERI, 499 14th St., Suite 320, Oakland, CA 94612-1934, (510) 451-0905, fax 510-451-5411, eeri@eeri.org, www.eeri.org.

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Positions Open

GEOLOGICAL ENGINEERING FACULTY
UNIVERSITY OF MISSOURI—ROLLA

The Department of Geological and Petroleum Engineering at the University of Missouri—Rolla invites applications for a tenure-track position in geological engineering. Rank will depend upon qualifications and previous experience in an area considered critical to the mission of the program. A Ph.D. in Geological Engineering or a related field is required and registration as a professional engineer or the qualifications to become registered are strongly desired. Appropriate areas of expertise include: engineering geology and geotechnics, groundwater hydrology and contaminant transport, GIS and remote sensing applications in geological engineering, applied geomorphology, or geo-environmental and geo-materials engineering. Other areas of geological engineering that compliment the mission and ongoing strengths of the program will be considered. The successful candidate should possess a strong commitment to undergraduate and graduate teaching and advising and the successful candidate must demonstrate or show potential for scholarly accomplishments and the ability to obtain external research funding.

The University of Missouri-Rolla offers B.S., M.S., and Ph.D. degrees in geological engineering. It is located in scenic south central-Missouri about 100 miles southwest of St.Louis. Outdoor activities and recreational opportunities are plentiful and Rolla is characterized by good public schools, medical facilities, and a relaxed, pleasant mid-western lifestyle. Additional information about the department and UMR may be obtained by visiting www.umr.edu.

Interested candidates should submit a curriculum vitae; a statement of teaching interests and research accomplishments; and the names, addresses, and telephone numbers of at least three professional references. The deadline for receipt of applications is May 1, 2000 although the selection process will begin immediately upon receipt of applications. Starting date will be September 1, 2000.

Send application materials to: Human Resource Services, Reference Number R50743, University of Missouri-Rolla, 1202 North Bishop, 1870 Miner Circle, Rolla, MO 65409-1050

The University of Missouri—Rolla is an equal opportunity employer.

ASSISTANT/ASSOCIATE PROFESSOR
IOWA STATE UNIVERSITY

Assistant/Associate Professor — Soil Science, 70% teaching, 30% research. Primary responsibility is the introductory soil science course at Iowa State University. Details: www.iastate.edu/hrs/jobs/jobs.html or teloynac@iastate.edu or 515-294-7636. ISU is an EO/AA Employer.

THE JUDSON MEAD GEOLOGIC FIELD STATION
INDIANA UNIVERSITY

The Judson Mead Geologic Field Station of Indiana University is seeking applicants for two visiting faculty positions for Summer 2000. These include: (1) a full time, 7-week position in G429, Geology of the Northern Rocky Mountains; and (2) a 2-week position in G329, Introduction to Environmental Field Science. Comfort and/or familiarity with teaching in a field setting are considered essential. The new faculty members will work with other faculty and associate instructors. For G429, any specialty will be considered, though a training in environmental geology and hydrology is most needed. For G329 we are looking for someone with a knowledge of surficial processes and hydrology. Additional information about the courses and program can be found at http://www.indiana.edu/~iugfs. Applicants should send letter of interest and resume to: Director, Judson Mead Geologic Field Station of Indiana University, 1001 E. 10th, St., Bloomington, IN 47405. Indiana University as an Equal Opportunity/Affirmative Action Employer encourages the candidacies of women and minorities.

DEPARTMENT OF EARTH SCIENCES,
DALHOUSIE UNIVERSITY AND THE
CANADIAN INSTITUTE FOR ADVANCED RESEARCH

Applications are invited for a probationary tenure track assistant professor position in Earth Surface Processes-Landscape Evolution. The successful candidate will strengthen surface processes at Dalhousie by teaching undergraduate and graduate classes, supervising M.Sc and Ph.D students, and by developing and maintaining a vigorous externally funded research programme. S/he will also be appointed a "Scholar" in the Earth System Evolution Programme (ESEP) of the Canadian Institute for Advanced Research (CIAR). Candidates should have an interest in quantitative interdisciplinary research in relationships between surface processes and Earth evolution. The successful candidate will have a record of research achievement, contribution to the discipline, and assessed potential necessary to be appointed by CIAR. As a member of ESEP, the incumbent will be partly supported by CIAR and during this time will benefit from reduced teaching responsibilities and from association with an international network of researchers in earth system sciences.

