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INSIDE

A New Look at the Long-term Carbon Cycle

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ABSTRACT

The long-term carbon cycle is the cycle that operates over millions of years and that involves the slow exchange of carbon between rocks and the surficial system consisting of the ocean, atmosphere, biota, and soils. It is distinguished from the short-term carbon cycle, in which carbon is rapidly exchanged only within the surficial system. A new type of diagram illustrates the cause-effect relations involved in the long-term carbon cycle and how these processes affect the levels of atmospheric O_2 and CO_2. The diagram also includes the cycle of phosphorus as it affects the burial of organic matter in sediments. The diagram is distinctly different from, and is here compared to, the more traditional representation of geochemical cycles in terms of box models. By following paths leading from causes to effects, one can trace complex loops that demonstrate positive and negative feedback, and this allows discovery of new subcycles that deserve further study. This type of diagram should be applicable in general to other geological and geochemical processes.

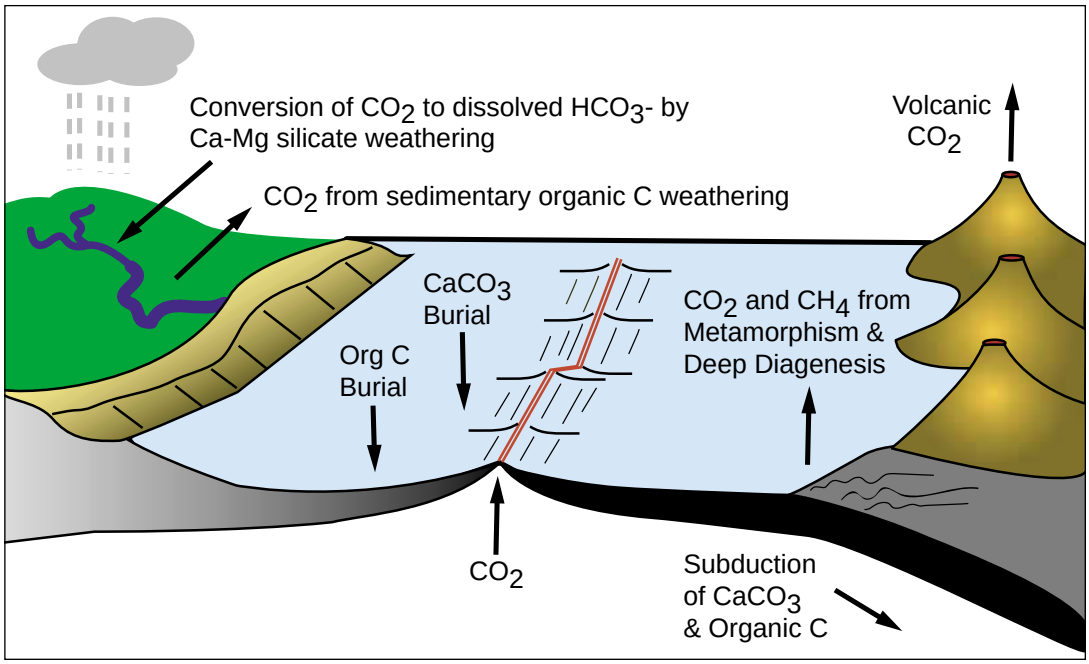

Figure 1. An idealized and simplified representation of the surficial aspects of the long-term carbon cycle. Note the exchange of carbon between rocks, on the one hand, and the oceans and atmosphere, on the other; this is the distinguishing characteristic of the long-term cycle.

INTRODUCTION

The term "carbon cycle" means many things to many people. For those concerned with the present growth of CO_2 in the atmosphere, due to deforestation and the burning of fossil fuels, the carbon cycle consists of those sources and sinks that exchange carbon with the atmosphere on a human time scale. This includes the biosphere, oceans, and soils, and I refer to it here as the short-term carbon cycle. This cycle is also the dominant control on atmospheric CO_2 over longer periods, including the glacial-interglacial stages of the Quaternary. However, as one goes back further in geologic time, one must take into account the exchange of carbon between rocks and the combined biosphere-hydrosphere-atmosphere-soil system. This gives rise to the concept of the long-term carbon cycle, and it is this cycle that is the dominant influence on the levels of atmospheric oxygen and carbon dioxide over millions of years (Holland, 1978). (Humans have accelerated this cycle by the burning of organic carbon in sedimentary rocks that otherwise would oxidize only very slowly by weathering.) A cause-effect–type diagram, previously used in modeling physiology (Grodins, 1963; Riggs, 1970), climate (Saltzman and Moritz, 1980; Saltzman and Maasch, 1991), and ocean nutrients and oxygen (Lenton, 1998) can be used also to illustrate the various kinds of feedbacks that control CO_2 and O_2 in the long-term (multimillion-year) carbon cycle.

LONG-TERM CARBON CYCLE

Summaries of the processes that affect carbon transfer as part of the long-term carbon cycle (Fig. 1), and how they affect atmospheric CO_2 and O_2 can be found in a variety of sources (e.g., Garrels and Perry, 1974; Walker, 1977; Holland, 1978, 1984; Berner, 1989, 1998). The processes affecting CO_2 can be divided into two subcycles. The first, the silicate-carbonate subcycle, involves the uptake of atmospheric CO_2 (processed mostly by photosynthesis and respiration to form soil CO_2 and organic acids) during the weathering of Ca and Mg silicate minerals. A representative generalized reaction for Ca is:

$$2CO_2 + H_2O + CaSiO_3 \rightarrow Ca^{++} + 2HCO_3^- + SiO_2. \quad (1)$$

The dissolved Ca^{++} and HCO_3- are carried by rivers to the sea, where they are precipitated (almost always by means of a biological process) as $CaCO_3$ in sediments:

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Champaign, Illinois
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Byron K. Thomas
Plano, Texas
November 14, 1997

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A New Look *continued from p. 1*

$$Ca^{++} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O. \quad (2)$$

(Mg is removed from the oceans by dolomite formation or by exchange for Ca with ridge basalts, the Ca being subsequently precipitated as $CaCO_3$). The net overall reaction (Ebelmen, 1845; Urey, 1952) is:

$$CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2. \quad (3)$$

In this way CO_2 is removed from the atmosphere and buried as limestone. The weathering of Ca and Mg carbonates, by comparison, does not result in net loss of CO_2 to the rock record because the weathering reaction for carbonates is simply the reverse of reaction 2 or its dolomite [$MgCa(CO_3)_2$] analogue. To replace the CO_2 lost to the rock record, degassing occurs as a result of the thermal breakdown of carbonates at depth by volcanism, metamorphism, or deep diagenesis. This process completes the silicate-carbonate subcycle and can be represented for Ca simply by:

$$CaCO_3 + SiO_2 \rightarrow CO_2 + CaSiO_3, \quad (4)$$

which is the reverse of reaction 3.

The other carbon subcycle is that for organic matter. This subcycle affects both CO_2 and O_2. The burial of organic matter in sediments represents a net excess of photosynthesis over respiration and can be represented by the reaction normally applied to photosynthesis:

$$CO_2 + H_2O \rightarrow CH_2O + O_2. \quad (5)$$

Dialogue

Sara Foland, CEO

The Need for Integrated Solutions

> "Ordinary mortals communicate rather freely, while intellectuals have succeeded in erecting barriers between them that they don't know how to dissolve."
>
> —*Marie Curie*

Many of the problems we face today — climate change, global warming, ozone depletion, species endangerment and habitat loss, earthquake prediction, coastal population centers, resource distribution and extraction—cannot be easily solved solely from the perspective of one discipline. Scientists, like physicians, are becoming more specialized; yesterday's naturalists are today's biologists, zoologists, botanists, geologists, geophysicists, meteorologists, and myriad other specialties.

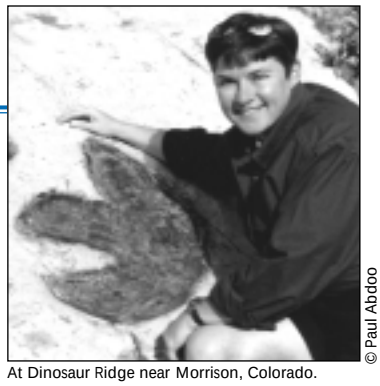
Earth now exists somewhere along a spectrum of an experiment started more than 4.55 billion years ago. We know neither the input parameters nor the experimental design. Geologists trained as the observers of clues produced from Earth's processes are in a unique position: as interpreters of these natural systems, we are adept at solving complex problems using knowledge from many different scientific disciplines.

GSA's leadership recognized the unique role that geoscientists play in interpreting earth systems but realized that the trend in earth science education, as in medicine, was toward increasing specialization. Therefore, they placed a specific goal within our strategic plan to emphasize the value of and need for integration. Goal 2 of the GSA strategic plan is: *To catalyze cooperative interactions among earth, life, planetary, and social scientists who investigate natural systems over varying scales of time and space.* This goal is further divided into objectives that specifically define GSA's role in creating opportunities for cooperative interaction.

This year's Annual Meeting in Denver provided an opportunity for our members to interact on key issues. With the theme "Crossing Divides," the meeting emphasized multidisciplinary and integrative science. Seven Pardee Keynote Symposia (named for the late Joseph Thomas Pardee) formed the core of the technical presentations and covered a wide range of topics from climate, global tectonics, and impact events, to the role geoscience plays in environmental and legal decisions.

Societal impact and focus were woven throughout the technical sessions, providing ethical, historical, legal, and philosophical points of view. Many other sessions addressed the impact of geoscience on society. Public policy was a critical element in sessions addressing coastal geological risk, the need for greater predictive capability, and creationism versus evolution in the classroom.

As we enter the new millennium, geoscience will continue to play a central role in interpreting natural systems for society. GSA will continue to enhance its role, providing venues for debate and dialogue for natural-system scientists.



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At Dinosaur Ridge near Morrison, Colorado.

A Definition of Geology

Eldridge Moores

A decade ago after extensive debate, the GSA Council adopted the following definition:

> *Geology is used in the broad sense—the study of Earth and other planets and planetary objects using any and all available techniques; it includes geochemistry and geophysics.*

Geology incorporates the study of rocks and their history, the internal structure and processes of the planet and their connection with the surficial rock and land form record, as well as the development and history of life. Geology is the study of complex systems that involves the oceans, atmosphere, biosphere, and the solid Earth. The planetary science revolution has extended geology's scope to include other planetary bodies in addition to Earth.

In keeping with this broad definition of geology, GSA's divisions focus, among other things, on resources, geophysics, planetary geology, global geologic processes, active geologic processes, and the societal impact of geology. Similarly, associated societies represent fields such as mineralogy, geochemistry, paleontology and paleobiology, engineering geology, geoscience education and information, and economic geology.

This diversity of interests encompassed under the GSA umbrella underscores the Society's involvement in and commitment to the integrative nature of geology.

This reaction explains how organic matter burial results in the production of atmospheric O_2. To complete the organic subcycle, O_2 is consumed and CO_2 produced by the oxidation of organic matter in old sediments exposed to weathering on land:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O. \quad (6)$$

This reaction also represents the overall process of the thermal breakdown of organic matter, followed by the degassing to the surface of reduced carbon-containing gases (exemplified by CH_4 in Fig. 1) and their rapid oxidation to CO_2 by atmospheric O_2.

In sum, reactions 3–6 constitute the long-term carbon cycle and are one way of representing it. Figure 1 is another means of representation, which can be simplified in the form of a box model diagram (see below). However, there is another way of looking at the long-term carbon cycle that does not simply show sinks, sources, and fluxes, as do cartoons like Figure 1 or box model diagrams. Instead of focusing on fluxes and reservoirs, one can look at causes and effects.

CAUSE-EFFECT FEEDBACK DIAGRAM FOR THE LONG-TERM CARBON CYCLE

Figure 2 is another way of looking at the long-term carbon cycle as it affects the levels of atmospheric CO_2 and O_2. (See caption for a detailed discussion of concepts and terminology.) Some processes involving phosphorus (P) are included because of the importance of P as a limiting nutrient in the photosynthetic fixation of carbon. An example of an inverse effect is the increased oxidation of organic carbon to CO_2 by weathering leading to a decrease in atmospheric O_2. An example of a direct response is increased burial of organic carbon in sediments leading to an increase in atmospheric O_2 (via reaction 5 above). *This type of diagram should not be confused with similar-appearing geochemical box models.* (For comparison, traditional box model diagrams for the short-term and long-term carbon cycles are discussed further below.)

Following arrows around a cycle, Figure 2 allows one to deduce whether the

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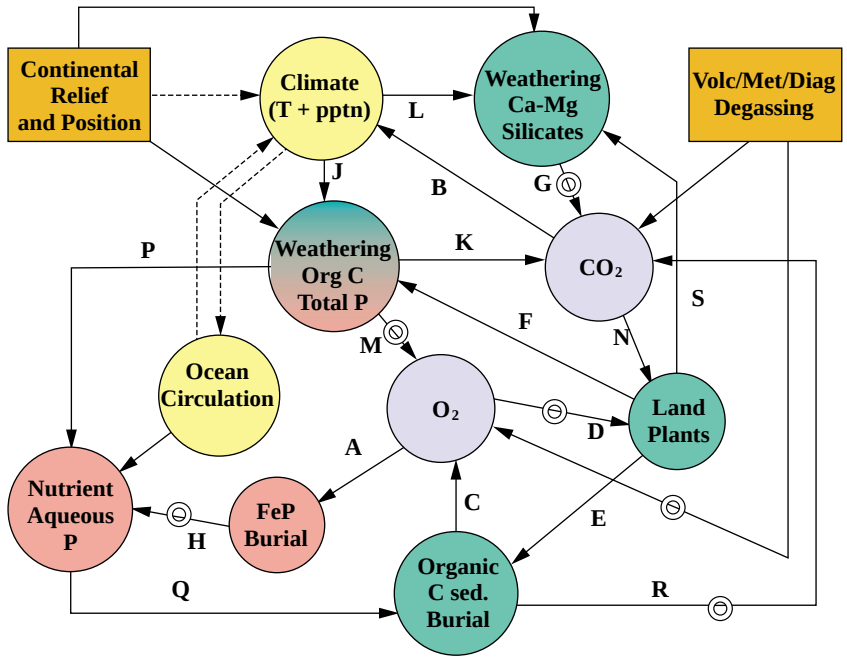

Figure 2. Cause-effect feedback diagram for the long-term carbon cycle. Arrows originate at causes and end at effects. *The arrows do not simply represent fluxes from one reservoir to another.* Arrows with small concentric circles represent inverse responses; e.g., as Ca-Mg silicate weathering increases, CO_2 decreases. Arrows without concentric circles represent direct responses; e.g., as organic C burial goes up, O_2 goes up. Letters adjacent to arrows designate paths followed by feedback loops. The blue regions marked O_2 and CO_2 refer to atmospheric gases. Surficial processes involving carbon are in green, phosphorus in pink, and those not directly involving either C or P in yellow (T is temperature; pptn is precipitation). Tectonic processes (volcanic, metamorphic, diagenetic degassing; continental relief and position) are in orange boxes. Dashed lines between climate and tectonics or ocean circulation refer to complex combinations of physical processes not discussed in this paper. Nutrient aqueous P is phosphorus dissolved in natural waters that is available for uptake via photosynthesis, both continental and marine; FeP represents phosphate adsorbed on hydrous ferric oxides. Organic C and P burial includes that on the continents and in marine sediments. For diagrammatic clarity, arrows from organic carbon burial to organic weathering or degassing (i.e., recycling of carbon) are not shown (see text). There is no arrow going directly from O_2 to the weathering of organic carbon because of evidence that changes in atmospheric O_2 probably do not affect organic carbon weathering rate (see text).

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cycle ends up leading to positive or negative feedback. Negative feedback results when an increase or decrease of a variable results, at the end of a cycle, in a dampening of this increase or decrease. Positive feedback results in amplification of an initial increase or decrease. Discerning negative from positive feedback is the major advantage of using diagrams like this. If during a cycle, the sum of small concentric circles is an odd number, the cycle leads to negative feedback. If the sum of small circles is even, including zero, the feedback is positive. As an example, follow the path marked by arrows B, L, and G. Because only one small circle is encountered, this cycle should result in negative feedback. Increased atmospheric CO_2 should lead to a warmer and wetter Earth, via the atmospheric greenhouse effect, which should lead in turn to enhanced weathering of Ca-Mg silicates and uptake of CO_2. This negative feedback loop has been emphasized in several studies as an important control on atmospheric CO_2 over geologic time (see discussion in Berner and Caldeira, 1997).

The loop N-S-G (just one small concentric circle) represents the fertilization of plant growth by CO_2, which in turn accelerates weathering of Ca-Mg silicates and uptake of CO_2. This process has been proposed as a means of providing additional negative feedback for stabilizing atmospheric carbon dioxide over geologic time (Volk, 1987). The quantitative significance of this feedback remains to be seen.

Other negative feedback loops that have been emphasized as controls on atmospheric oxygen are also shown on the diagram. Consider the loop A-H-Q-C. An increase in the level of atmospheric O_2 should lead to a more oxygen-rich ocean and greater burial of hydrous ferric oxides in sediments. Dissolved phosphate adsorbs strongly to ferric oxides under aerobic conditions, so that greater burial of ferric oxides should entail greater burial of adsorbed phosphate (designated as FeP in Fig. 2). For a constant flux of P to the sea, removal of P from seawater as FeP should lead to less nutrient phosphorus available for organic production. If it is assumed that the limiting nutrient for organic production in the ocean is phosphate (Holland, 1978), less P availability for organic uptake should lead to a lower rate of organic matter sedimentation and burial and, thus, a lower production of O_2. Overall what started as an increase in O_2 results ultimately in a decrease—i.e., a negative feedback. This loop has been forcefully advocated by Holland (1994) and Van Cappellen and Ingall (1996) as a major control of atmospheric O_2.

Another negative feedback loop involving phosphorus has been advanced by Kump (1988). Following path D-E-C we get negative feedback as follows: increased O_2 leads to a greater frequency of fires, which reduces the standing crop of land plants. Fewer land plants leads to less sedimentary burial of terrestrial organic carbon and, consequently, less global burial of total organic matter. This then results in less oxygen production. (Phosphorus not buried with terrestrial organic matter is carried to the sea where it is deposited with marine organic matter that has a lower C/P ratio than terrestrial organic matter, leading globally to less C burial per unit of P burial.)

Another negative feedback loop involving phosphorus is shown by the complex path D-F-P-Q-C, which has one concentric small circle, a path advanced by Lenton (1998) as a major control on O_2. Higher O_2 should lead to greater frequency of forest fires and a lower standing crop of land plants. Fewer land plants should lead, in turn, to less weathering of phosphate minerals because of the accelerating effect of plants on weathering in general (e.g., Lovelock and Watson, 1982; Berner, 1998). Less weathering of phosphate means less liberation of P to solution, and ultimately to less phosphate in seawater. Less oceanic dissolved P, if it is a limiting nutrient, should lead to less burial of organic matter, and finally a lower production of O_2—a negative feedback.

Several feedback loops have heretofore been neglected but should lead to positive feedback. Consider the simple loop D-F-M, which contains two small concentric circles signifying positive feedback. Greater atmospheric O_2 should lead to fewer land plants, which should lead to less weathering of organic matter, which should lead to less O_2 uptake and, therefore, an increase in O_2. Another positive loop is B-J-K. Higher CO_2 should bring about warmer temperatures and greater precipitation, leading to enhanced weathering of organic matter and production of CO_2.

Finally, there is the complex cycle B-J-P-Q-R. This is an additional possible negative feedback mechanism for stabilizing atmospheric CO_2. Higher atmospheric CO_2 should lead to: a warmer and wetter climate, greater weathering of phosphate minerals, more P delivered to the sea, more organic matter burial, and, thus,

enhanced removal of CO_2. This possible stabilizing mechanism and the two destabilizing feedbacks discussed above deserve further study.

Examination of Figure 2 reveals that there is no positive arrow directly from atmospheric oxygen to weathering of organic matter. It is often assumed that a higher level of atmospheric oxygen would lead to greater oxidation of organic matter during weathering. However, because organic matter weathers so fast, the rate-limiting step in oxidation is likely to be the exposure of organic matter in sedimentary rocks to air by erosion, and not the actual oxidation process (Holland, 1978, 1994). (Lack of direct dependence of organic-matter oxidation on O_2 does not preclude possible indirect dependence involving land plants—see path D-F, for example.) The idea of direct dependence of organic matter weathering on O_2 is not supported by laboratory determinations of the rate of aqueous coal oxidation as a function of O_2 level (Chang and Berner, 1999). (Coal was studied as a sulfur-free representative of sedimentary organic matter.) Results indicate that there is a low-order dependence of oxidation rate on O_2 level, possibly approaching zeroth-order kinetics on long time scales, and the oxidation rate itself is rapid compared to rates of erosion.