A Ph.D is required and post-doctoral experience is normally expected. Applicants should submit a c.v.; a statement of research/teaching objectives and the name, address, phone, and e-mail of four referees. The deadline for applications is May 31, 2000, however, applications will be considered as soon as they are complete. Applications should be sent to: Chair, Earth Surface Processes Search Committee, Department of Earth Sciences, Dalhousie University, Halifax, NS, Canada,B3H 3J5. Phone (902) 494-2358, Fax (902) 494-6889, e-mail: earth.sciences@dal.ca. For more specific information, access our websites: http://is.dal.ca/~es/es-home.htm; www.ciar.ca.

DALHOUSIE UNIVERSITY is an Employment Equity/Affirmative Action Employer. The University encourages applications from qualified women, Aboriginal peoples, racially visible people, and persons with a isability. In accordance with Canadian immigration requirements, priority will be given to Canadian citizens and permanent residents.

HOPE COLLEGE, ASSISTANT PROFESSOR

Hope College has a one-year, term appointment for a geologist at the Assistant Professor level available beginning in August 2000. The exact teaching responsibilities will depend on the background of the candidate, but will involve 12 contact hours per semester (typically 6 hours of lecture and 6 hours of lab) in some subset of the following courses: Mineralogy, Petrology, Introductory Earth Science, Surficial Geology, Structural Geology, Geochemistry, and introductory Environmental Science. The mission of Hope College is to "offer with recognized excellence, academic programs in liberal arts, in the setting of a residential, undergraduate, coeducational college, and in the context of the historic Christian faith." Hope College is affiliated with the Reformed Church in America. Applicants should arrange to have a curriculum vitae, transcripts, a statement of teaching philosophy and competencies, and the names and addresses of three referees forwarded to: Dr. Edward Hansen, Chair; Geological and Environmental Sciences Department; Hope College; 35 East 12th Street; Holland, MI 49422-9000. Preliminary inquiries can be sent by e-mail to Hansen@hope.edu. Hope College complies with Federal and State requirements for non-discrimination in employment.

DEPARTMENT OF EARTH AND OCEAN SCIENCES
UNIVERSITY OF BRITISH COLUMBIA

Applications are invited for one or more tenure-track positions. We seek individuals who have proven ability or exceptional potential in research, excellent communication skills for teaching, and leadership potential in order to augment and complement current activities in the department. We seek outstanding applicants who will establish vigorous and well-funded research programs and enhance the interaction between the various research programs within our department. The priority fields for these appointments and non-exclusive examples of areas of expertise sought are as follows: (1) Mineral deposits geology - chemistry of ore fluids, stable isotope geochemistry, applied geochemistry, metallogenic analysis; (2) Applied geophysics - theoretical, computational and experimental examination of Earth's near-surface properties and structure; application to environmental, exploration and engineering geophysics; (3) Organic geochemistry - origins of hydrocarbons and carbon-rich sediments, early diagenesis of organic compounds, metal-phytoplankton interactions on the molecular scale, stable isotopes and organic compounds as tracers of organic processes and/or climate change; (4) Geological engineering (geotechnical) - remote sensing, geotechnical or geophysical methods to characterize weak rock and coarse soils. This appointment may be jointly with a second department.

Outstanding candidates in other areas that fall within the long-range hiring plan of the department (see www.eos.ubc.ca) may also be considered. Appointments will be at the assistant professor level except in the case of exceptionally well-qualified females who may be appointed at a higher rank. We particularly encourage women to apply as we may be able to expand our hiring program through the Natural Sciences and Engineering Research Council (NSERC) University Faculty Awards Program. Applicants must possess a Ph.D.

In accordance with Canadian immigration requirements, priority will be given to Canadian citizens and permanent residents of Canada. UBC hires on the basis of merit and is committed to employment equity. We encourage all qualified persons to apply. These positions are subject to final budgetary approval. Applications including a resumé, a statement of research interests, and the names of three referees should be sent to Dr. Robert M. Ellis, Head, Department of Earth and Ocean Sciences, 6339 Stores Road, University of British Columbia, Vancouver, B.C., Canada V6T 1Z4, by June 15, 2000.