The tectonic processes included within orange squares in Figure 2—continental relief and position and volcanic, metamorphic, and diagenetic degassing—have been considered here as boundary effects (forcing functions), not involved in feedback loops. The actual situation is more complicated (see Fig. 1). Organic matter and the Ca-Mg carbonates resulting from Ca-Mg silicate weathering are eventually buried to depths where they are thermally decomposed, leading to metamorphic (plus diagenetic) and volcanic degassing of CO_2 and degassing of reduced carbon-containing gases (generalized in Fig. 1 as CH_4) that react with atmospheric O_2. Thus, there should be more arrows in Figure 2. However, because of the time lag for burial and thermal decomposition, these longer-term processes have been omitted from the diagram for clarity, as has the effect of exposing previously deposited organic matter much later to oxidative weathering (arrow from organic burial to organic weathering). However, if sea-level change is rapid, this process may constitute rapid recycling of carbon (Berner, 1989) and can lead to negative feedback and the stabilization of O_2.

Although it affects mainly the short-term carbon cycle, ocean circulation is also shown in Figure 2 because of its effect on the phosphorus cycle and eventually on the carbon cycle. Greater overturn of the ocean should lead, in general, to a greater supply of P to surface waters ("nutrient aqueous P") where it can be used to fix carbon during photosynthesis, resulting ultimately in increased organic-carbon burial. Ocean circulation is affected by climate and vice versa, which leads to a link to the whole panoply of processes connected with climate and the necessity of using a much enlarged cause-effect diagram involving continental ice sheets, ocean temperature, solar forcing, etc., as well as some of the processes shown in Figure 2 (see Saltzman and Moritz [1980] or Saltzman and Maasch [1991] for an example of such an expanded diagram). To retain clarity, these relations are omitted from Figure 2 and represented by dashed arrows.

A summary of the effects of increased elevation and relief, due to mountain uplift, on climate (dashed arrows in Fig. 2) is presented by Ruddiman (1997); for the effect on climate of changes in land size, and position relative to latitudinal climate zones (i.e., continental drift), see Otto-Bliesner (1995). In general, it is believed that large-scale mountain uplift results in

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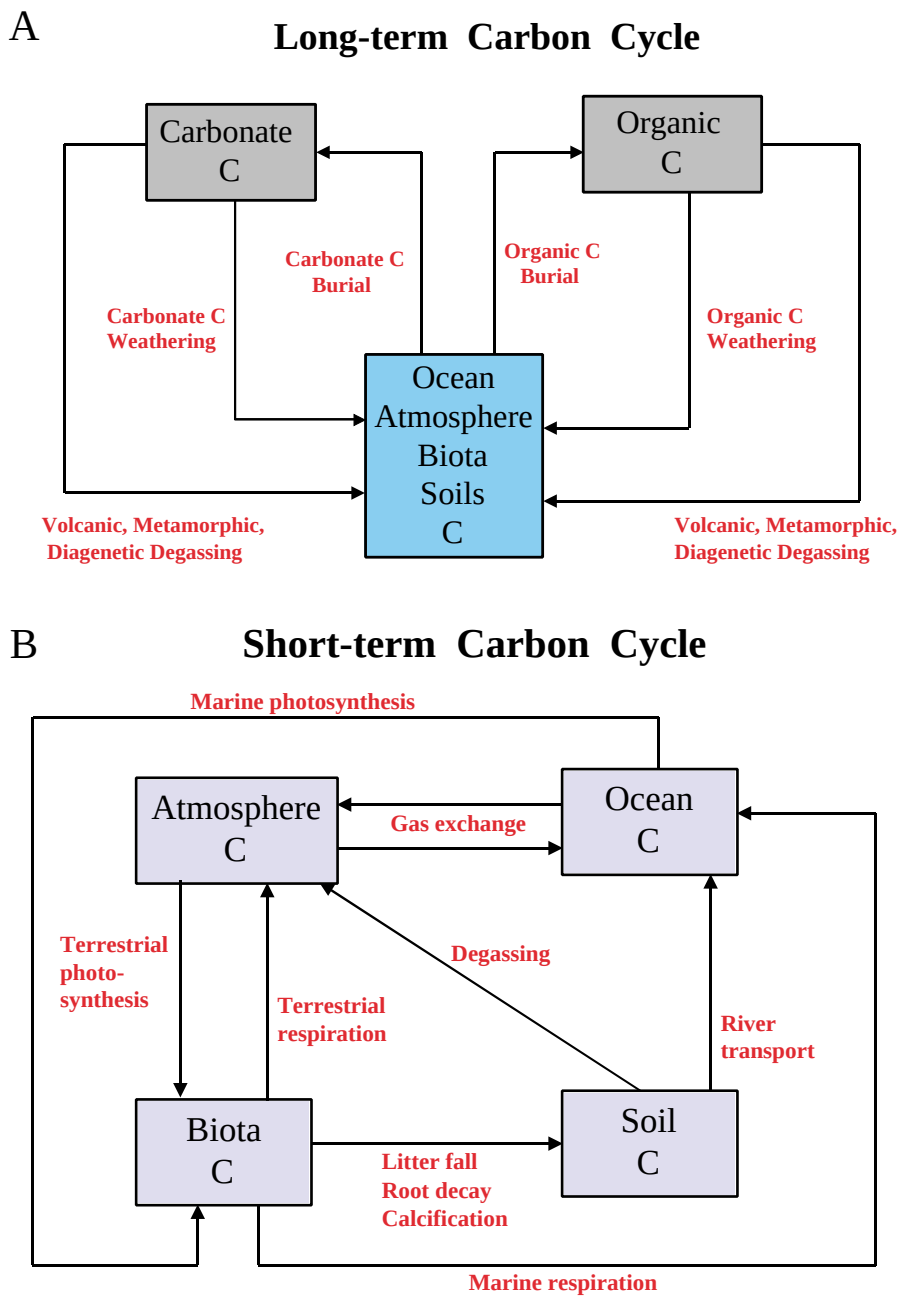

Figure 3. Box model diagrams for the carbon cycle. Boxes represent reservoirs, and arrows represent mass fluxes between reservoirs. A: The long-term carbon cycle. The sum of all input fluxes to the surficial reservoir must be very close to the sum of all output fluxes because storage of appreciable carbon in the surficial reservoir over millions of years is impossible (see Berner and Caldeira, 1997). B: The short-term carbon cycle. Human effects are not shown; deforestation would be an acceleration of terrestrial respiration, but fossil fuel burning is an acceleration of sedimentary organic matter weathering, a flux from the long-term carbon cycle (see A).

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global cooling, which has led some workers to suggest that such cooling led in the past to increased, not decreased, weathering of silicates. However, this constitutes positive feedback, because the removal of CO_2 during weathering results in further global cooling due to the atmospheric greenhouse effect. If this positive feedback were continued for a million years or more, unreasonable drops in CO_2 and runaway icehouse conditions would result—see Berner and Caldeira (1997).

BOX MODEL DIAGRAMS

The traditional geochemical box models shown in Figure 3 are very useful for constructing models that quantify fluxes and changes in sizes of various repositories. However, by themselves they shed no light on the various processes affecting the fluxes nor can they be used to decipher negative or positive feedback. In this way they are complemented by cause-effect diagrams like Figure 2.

Note that the reservoirs normally considered in studies of the short-term carbon cycle (ocean, atmosphere, biota, soils) are combined in the long-term cycle. This is reasonable because of the very small masses of carbon in these surficial reservoirs (total of 50×10^{18} g C, most in the ocean) as compared to the carbon in carbonate rocks ($60\,000 \times 10^{18}$ g C) and in shales and coals ($15\,000 \times 10^{18}$ g C). Because of their small size and lack of long-term storage capacity over millions of years, the sum of all input fluxes to the combined surficial reservoir in the long-term carbon cycle must be very close to the sum of all output fluxes (Berner and Caldeira, 1997).

Perturbation of the carbon cycles (Fig. 3) by humans comes from burning coal, oil, and natural gas, by cement production, and by deforestation. Fossil-fuel burning involves the acceleration of the oxidative weathering of sedimentary organic matter, which is a component of the long-term cycle (Fig. 3A). Cement production, which involves decarbonation of limestone and is analogous to metamorphic degassing, also brings about an acceleration of the long-term C cycle. Only deforestation, which is analogous to excess terrestrial respiration, involves a perturbation of the short-term cycle. Thus, both long- and short-term carbon cycles are involved in the whole problem of anthropogenically altered carbon fluxes, the present-day increase of CO_2 in the atmosphere, and consequent global warming due to the atmospheric greenhouse effect.

CONCLUSIONS

The diagrams shown here summarize present knowledge of processes involved in the carbon cycles that affect atmospheric CO_2 and O_2 over multimillion year time scales. Cycles of other elements, like sulfur and iron, exert an important, but secondary, effect on the level of atmospheric oxygen. (A summary of the geochemical cycles of carbon and sulfur as they affect O_2 and how modeling of them is done can be found in papers by Berner and Petsch [1998] and Berner [1999].) Processes affecting methane, such as clathrate formation and decomposition, or the methane greenhouse effect, require new diagrams. (The methane shown emitting to the atmosphere in Fig. 1 is assumed to be oxidized rapidly to CO_2.) To investigate the carbon cycle further, the time constants for the various cause-effect relations must be enumerated, as has been attempted recently for processes affecting O_2 by Lenton (1998). It is possible that with the proper time constants, a combination of negative and positive feedback could result in oscillations in concentrations of O_2 or CO_2. Although the diagram shown in Figure 2, representing a new way of thinking about the carbon cycle, will be revised, it provides a simple shorthand representation of our knowledge of the long-term carbon cycle and a mechanism for illustrating and discovering negative and positive feedback loops. Application of this diagram to other geochemical or geological cycles could provide new insights into earth processes.

ACKNOWLEDGMENTS

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About People

GSA Fellow Ian Carmichael, University of California, Berkeley, has been elected a Fellow of the Royal Society (London).

Fellow Margaret Leinen, University of Rhode Island, has been named the National Science Foundation's assistant director for geosciences, as of January 2000.

Fellow Richard Marston has assumed the Sun Chair of Earth System Science in the School of Geology at Oklahoma State University.

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2000 GSA Annual Meeting Field Trips

Reno is in an active tectonic zone near the boundary between the Sierra Nevada Range and the Basin and Range province, and it provides an outstanding opportunity for field trips of interest to all geoscientists. Field trips for the 2000 GSA Annual Meeting will explore well-exposed and well-studied examples of both ancient and modern tectonic systems ranging from plate-boundary to plate-interior settings, and associated mineral deposits. Trips will cover both scenic and classic areas from northern California to eastern Nevada, and some international trips are under consideration. Proposed topics include crustal extensional tectonics and magmatism, Antler and Sonoma orogenies, neotectonics of the Sierra Nevada–Great Basin transition zone, Paleozoic and Mesozoic magmatic arc systems, granite emplacement and crustal evolution, early Paleozoic continental margin sedimentation and biostratigraphy, Carlin-type, sediment-hosted gold deposits, epithermal and porphyry copper systems, and geomorphology.

The following list is tentative. Proposals for trips are still coming in, and final selections have not yet been made. Further details will be given in the April issue of *GSA Today*. For further information, contact the 2000 Field Trip Co-chair Paula Noble, Dept. of Geological Sciences, University of Nevada, Mackay School of Mines, MS 172, Reno, NV 89557-1038, (775) 784-6211, fax 775-784-5079, noblepj@unr.edu. The deadline for proposals is December 1, 1999.

Carlin-Type Gold Systems in China. Steve Peters and others.

Carlin-Type Gold Systems in the Getchell Trend, North-Central Nevada. Greg Arehart, Tommy Thompson.

Earthquakes, Surface Faulting, and Paleoseismology of the Central Nevada Seismic Belt: The Grand Tour. S. John Caskey, John W. Bell, Alan R. Ramelli, D. Burton Slemmons.

Epithermal Systems of Northern Nevada. John McCormack and others.

Evidence for a Major Right-Lateral Crustal Boundary of Cretaceous Age in Black Rock Desert Region, Northwestern Nevada. Sandra Wyld, Jim Wright.

Geomorphology and Sedimentology of the Panaca Basin, Eastern Nevada. Joel Pederson.

Giant Sedimentary Rock–Hosted Mineral Systems of the Carlin Trend: Gold Quarry and Post-Betze Deposits, Nevada. Lane Griffith and others.

Global Ordovician Series Boundaries and Global Event Biohorizons, Monitor Range and Roberts Mountains, Nevada. Stan Finney, Ray Ethington.

Lake Tahoe Active Faults, Landslides, and Tsunamis. Richard A. Schweickert and others.

Late Cenozoic Crustal Extension and Magmatism in Southern Death Valley, California. James Calzia, Tapani Ramo.

Lower Paleozoic Stratigraphy and Structure of Central Nevada: Comparisions and Contrasts Between the Lower and Upper Plates of the Roberts Mountains Thrust. Stan Finney, Paula Noble, Kelly Cluer.

Paleozoic and Mesozoic Arc Magmatism, Northern Sierra Nevada, California. Richard E. Hanson and others.

Processes of Granite Emplacement, White-Inyo Range, California. Sven Morgan.

Reconstruction of Basin and Range Extension and Westward Motion of the Sierra Nevada Block. Brian Wernicke.

Tectonics of the Trinity Terrane, Klamath Mountains, California. E. T. Wallin, R. Metcalf.

Yerington Porphyry Cu System, Western Nevada. John Dilles, Marco Einaudi.

USArray Initiative

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Consider what our understanding of North American tectonics would be like if our best image of the continent's topography was as blurred as that in Figure 1. First-order features like the Cordillera are barely resolved, and the characteristic topography within provinces like the Basin and Range and Great Valley are obscured beyond recognition. Yet it is precisely such a fuzzy view of the lithosphere and deeper mantle that we currently bring to the four-dimensional problem of understanding the structure, evolution, and dynamics of the North American continent.

At a workshop in Albuquerque, New Mexico, in March 1999, jointly sponsored by the National Science Foundation and IRIS (Incorporated Research Institutions for Seismology), seismologists and geologists discussed an ambitious plan to explore, map, and develop an integrated understanding of North American geology. Proposed is the development of a facility, USArray, that amounts to a "Hubble telescope for the earth sciences" (Levander et al., 1999).

OVERVIEW OF USARRAY

The USArray initiative will integrate a dramatic improvement in the resolution of seismic images of the continental lithosphere and deeper mantle with a diversity of geological data to address significant unresolved issues of continental structure, evolution, and dynamics. The USArray facility will consist of three major seismic components: (1) a transportable array of broad-band seismometers that will systematically cover the United States one region at a time; (2) about 2,400 seismometers of various types designed to augment the transportable array so that a range of specific targets can be addressed; and (3) several dozen permanent high-quality seismic stations administered largely by the U.S. Geological Survey within the context of the national seismic network. The goal of this layered design is to achieve imaging capabilities that flexibly span the continuous range of scales from global, through lithospheric and crustal, to local. The infrastructure provided by USArray presents a platform for a multidisciplinary field laboratory integrating geologic, geochemical, and geophysical data.

The core of USArray is a transportable telemetered array of 400 broad-band seismometers designed to provide real-time data from a regular grid with dense and uniform station spacing of ~50 km and an aperture of ~1,000 km. The array will record local, regional, and teleseismic earthquakes, providing resolution of crustal and upper-mantle structure on the order of tens of kilometers and increased resolution of structures in the lower mantle and core-mantle boundary. About 50 magnetotelluric field systems will be embedded within the array to provide constraints on temperature and fluid content within the lithosphere. The transportable array will roll across the country, being deployed for 1–2 years at each site. Multiple deployments will cover the entire continental United States over a period of 8–10 years, providing unprecedented coverage for 3-D seismic imaging. When completed, this will amount to systematic imaging from approximately 2,000

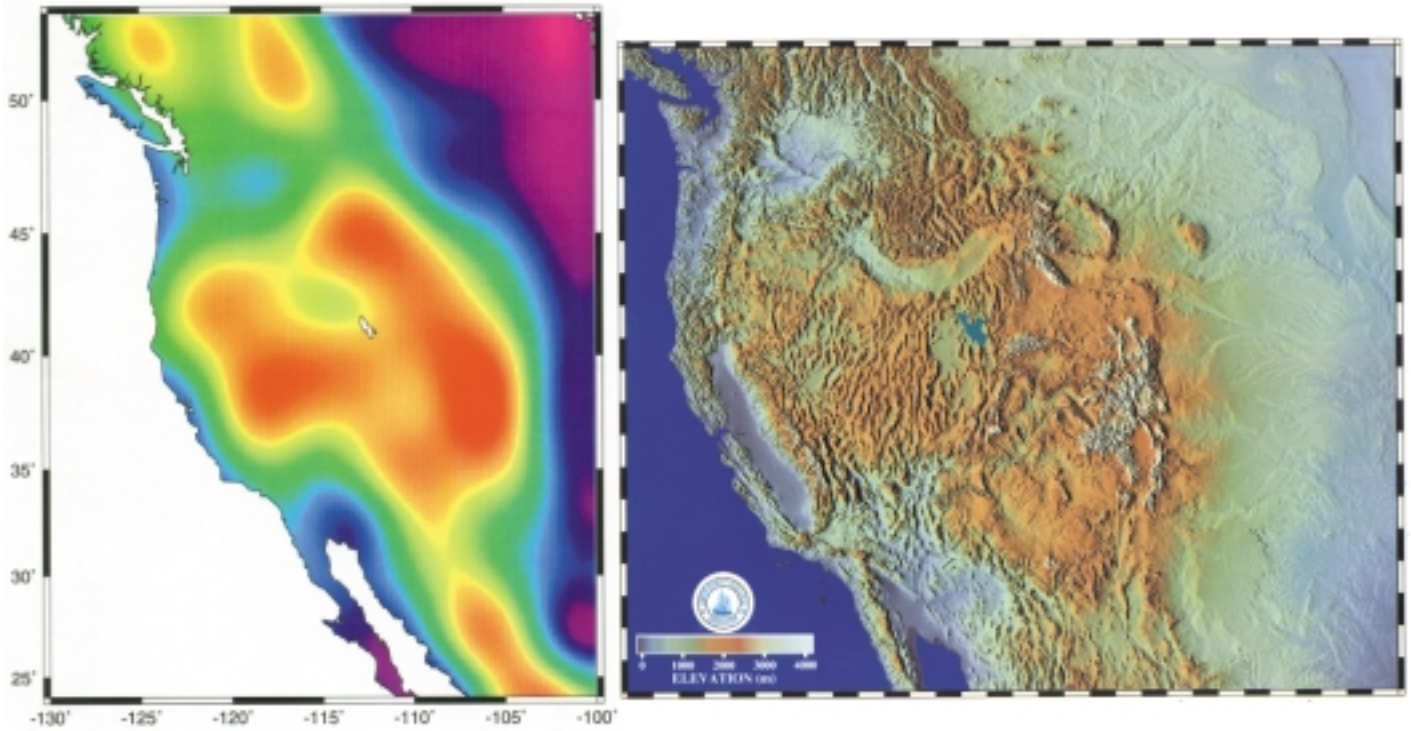

Figure 1. Topography of the western United States at different degrees of resolution. Left: Filtered at 500 km, a resolution similar to that of current global tomographic models. Right: At resolution of 1 km (Simpson and Anders, 1992). USArray will provide resolution of crustal and upper-mantle structure on the order of tens of kilometers.

seismograph stations (Fig. 2). The initial focus of USArray is coverage within the United States; extensions of the array into neighboring countries and onto the continental margins, in collaboration with scientists from Canada, Mexico, and the ocean science community, are natural additions to the initiative (Fig. 2).

The second component of USArray, an additional pool of about 2,400 instruments (broad-band, short-period, and high-frequency) that use flexible source-receiver geometries, will allow for high-density, shorter-term observations of key targets within the footprint of the larger transportable array. This component of USArray offers opportunities for a variety of focused investigations requiring high-resolution images within the context provided by the larger array. Linked with coordinated geological, geochemical, and/or geodetic studies, this part of USArray can address a wide range of problems in continental geodynamics and tectonics. Examples include imaging and study of the continental arc system in the Cascades from slab to edifice; examination of the deep roots of the North American craton and the paleotectonics by which the craton was formed; imaging old and modern orogens and rifts to determine secular variation in continental tectonics; and identifying the role of the mantle lithosphere during orogenesis and rifting.

The third component of USArray, an augmentation of the permanent seismic network in the United States, will provide fixed reference points for calibration of the transportable array, covering the continent with a uniform spacing of 300–350 km. The permanent network also adds an important fourth dimension—time—to the USArray facility, by providing a platform for continuous long-term observations. This component of USArray, to be undertaken in coordination with the USGS, complements the initiative under way at the Survey to install an Advanced National Seismic System. Some or all of the stations of the permanent component of USArray will be equipped as expanded geophysical observatories, with GPS receivers to provide direct real-time data on crustal deformation. Other investigations (for example, heat flow, coring, downhole logging) could take advantage of these platforms also.