VISITING ASSISTANT PROFESSOR
UNIVERSITY OF AKRON

The Department of Geology has a one-year sabbatical replacement position for the August, 2000–May 2001 academic year. Responsibilities include teaching introductory-level geology courses (Environmental Geology and Physical Geology) and possibly an undergraduate/graduate course in the candidate's field of specialization. Candidates may be required to teach three classes per semester. A Ph.D. in the geosciences is required. Review of applications will begin April 16. Applications will be accepted until the position is filled. Candidates should submit a curriculum vitae, including three references (with e-mail addresses and phone numbers) to Dr. David McConnell, Department of Geology, University of Akron, OH 44325-4101. Further information on the department is available at http://www.uakron.edu/geology/. The University of Akron is an equal opportunity/affirmative action employer.

DIRECTOR
INSTITUTE FOR ENVIRONMENTAL SCIENCE AND POLICY, UNIVERSITY OF ILLINOIS AT CHICAGO

UIC has a significant opportunity for the Director to establish and develop the recently approved Institute for Environmental Science and Policy. The ideal candidate will be a leader who can create a dynamic synergy in interdisciplinary research across the several collaborating colleges. Applicant must have a doctoral degree or equivalent, a breadth of knowledge across several disciplines, a distinguished research program, and be tenurable. The Institute's strengths currently are in the areas of conservation and sustainable development, environmental restoration, biosphere response to global and environmental change, and the interaction of pollutants with the ecosystem. The ideal candidate will have extensive research relationships with federal agencies such as NIH, NSF, EPA, and NOAA and have the capacity to serve as a liaison to industry partners and the media. The University of Illinois at Chicago (http://www.uic.edu) is an ambitious, urban, state-supported, Research I institution with world-renowned programs in medicine, public health, engineering, urban planning, business, architecture and liberal arts - all of which are represented within the Institute. Send a cover letter, complete vitae, and the names and addresses of at least three references to: Mr. Anthony Halford, Office of the Vice Chancellor for Research (MC 672), University of Illinois at Chicago, 1737 West Polk Street, 304 AOB, Chicago, Illinois, 60612-7227. For fullest consideration, submit application by 5/1/2000.

The University of Illinois at Chicago is an Affirmative Action and Equal Opportunity Employer.

EASTERN KENTUCKY UNIVERSITY
SOILS GEOLOGIST / GEOMORPHOLOGIST
SURFACE HYDROLOGIST

The Department of Earth Sciences invites applications for a tenure-track position at the Assistant/Associate Professor level beginning August 15, 2000. We seek a colleague with academic training and practical experience in surface active geological processes and their consequences, who will complement the department's existing strengths in hydrogeology and environmental science. Candidates must exhibit a commitment to excellence in teaching general education science courses, as well as courses for geology majors and masters degree candidates. We expect the incumbent to involve students in his/her research. Ph.D. required. Eastern Kentucky University (www.eku.edu) is a large, comprehensive, regional university located in the Bluegrass region of Kentucky, 25 miles south of Lexington. Candidates should submit a letter of application, curriculum vitae, statement of teaching and research interests, and arrange to have three letters of recommendation sent to Dr. Malcolm P. Frisbie, Acting Chair, Department of Earth Sciences - 2, Eastern Kentucky University, Richmond, KY 40475-3102. Review of applications will begin 1 May 2000; position will remain open until filled. Address questions to natfrisbie@acs.eku.edu. Eastern Kentucky University is an equal opportunity / affirmative action employer and encourages applications from minority and female candidates.

LOW-TEMPERATURE GEOCHEMISTRY
U.S. GEOLOGICAL SURVEY, TUCSON, ARIZONA

The U.S. Geological Survey (USGS) is seeking candidates to design and conduct research on low-temperature geochemical processes involving minerals, water, soils, and related materials (e.g., organic matter, mine wastes) in both mineralized and unmineralized areas at scales ranging from a mine site to a region. Research will include the fate of toxic elements associated with metallic and industrial mineral deposits, surficial weathering behavior of mineral deposits, and the relationship of regional geochemical abundances to the environment and human health, especially in the arid climatic conditions of the southwestern U.S. Results contribute to both mineral-resource and environmental studies on public lands.

This is a full-time, permanent position with a starting salary range between $54,003-64,218 per year. We are seeking applicants who have conducted process-oriented field and laboratory investigations related to mobility and transport of trace elements, rock-water interaction, and chemical speciation in aqueous media, as well as the geology and geochemistry of mineral deposits.