Scientific studies that will be greatly enhanced by USArray include: processes of continent formation and breakup; relationship between crustal tectonic provinces and upper mantle structure; rheological stratification of the lithosphere with depth and its variation from orogenic belts to the cratonic interior of the continent; nature of the Moho, and mass transfer between the crust and mantle; lithospheric deformation and earthquake hazard assessment; variations in depth and sharpness of the 410 and 660 km seismic discontinuities and their relations to surface tectonics; heterogeneity, anisotropy, and flow in the mantle; role of fluids (magmas, partial melts, hydrothermal) in the crust; imaging of deep mantle and core structures using beam-forming methods; history of North American subduction and the locations of ancient slabs in the mantle; amd crustal recycling during subduction and orogenesis.

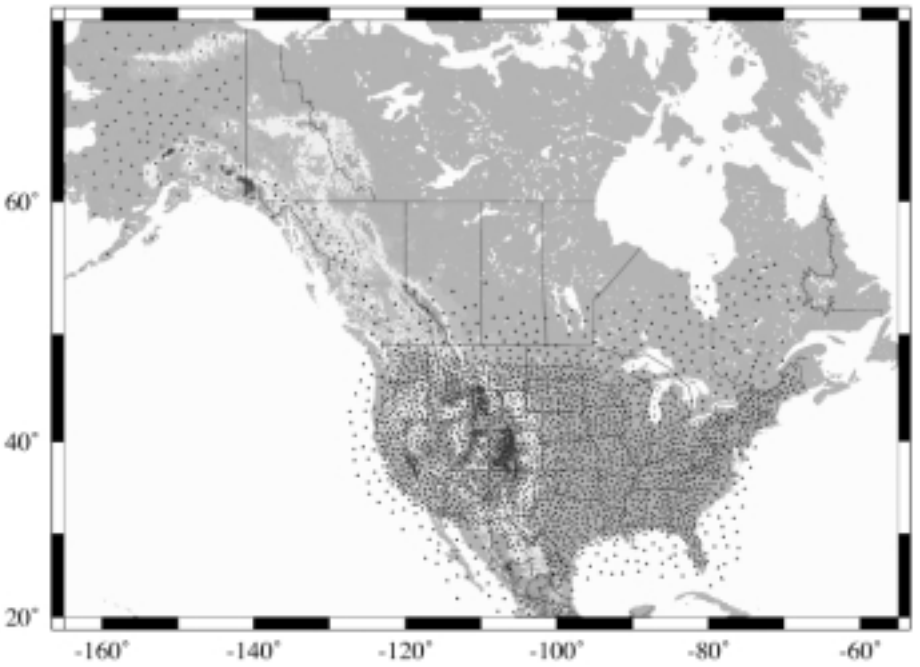

Figure 2. Coverage provided by the transportable component of USArray after installation of 2,000 stations in the continental United States and Alaska. Augmented by stations in Canada, Mexico, and the continental margin.

USArray has been designed to provide a structured yet flexible foundation for integrated studies of the continental lithosphere and deep Earth structure over a wide range of scales. The outcome will be an integrated, whole-continent view of North America and improved understanding of the processes that have shaped and continue to shape the continent. As USArray moves across the country, it will be accompanied by a comprehensive educational and outreach program highlighting both overarching and regional earth science issues (hazards, structures, resources) and links between earth science and society. Specific initiatives will include coordination with local news media, museum displays, teacher workshops, and distribution of educational materials, including activities linked to USArray data and results made available over the Internet. Programs will be designed and targeted to engage communities in USArray before, during, and after passage of the array through specific regions of the country.

STATUS AND ORGANIZATION OF USARRAY

An initiative of the scope of USArray requires partnerships between the academic earth science community and such organizations as the National Science Foundation, the U.S. Geological Survey, regional seismic networks, state geological surveys, IRIS, UNAVCO (University NAVSTAR Consortium), and EMSOC (Electro-Magnetic Studies of the Continent). International partnerships and collaborations with industry will also be important as the project matures.

At NSF, program officers of the Division of Earth Sciences (EAR) have united several intertwining streams of research into a single integrated effort known as "EarthScope—A Look into Our Continent." EarthScope includes USArray and initiatives for a Plate Boundary Observatory (Silver, 1998), the San Andreas Fault Observatory at Depth (SAFOD); and Interferometric Synthetic Aperture Radar.

An appropriate source of support for the facilities component of USArray is the MRE (Major Research Equipment) account, an NSF-wide program created in FY1995 to provide funding for the construction and acquisition of major research facilities that are beyond the funding resources of any one directorate. MRE projects advanced by a directorate are reviewed in an NSF-wide competition and require approval by the National Science Board. The MRE account is funded as

USArray *continued on p. 10*

USArray *continued from p. 9*

a separate item within the NSF budget, distinct from support for research programs; research budgets at the directorate or division level are augmented to facilitate research to be carried out with these new facilities. Other scientific disciplines (e.g., astronomy and physics) commonly champion successful MRE proposals for support in the range of tens to hundreds of millions of dollars, but to date no such proposal in support of earth science research has been forwarded or funded. The EAR Division and GEO Directorate at NSF and members of the steering committees of the initiatives involved have worked together to develop an EarthScope proposal for the MRE competition. The first phase of the EarthScope initiative, which includes USArray and SAFOD, has advanced and received approval within NSF to move forward for consideration by the National Science Board.

NEXT STEPS

The challenge of developing the technical facility is only one component of USArray. There is broad interest in exploring ways to leverage the resources associated with the USArray facility to catalyze establishment of a fully multidisciplinary field laboratory and to determine the diverse data sets and measurements that should become part of an integrated North American geoscience information system. The USArray initiative has the potential to unite North American geologists and geophysicists into a broad coalition of earth scientists devoted to a decade or more of multidisciplinary studies of the continent. Like the highly successful Lithoprobe program in Canada (Clowes, 1998), USArray stands to expand the culture of shared and coordinated resources within the earth sciences as a whole. A further goal of USArray is to develop an earth science information system including geophysical, geochemical, and geological data that can be easily accessed by the earth science community, educators, and government agencies. All data from USArray will be archived and available in near–real time to the community at large.

The USArray steering committee will continue to seek community input and involvement. The committee is coordinating workshop reports from the meeting in Albuquerque and a second one, in Houston, as well as a science and implementation plan that will be submitted to NSF as the geoscience community's input to USArray's role in the EarthScope MRE initiative. Forums at the autumn meetings of GSA and AGU provide further discussion of the opportunities of USArray to facilitate research in continental structure, evolution, and dynamics across the geoscience communities. Because the MRE competition will extend over the next 12–15 months and because USArray will take 3–4 years to begin operation if approved, there will be ample opportunity for all those having interests in the structure and evolution of North America to become engaged in the project.

USArray and our approach to solving scientific problems will evolve over the 10–15 year period of its operation. Novel ideas and new research targets will require new theory, analysis techniques, and research tools. USArray needs enthusiastic, broad-based support from the earth science community. Scientists in other disciplines regularly organize themselves to their advantage; USArray is a golden opportunity for earth scientists to do the same.

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Silver, P., et al., 1998, A plate boundary observatory: IRIS Newsletter, v. 16, no. 2, p. 3, 7–9.

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Note: More information about USArray can be obtained from: www.iris.edu; www.iris.edu/newsletter/EE.Fall98.web/usarray.html; and IRIS Newsletter, v. 16 (1998), no. 2, p. 2–6.

Send comments and suggestions about the initiative to any of the members of the USArray steering committee listed as authors of this article. ■

WASHINGTON REPORT

Bruce F. Molnia, *bmolnia@erols.com*

Washington Report provides the GSA membership with a window on the activities of the federal agencies, Congress and the legislative process, and international interactions that could impact the geoscience community. These reports present summaries of agency and interagency programs, track legislation, and present insights into Washington, D.C., geopolitics as they pertain to the geosciences.

A Turn in U.S. Ocean Policy? A New Report Surfaces

Last year's Ocean Conference launched an important national dialogue on the future of our oceans—a resource as vital as they are vast. With this report, the Cabinet has elevated this dialogue to the next level, and set the stage for a truly comprehensive ocean policy for the 21st century. I commend the Cabinet for its vital contribution, and I urge the task force to move swiftly on its recommendations.

—Vice President Al Gore, September 2, 1998

At the National Ocean Conference last year in Monterey, California, President Clinton directed the Cabinet to prepare a report with recommendations for a comprehensive ocean policy to guide federal efforts in the 21st century. After nearly 15 months, the report, *Turning to the Sea: America's Ocean Future,* has finally surfaced. The 64-page report, released on September 2, presents 145 bulleted recommendations, raises 106 "ongoing concerns," and identifies 102 World Wide Web sites to visit for additional information. Prepared by a "final writing group" of 15, the report is focused on sustaining, strengthening, protecting, and discovering America's ocean resources. In accepting the report, Vice President Gore announced the formation of an Oceans Report Task Force. The task force, which will be co-chaired by the chair of the Council on Environmental Quality and the Deputy National Security Advisor, will include high-level representatives of agencies with responsibility for ocean affairs. It will set priorities for implementing key recommendations in the Cabinet's report and will meet quarterly to review progress. The new report is very broad in its coverage, dealing with topics ranging from creating new incentives to reduce overfishing; working with the Senate to ensure that the United States joins the Law of the Sea Convention; coordinating federal programs with local "smart growth" efforts in coastal communities; and expanding federal support for underwater exploration.

The report is organized into five sections: an Introduction and treatments of Sustaining Economic Benefits of the Ocean, Strengthening Global Security, Protecting Marine Resources, and Discovering the Oceans. Each of the four treatments is divided into discussions of individual topics. The two-page discussions consist of introductory paragraphs, a listing of "ongoing concerns," recommendations, and suggested Web sites to visit. Each discussion contains a highlighted sidebar and numerous illustrations and begins with a statement, actually an additional major recommendation, presented at the start of the descriptive text paragraphs.

Topics included in the Sustaining Economic Benefits of the Ocean section are: Marine Transportation, Safe Navigation, Coastal Tourism, Coastal Communities, Domestic Fisheries, International Fisheries, Aquaculture, Biotechnology, and Offshore Oil and Gas. Topics included in the Strengthening Global Security section are: The Law of the Sea Convention, Freedom of Navigation, and Maritime Law Enforcement. Topics included in the Protecting Marine Resources section include: Submerged Heritage Resources, Coral Reefs, Estuaries, Marine Protected Species, Marine Protected Areas, Ocean and Coastal Habitats, Water Quality, Nonindigenous Species, and Marine Debris. Topics included in the Discovering the Oceans section include: Ocean Education, Ocean Observations, Ocean Research, and Ocean and Coastal Exploration.