A Ph.D. in geochemistry is desirable. U.S. citizenship is required. The job announcement and application materials can be found on our Web site: http://www/usajobs.opm.gov. Applications for this position must be submitted by April 30, 2000.

The U.S. Geological Survey is an equal opportunity employer.

LOW-TEMPERATURE GEOCHEMISTRY
U.S. GEOLOGICAL SURVEY
SPOKANE, WASHINGTON

The U.S. Geological Survey (USGS) is seeking candidates to design and conduct research on low-temperature geochemical processes involving minerals, water, soils, and related materials (e.g., organic matter) in mineralized and unmineralized areas at scales ranging from a mine site to a region. Research will include the fate of toxic elements associated with metallic and industrial mineral deposits, the role of nutrient elements in forest health and ecology, and the relationship of regional geochemical abundances to the environment and human health, especially in the Pacific Northwest. Results contribute to both mineral-resource and environmental studies on public lands.

This is a full-time, permanent position with a starting salary range between $50,139-59,623 per year. We are seeking applicants who have conducted process-oriented field and laboratory investigations related to mobility and transport of trace elements, rock-water interaction, and chemical speciation in aqueous media, as well as the mineralogy and geochemistry of soils.

A Ph.D. in geochemistry is desirable. U.S. citizenship is required. The job announcement and application materials can be found on our Web site: http://www/usajobs.opm.gov. Applications for this position must be submitted by April 30, 2000.

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Opportunities for Students

Graduate Student Support Opportunities in Earth Sciences, Lehigh University--The Department of Earth and Environmental Sciences of Lehigh University has Graduate Student Fellowships for highly qualified individuals. The department has active research programs in tectonic studies (geochronology, stable isotope geochemisty, low temperature geochemistry, seismology, high resolution geophysics, structural geology, paleomagnetism) and surficial processes (low temperature geochemistry, fluvial and tectonic geomorphology, glacial geology, hydrology, and limnology). Please contact Prof. D. Morris, Dept. of Earth and Environmental Sciences (dpm2@lehigh.edu) or see our Web page for more details (http://www.ees.lehigh.edu).

Graduate Student Opportunities, Department of Geological and Petroleum Engineering, University of Missouri—Rolla. We are pleased to announce the availability of several graduate assistantships. A research assistantship funded by the NCRHP-IDEA Program under the Transportation Research Board is offered for students interested in engineering geology. More information on the project may be found at www.umr.edu/~psanti/wick.html. In addition, a GAANN Ph.D. Fellowship funded by the U.S. Department of Education is available for highly qualified individuals, supporting research, travel, and teaching in the field of "computational earth science." A third area of support is from teaching assistantships, which are still available for M.S. and Ph.D. candidates starting in the Fall 2000 and Winter 2001 semesters.

The department offers a wide range of graduate specialties, including emphasis areas in environmental protection and hazardous waste management, ground-water hydrology and contaminant transport, engineering geology and geotechnics, and natural resources, minerals, and energy. More information may be found on the department's home page at www.umr.edu/~gee or write to: Graduate Advisor, Dept. of Geological and Petroleum Engineering, 129 McNutt Hall, University of Missouri—Rolla, Rolla, MO 65409.

Graduate Research Fellowship – Kansas Geological Survey, University of Kansas. The Kansas Geological Survey (KGS) invites applications for a Ph.D. or MS graduate research fellowship in the general area of carbonate sedimentology and stratigraphy. This fellowship provides research opportunities at the Kansas Geological Survey, full tuition at the University of Kansas for the fall and spring semesters (9 months) and possibility for summer salary (3 months). Depending on qualifications, the total financial package could exceed $25,000/year. Possible research topics with this fellowship include: Sedimentologic, sequence-stratigraphy, and diagenetic studies on Paleozoic carbonate and chert strata that form important reservoirs in Kansas; Integrated sedimentologic, stratigraphic, hydrologic, petrophysics, and geophysics studies utilizing outcrop, ground-penetrating radar, seismic, modeling and attribute analysis for high-resolution 3-D imaging and characterization of sedimentaryfacies, surfaces, and geometries. These studies are designed to develop methods for better understanding stratal relationships and heterogeneity in lithified and unconsolidated strata that are important reservoir and aquifer analogs.

Send letter of application explaining research interest and resume to: Dr. Evan K. Franseen, Kansas Geological Survey, 1930 Constant Ave., The University of Kansas, Lawrence, KS 66047, phone: (785) 864-2072, fax: 785-864-5317, e-mail: evanf@kgs.ukans.edu.