The Introduction is presented as a letter to the President signed by Secretary of the Navy Richard Danzig and Secretary of Commerce William M. Daley, in which they, on behalf of the Cabinet, present this report to the Administration. They state, "Our report reflects a broad national consensus on the vital importance of the oceans to our nation's future."

Recommendations for each of the four sections were guided by a single core principle. For the 61 recommendations in Sustaining the Economic Benefits of the Ocean, the core principle was "Future generations deserve to inherit healthy, bountiful oceans." Key recommendations (one per topic except for Offshore Oil and Gas) include: Marine Transportation—achieve environmental protection and safety through improving local coordination, ballast water management, and design and system management of dredged channels; Safe Navigation—conduct research on effective and environmentally sensitive management of sediment, reduction of the flow of sediment into waterways, remediation of contaminated sediment, and disposal of dredged spoil in an environmentally sound manner; Coastal Tourism—collect and provide access to information on the magnitude, value, and impacts of ocean and coastal recreation and tourism, including information on a coastal-county basis and studies on the dynamics of tourism in marine and coastal areas; Coastal Communities—examine and revise policies and programs, such as flood insurance subsidies, that promote unsustainable or hazardous development; Domestic Fisheries—explore the scientific and conservation benefits of marine harvest refugia and other protected areas; International Fisheries—increase bilateral pressure to foster agreements to rebuild overfished species and to deter illegal, unregulated, and unreported fishing. Participate actively in FAO initiatives to develop an international plan of action to address such fishing practices; Aquaculture—work with stakeholders to develop guidelines for environmentally sound and sustainable aquaculture by the year 2000, and promote domestic and international compliance with them; Biotechnology—consider establishing a federal marine environmental fund to benefit from royalties and payments from commercial uses of federally owned resources; and Offshore and Gas—increase research on methods and technology to minimize risks to human safety and to coastal and ocean environments; encourage production of natural gas, as a cleaner source of energy, from areas where production is still permitted under the outer continental shelf moratoria; accelerate scientific research on marine gas hydrates as a potential long-term energy resource.

For the eight recommendations in Strengthening Global Security, the core principle was "Freedom of the seas is integral to the strength and security of our nation." Key recommendations include: The Law of the Sea Convention—the President, the Vice President, and the Cabinet should continue to work with the Senate, and particularly the Senate Foreign Relations Committee, to ensure that the United States joins the Law of the Sea Convention as soon as possible; Freedom of Navigation—expand the U.S. freedom of navigation program using Navy, Coast Guard, and other national assets to exercise openly the traditional freedoms of navigation and overflight in areas of unacceptable claims; and Maritime Law Enforcement—declare a 24-nautical-mile contigu-

Washington Report *continued on p. 12*

Washington Report *continued from p. 11*

ous zone consistent with international law, as reflected in Article 33 of the Law of the Sea Convention.

The Administration wasted no time in implementing this recommendation. On September 2, Vice President Gore pronounced that effective immediately, this would be the new U.S. standard. Specifically, the Vice President announced that the United States was strengthening its ability to enforce environmental, customs, and immigration laws at sea by expanding a critical enforcement zone to include waters within 24 nautical miles of the U.S. coast. A proclamation signed by President Clinton formally extended the U.S. "contiguous zone" from 12 to 24 miles, doubling the distance from shore within which the Coast Guard and other federal authorities can board foreign vessels and take other actions to enforce U.S. law.

For the 60 recommendations in Protecting Marine Resources, the core principle was "Strong protection of our ocean and coastal environment, using a precautionary approach and sound management, is no longer a choice, but a necessity." Key recommendations include: Submerged Heritage Resources—enact federal legislation that will prohibit the destruction and loss of submerged heritage resources; punish those who injure or destroy these and associated natural resources; provide for appropriate public access; develop a research and recovery permitting process; require adherence to scientific standards; provide for the conservation and deposition of recovered materials in qualified repositories; ensure sensitive treatment of any human remains; and protect sovereign immune vessels and aircraft that have not been expressly abandoned; Coral Reefs—increase research efforts to understand the causality behind the current worldwide decline of coral reefs and how it relates to disease, temperature change, and pollution; assist in the design and implementation of local and regional reef management plans that integrate protected areas and fishery management with coastal zone and marine management planning efforts, and increase support for local actions; increase monitoring, protection, and sustainable use of coral reefs worldwide by supporting international partnerships at national, regional, and global scales; Estuaries—create a national framework for estuarine research; Marine Protected Species—address key existing and emerging threats, including modification and destruction of coastal and estuarine seafloor ecosystems by fishing gear, coastal habitat destruction resulting from shoreline protection efforts, and watercraft collisions with marine mammals; Marine Protected Areas—evaluate the ability of existing marine protected areas to protect unique or representative examples of biological, cultural, or historical resources; identify new areas of important ocean diversity and productivity; and add sites and capacities to address specific local, tribal, regional, national, or international issues and needs; Ocean and Coastal Habitats—develop cost-effective, environmentally acceptable regional sediment management procedures that speed remediation of contaminated sediment and increase beneficial reuse of both clean and remediated dredged material; Water Quality—increase research on the effects of water quality and ocean discharges on the marine environment, including on marine wildlife, and use this information to improve protection for ocean and coastal resources where necessary; Nonindigenous Species—develop effective monitoring, education, research, and rapid-response capabilities to quickly identify and eliminate nonindigenous species before they become established; and Marine Debris—improve controls on potential sources of marine debris, including working with communities to implement and enforce anti-litter laws, improve floatable controls for local sewer systems, and employ statistical marine-debris monitoring protocols.

For the 16 recommendations in Discovering the Oceans, the core principle was "Exploring and understanding the oceans is critical to our well-being and survival." Key recommendations include: Ocean Education—establish a nationally coordinated effort to improve and promote ocean science education; make ocean science education materials widely available to educators and the general public; expand efforts to create discovery-driven, interactive Web sites for all federal ocean programs to engage children and adults in a lifetime of ocean discovery; Ocean Observations—expand and integrate seafloor observation capabilities to improve basic knowledge of Earth's temperature, chemistry, and structure. This will support pipeline and cable-laying operations and national security and research needs and will improve disaster warning from seafloor disturbances; Ocean Research—emphasize an interdisciplinary approach in oceanography and marine ecosystem science, linking the fields of physics, biology, chemistry, and geology, and allowing a better view of Earth as an integrated system; our coastal and ocean research infrastructure, from submersibles and research vessels to laboratories, is aging and cannot meet the technological demands of the 21st century; and Ocean and Coastal Exploration—support exploratory research in geographic areas, such as the deep-sea vent sites, and topical areas, such as undiscovered deep-sea species; develop ways to explore the oceans remotely, including new observatories and sensors and innovative uses of technologies.

Turning to the Sea: America's Ocean Future can be viewed on the Internet at www.publicaffairs.noaa.gov. Copies also can be requested by telephone, (202) 482-6090, or by fax, 202-482-3154. Printing from the Internet may be difficult, because the report is available only as a large PDF file. ■

Managing America's Coastal Parks

Cathleen May, *Director of Science and Outreach*

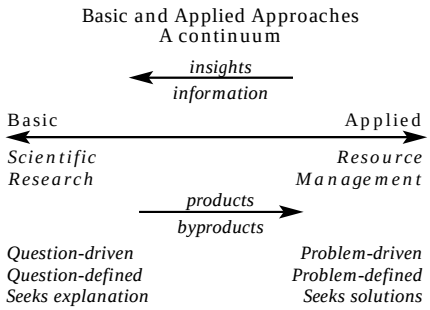
Dennis and Floyd: The Calm Between Storms

For three blustery, sodden days on the heels of Hurricane Dennis and anticipating Hurricane Floyd, 120 people gathered on a barrier island off the coast of Maryland to talk about managing dynamic coastal systems for a society that demands stasis. The Geology of Coastal Ecosystems Workshop took place in Ocean City, Maryland, and on Assateague Island National Seashore September 8–10, 1999. The workshop was conceived, designed, financed, and hosted through collaboration among GSA's Institute for Earth Science and the Environment (IEE), the Geologic Resources Division of the National Park Service (NPS), and the Coastal and Marine Geology Program of the U.S. Geological Survey (USGS). The NPS participants (about 60) came from coastal parks as distant as Alaska and as near as the local host unit at Assateague. About 40 USGS scientists and administrators, from all coastal regions as well as from the Director's Office in Reston, participated. Academic participants came from university programs by special invitation from GSA.

Making Connections

The stated goals of the workshop were to make the connections among: (1) scientific research and resource management, (2) geology and ecosystem management, and (3) National Park System units and external sources of expertise and knowledge.

The first two goals serve areas of emphasis within IEE's mission to promote the use of geoscience in addressing environmental challenges. The third serves GSA Strategic Plan goals to provide opportunities for our member scientists. We expect this to be the first in a periodic series of similar efforts in collaboration with the National Park Service and the U.S. Geological Survey. The long-term goals for such a series of collaborative efforts are expressed as desired outcomes: geoscientists know what managers need; managers know what geoscientists can provide; geoscientists and managers know when and how to collaborate. To achieve any of these short-term workshop goals or long-term partnership goals, participants must first abandon the notion that "basic science" and "applied science" are essentially decoupled. There is neither a real nor a usefully arbitrary demarcation between the two. In my introductory remarks, I asked the participants to view research and resource management along a continuum that spans basic and applied approaches to questions, explanations, information, and problem-solving, as illustrated here:



Coastal Parks: Complexity, Variety, Commonality

Sixty-six national park units have coastlines. The Park Service manages an estimated 7,310 miles of marine coastline distributed among 10 Alaskan coastal parks, 17 Atlantic parks, eight Gulf Coast and Virgin Islands parks, 19 Pacific parks, and six Hawaiian parks. Per park unit, miles of shoreline vary from less than one at Klondike Gold Rush National Historical Park to more than 1,070 at Glacier Bay National Park and Preserve. Among these regions, coastal zone geology, geomorphology, hydrology, and ecology vary significantly, as does the degree and the impact of human development and visitor use. During the introductory plenary session, Suzette Kimball, Regional Chief Biologist, Eastern Division, USGS, illustrated this variety by describing the most salient attributes of each region's coastal system.