For background information see: http://www.kgs.ukans.edu/general/personnel/def/evanfranseen.html. Applications will be considered starting immediately for the 2000-2001 academic year. For more complete information and applicable KU graduate school deadlines see http://www.kgs.ukans.edu. The University is an EO/AA employer. ■

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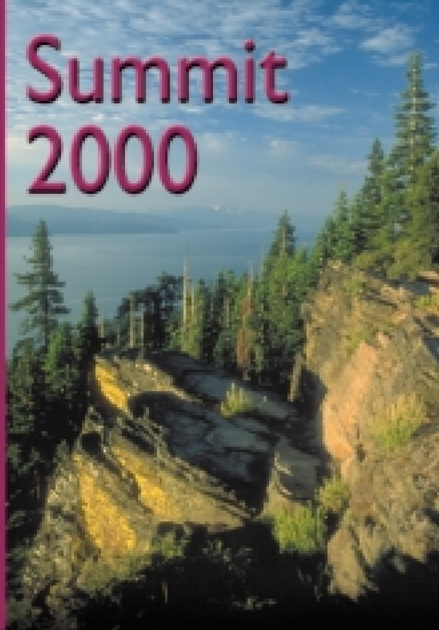

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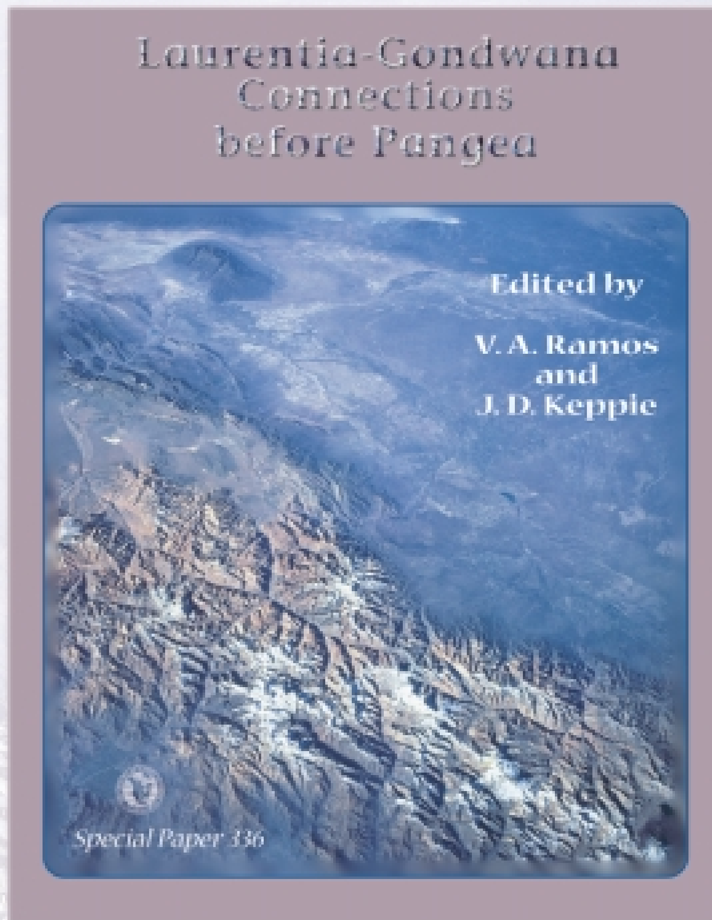
2000 GSA Annual Meeting and Exposition — November 9–18, 2000

Laurentia-Gondwana Connections before Pangea

Edited by
V.A. Ramos and J.D. Kepple



More than 45 authors explore the tectonic interaction among the exotic terranes between Laurentia and southwest Gondwana.

The authors reveal new data that sheds light on pre-Pangea connections between Laurentia and southwest Gondwana. These data concern the presence of Ollenelus and associated fauna in the Precordillera of central western South America, the common early Paleozoic paleomagnetic data, the presence of a large early Paleozoic carbonate platform distinct from the typical southwest Gondwanan clastic platforms associated with glacial deposits, and the exotic nature of the Grenville basement of this platform.

Additional new data on Grenvillian basement terranes, such as Oaxaquia in Mexico, with typical early Paleozoic South American faunas, indicate some extra constraints on the Cambrian–Ordovician paleogeography between Laurentia and Gondwana.

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