Yet, it was commonality of need for scientific understanding and information that brought these participants together as a forum. Opening remarks by Department of Interior Deputy Assistant Secretary for Water and Science Mark Shaefer stressed the importance of integrative approaches to coastal system science and congratulated the group on bringing together scientists from disparate specialties to address coastal management issues. USGS Deputy Director Tom Casadevall (now Central Region director) emphasized the value of joint GSA-USGS efforts to bring together those who generate scientific understanding and information with those mandated to use science to manage lands and resources.

After the half-day opening plenary session, participants worked in groups organized by regions to identify the common needs and issues among parks in each region. Later, the groups reported their findings. Common themes emerged despite the physical, biological, and cultural diversity among park units. Not surprisingly, the most inclusive theme was the impact of people, in the forms of development, agriculture, and visitor use, on coasts and coastal processes. Beach starvation due to engineered disruption of longshore and watershed sediment transport surfaced again and again as an ongoing management concern. Eutrophication due to groundwater contamination from agriculture and development surfaced as an increasing concern for units with estuarine, bay, and inlet habitats to manage. These are but two of the many anthropogenically induced management problems identified by the working groups. As significant as the impact of people on coasts proves to be, in terms of management, the impact of natural coastal processes on people can be of equal or greater concern. Coastal hazards and the need for greater predictability of episodic and catastrophic change in coastal systems appeared close to the top of the list for all working groups. Finally, the need for more and easier access to scientific information was articulated over and over throughout the workshop, in both formal sessions and informal conversations among participants. Workshop participants sounded a clear call for centralized sources of information and for rapid response to short-term needs for scientific expertise.

Socioeconomic Demands—Geoecologic Reality

Nowhere is the paradox of the Organic Act—to manage "for the enjoyment of the people" and to manage to "leave unimpaired for future generations"—more apparent than in coastal National Park units, especially those located on barrier islands. The defining attribute of coastal zones is change. In the usually comforting constancy of waves breaking on shorelines is the unrelenting reminder that our planet is dynamic. As much as human beings enjoy the gentle and continuous shoreline processes that drive us to build as close to the edge of the continent as possible, still we seek to control those processes: to stabilize dunes, to provide quiet waters, to protect our dwellings and businesses. When the system becomes less than gentle, when hurricanes blow and cut barrier islands into pieces, we want our shorelines "restored"

Environment Matters
continued on p. 14

Proposal Deadline: January 10, 2000

Submit Session Proposals for the 2000 GSA Annual Meeting

You are invited to participate in the 2000 GSA Annual Meeting, in Reno, Nevada—*Summit 2000!* We encourage you to submit proposals for topical sessions and Pardee Keynote Symposia that will make this meeting *the* meeting of the year for earth scientists. Proposals are due by January 10, 2000, and must be submitted electronically. As GSA enters the next millennium, we anticipate an increasingly vital, dynamic, and high-quality annual meeting program.

GSA in Reno, *Summit 2000!*

Bob Karlin, Technical Program Chair

Reno, Nevada, is proud to be the site of the Geological Society of America's Annual Meeting, Summit 2000, next November. Reno lies near the boundary between the Sierra Nevada Range and the Great Basin, affording many opportunities to view diverse geologic phenomena. Well-exposed examples of ancient and modern tectonic systems, ranging from plate boundaries to continental interiors, are within close proximity of the meeting site. The Reno-Tahoe area is also an entertainment and recreational mecca, with a wide assortment of casinos, museums, and theatres; and a dazzling array of fine restaurants and pubs. World-class alpine and nordic skiing are less an hour away. Scenic attractions such as Lake Tahoe and historic locales such as the Comstock-era mining town of Virginia City are within a 45-minute drive.

Summit 2000, our theme, acknowledges this meeting as the largest and most important gathering of earth scientists in North America; in time, near the beginning of the third millennium; and in space, near the summit of the western ranges of the continent. One hundred years ago, no one could have envisioned what we now know about our planet, the technological advances we have made in imaging Earth and planetary systems, or the impact of humans on Earth. Although it is even more difficult now to imagine the advances and challenges in the next century, it is important to look forward, but also to reflect on the past.

The goals of Summit 2000 are to:

- Emphasize the multidisciplinary nature of the chemical, physical, and biological subdisciplines of the earth sciences;
- Provide a high-visibility forum to communicate both important developments in our traditional disciplines and creative new approaches using promising new technologies;
- Explore opportunities for earth science research and education via the World Wide Web; and
- Promote the importance of earth science and society, earth science education, and balancing between resource needs and environmental preservation.

We welcome proposals for Pardee Keynote Symposia and topical sessions; they must be sent via www.geosociety.org/meetings/2000 on or before January 10, 2000.

PROGRAM OPPORTUNITIES

The GSA 2000 Annual Meeting program structure offers opportunities for effective and dynamic program building and flexibility by allowing a mixture of invited and volunteered papers and different session formats. Joint Technical Program Committee (JTPC) representatives play a large role in program decisions. Descriptions of the various program options and guidelines are available at www.geosociety.org/meetings/2000. Some modifications have been made since last year; please read these guidelines carefully before submitting a proposal. Two types of sessions can be proposed:

Pardee Keynote Symposia. The Pardee Keynote Symposia are made possible by a grant from the Joseph T. Pardee Memorial Fund. These sessions are *special events* that should be of broad interest to the geoscience community. Topics appropriate for these keynote symposia should be on the leading edge in a scientific discipline or area of public policy, address broad fundamental problems, be interdisciplinary, or focus on global problems. The primary criterion for selection is excellence. Selection is on a competitive basis with *only four to eight* half-day, nonconcurrent (one per half day; minimum of one per day) sessions being offered. All speakers will

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to some previous state that suits our needs and desires. When our shoreline developments fragment habitats and desirable species vacate the premises, we want them "restored" to their now not-so-natural habitat. How do coastal parks manage their contradictory mandate? They are required to make trade-offs in a constant balancing act between socioeconomic demands and geoecologic realities.

"What If?" vs. "What Now?"

In what I have observed over the years as a characteristically optimistic attitude, National Park Service managers continue to seek increased understanding of the natural systems for which they are trustees. Science—especially geoscience integrated with ecology and social science—can contribute to that understanding. Scientists can ask "what if" questions about coastal systems. Land and resource managers are frequently trapped in a reactive mode where the only relevant question is "what now?" The better science understands "what if," and the better that understanding is articulated to decision-makers and problem-solvers, the better able they will be to deal with "what now."

What's Next?

The Geology of Coastal Ecosystems Workshop is evidence that coastal parks feel the need and have the desire to manage proactively. A proactive management paradigm requires a significantly richer scientific basis for decision-making than a reactive paradigm, as well as public acceptance of managing for change rather than stasis. Coastal parks are diverse geologically, ecologically, and culturally. They are excellent examples of the need for integrative approaches to the science that supports land and resource management, and they share a common need for supporting science.

The workshop organizers feel that we progressed toward articulating both the need for and the opportunities for research in coastal national park units. Evaluations from workshop participants confirm such progress. It is up to the scientific community to hear the need and to respond. Please check the GSA Web site at www.geosociety.org in January 2000 for a full report on the workshop. The report will include transcripts of keynote addresses, findings of working groups, conclusions and syntheses, information on individual coastal parks, lists of participants and contacts, and recommendations for further collaborative efforts among government, academia, and the Geological Society of America. ■

be invited. We are striving for a good mix of Pardee Keynote Symposia, of interest to the GSA and Associated Society memberships.

Topical Sessions. These sessions are designed to promote the exchange of timely or state-of-the-art information with respect to a central topic and to allow scheduling of interdisciplinary talks that bear on a specific topic. Organizers (advocates) may invite specific papers to ensure a successful and excellent session and are encouraged to solicit volunteered contributions. A maximum of four invited speakers is automatically allowed, but an advocate may request more invitations if he or she can justify the larger number. Volunteered abstracts will be automatically solicited in *GSA Today* for all approved topical sessions.

Oral and Poster General Sessions. Consisting entirely of volunteered papers, these sessions remain an important component of the GSA Annual Meeting. The number of abstracts received determines the number of general sessions in each discipline. The rejection rate for recent GSA Annual Meetings has been much less than 5%. The goal of the Technical Program Committee (TPC) and JTPC representatives is to provide presenters the best possible opportunity for communicating new scientific information rather than to dictate what can or will be presented. Poster sessions have been expanded to allow presentation of more papers. Poster sessions will not be scheduled concurrently with oral sessions in the same discipline, to allow for well-attended, dynamic sessions. This year a combined oral and poster session format in a technical session meeting room with poster boards is offered as an option.

Hot Topics. These popular lunchtime forums will be continued (one each day, Monday–Thursday). If you are interested in organizing one of these sessions or in being a Hot Topics chair, contact Technical Program Chair Bob Karlin. These sessions are different from technical sessions and are not to be talks by "experts." Most of the one-hour time is for discussion, with audience participation. A debate format is recommended, and panels are discouraged. Each session must have a moderator. Titles should be catchy and provocative.

We strongly encourage you to participate in the 2000 GSA Annual Meeting in Reno! The new program initiatives inaugurated in 1999 are designed to encourage program excellence and to provide an opportunity for flexible scheduling and creativity. Topical session organizers have the ability to ensure a successful, excellent program, and all members may contribute papers to sessions with invited speakers. The Pardee Keynote Symposia expand the opportunity for high-profile sessions on significant scientific developments that have an impact on our science. Help us make the GSA Annual Meeting increasingly dynamic and stimulating for all GSA and Associated Society members as well as one that appeals to a wide audience. We look forward to working with you. If you have any questions or concerns regarding these program initiatives, please call or e-mail one of us:

Sharon Mosher, Annual Program Committee Chair (through 1999), mosher@mail.utexas.edu.

Rob Van der Voo, Annual Program chair (2000–2001), voo@umich.edu.

Bob Karlin, Technical Program Chair, karlin@mines.unr.edu.

2000 Schedule

January 10	Proposals due. *Firm deadline; electronic submission required.*
March 1	Paper copy of 2000 abstract forms will be available from Nancy Carlson at GSA, (303) 447-8850, ext. 161, ncarlson@geosociety.org. A set of forms will automatically be mailed to conveners and advocates in March.
May 1	Electronic abstract form will be on GSA home page for active submission: www.geosociety.org.
July 25	*Paper Submission Deadline.* Paper copy original and 5 copies due at GSA. Authors should submit all abstracts directly to GSA. *Firm deadline.* Paper abstracts will not be accepted after this date—*no exceptions.*
August 1	*Electronic Abstracts Deadline.* Electronic copies accepted until 12 midnight.
August 12	Schedule finalized.
September 1	All accepted abstracts will appear on the Web after September 1. All speakers and titles appear on the Web with links to these abstracts. ■

SEG Foundation Offers Student Research Grants

Students of mineral resources throughout the world may apply for thesis research grants available in 2000 from the Society of Economic Geologists Foundation and the Society of Economic Geologists. These grants are intended to provide partial support of master's and doctoral thesis research for graduate students. Grants from the Hugh E. McKinstry Fund are awarded to support research with a substantial field component. The Hickok-Radford Fund awards grants for field projects in arctic, sub-arctic, or other challenging field areas. A third group of student research grants is in part funded by gifts from BHP Minerals. These provide funds for research in economic geology that focuses on new descriptive data on ore deposits and mining districts (mainly outside of North America) and on topical subjects.

Individual grants range from $500 to $3000 and are intended to fund specific thesis research expenses. Application forms may be obtained from: Chair, SEG Student Research Grants, 5808 South Rapp St., Suite 209, Littleton, CO 80120, (303) 797-0332, fax 303-797-0417, socecongeol@csn.net. Forms are also available on the Web: http://www.segweb.org.

Applications must be postmarked by February 1, 2000, and awards will be announced by April 15, 2000. ■

GSA To Co-Sponsor

Celebrating the Age of the Earth

A Geological Society, London, symposium, "Celebrating the Age of the Earth," co-sponsored by the Geological Society of America, intends to recreate the atmosphere of interdisciplinary discussion that prevailed at the end of the 19th century when geologists, biologists, physicists, chemists, and astronomers gathered to hotly debate the age of Earth. The symposium, June 28–29, 2000, will be held in London. Cherry Lewis (clelewis@aol.com) is the convener.

Presenters from Britain, Europe, and the United States will discuss the concept and development of geological time up to the end of the 19th century and the discovery of radioactivity and applications of geochronology in the 20th century. The UK's Astronomer Royal, Martin Rees, will end the meeting with a presentation that places the age of Earth within its modern context in the age of the Universe. An optional time-related field trip will take place on the following day.

On-line registration begins December 1, 1999 at www.geolsoc.org.uk. ■

First GSA Field Forum Will Be Held at the Matanuska Glacier, Alaska

Stratified basal ice (black) overlain by clean, white, englacial ice (summer exposure). Photo by Edward B. Evenson.

Glaciohydraulic Supercooling, Basal Freeze-on, Stratified Basal Ice, and "Deformable Till Beds": Matanuska Glacier, Alaska

Dates: March 18–22, 2000

Leaders: Edward B. Evenson, Earth and Environmental Sciences, Lehigh University; Daniel E. Lawson, Cold Regions Research and Engineering Laboratory; Grahame Larson, Geological Sciences, Michigan State University; and Richard B. Alley, Geosciences, Pennsylvania State University.

Description: Recent debates concerning the nature and importance of deformable beds, ice-bed interactions and glaciohydraulic supercooling make a field forum focused on subglacial processes timely, especially with respect to the flow and dynamics of former ice sheets. This field forum—GSA's first—is designed to investigate the entire complex of processes operating at the base of the Matanuska Glacier, Alaska. The excellent winter exposures at the Matanuska Glacier will allow glacial geologists, glaciologists and structural geologists to simultaneously examine the spectacular, stratified, and debris-rich basal ice facies, the deforming till beds, and the complex ice and sediment deformation occurring in the basal ice and the bed of the glacier. One of the primary objectives of the forum will be to attempt to understand whether frazil ice and poorly laminated anchor ice evolve into the distinctly laminated "stratified basal ice," or if it forms directly from freeze-on in a subglacial, linked cavity system. Another objective will be to investigate the complex shear occurring in the deforming subglacial bed, in the stratified basal ice, and at the "shear zone" that separates the basal ice from the clean ice of the glacier body.

Itinerary

Saturday, March 18

Participants fly to Anchorage and convene at the Copper Whale Bed & Breakfast.

Sunday, March 19

8:00 a.m.—Breakfast at Copper Whale Bed & Breakfast.

10:00 a.m—Drive from Anchorage to Palmer, with stops along the Glen Highway to discuss glacially streamlined topography, river icing, and frazil ice growth in open, supercooled water of the Matanuska River.

Noon–1:30 p.m.—Lunch at Goldminer Inn, Palmer.

2:00 p.m.—Drive from Palmer to Majestic Valley Wilderness Lodge, with two stops to discuss extensive gravel deposits and crevasse fills in the Palmer area, and an orientation stop at the Matanuska Glacier.

5:00 p.m.—Check in at Majestic Valley Wilderness Lodge.

6:00 p.m.—Dinner.

8:00–10:00 p.m.—Field trip orientation.

Monday, March 20
8:00 a.m.—Breakfast at Majestic Valley Wilderness Lodge.

10:00 a.m.—Depart for Matanuska Glacier.

10:30 a.m.–4:30 p.m.—Walking tour of basal ice exposures.

5:00 p.m.—Return to Majestic Valley Wilderness Lodge.

6:00 p.m.—Dinner, followed by discussion of day's observations and planning of next day activities. We anticipate that participants will want to return to many of the exposures to take samples, make measurements, and take detailed photographs.

Tuesday, March 21
8:00 a.m.—Breakfast at Majestic Valley Wilderness Lodge.

10:00 a.m.—Depart for Matanuska Glacier.

10:30 a.m.–4:30 p.m.—Investigation of basal ice–clean ice contact and shear zone; deformation and lodgment till exposures; exploration of frazil growth in uplifted subglacial conduits; and melt-out and sublimation till formation.

5:00 p.m.—Return to Majestic Valley Wilderness Lodge.

6:00 p.m.—Dinner, followed by discussion of day's activities.

Wednesday, March 22
8:00 a.m.—Breakfast at Majestic Valley Wilderness Lodge; checkout.

10:00 a.m.—Depart for Matanuska Glacier.

10:30 a.m.–1:00 p.m.—Free time to visit, sample, and photograph sites of interest; photography flight, ski landing on glacier for those interested.

1:00–2:00 p.m.—Lunch at Long Rifle Lodge.

2:00–5:00 p.m.—Transport to Copper Whale Bed & Breakfast, Anchorage.

6:00 p.m.—Dinner at Copper Whale and wrap-up.

Thursday, March 23
Transport to airport.

Logistics, Participants, and Costs

A maximum of 21 participants can be billeted at the Majestic Valley Bed & Breakfast, which has eight double rooms and two cabins, with a total of 21 beds. Majestic Valley will provide meals and pack lunches. The hiking is not strenuous, and anyone in reasonably good physical condition should be able to visit all the sites on the itinerary. Participants will need warm clothing, boots, hats, and gloves. A winterized warming hut, located 200 m from the terminus of the glacier, will serve as the hub of activity on field days. A winter road allows vehicles and snowmobiles direct access to the snout of the glacier. Glacier Park Lodge is located 2 km from the glacier.

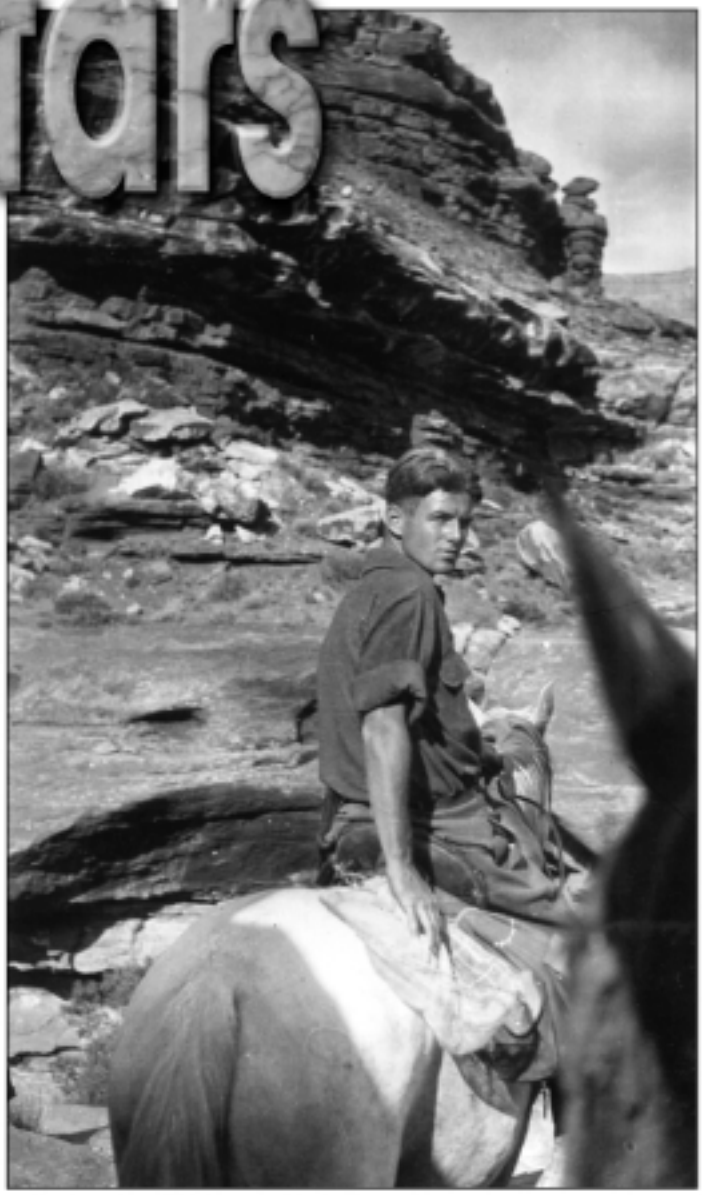
Participants must make their own travel arrangements to and from Anchorage. A flat fee of U.S. $510 will be charged to cover all meals, transportation, lodging and access fees. Registration deadline—December 15, 1999; cancellation deadline—January 15, 2000.

For Registration Applications and Information
Contact Edward B. Evenson, Dept. of Earth and Environmental Sciences, Lehigh University, Williams Hall #31, Bethlehem, PA 18015, (610) 758-3659, fax 610-758-3677, ebe0@lehigh.edu. ■

Rock Stars

Grand Vision of Edwin D. McKee

Earle E. Spamer, Academy of Natural Sciences, Philadelphia, PA 19103-1195



E. D. McKee on the trail from Supai, Havasupai Indian Reservation, Arizona, ca. 1939. Photo NAU.PH.95.48.141, McKee Collection, Cline Library, Northern Arizona University. Used with permission.

We geologists are all attached to places—our home landscape, the place we did our first field work, a locality where we discovered something—but few of us devote our careers to one place and use it as a prism through which to view the world. Edwin McKee fell in love with the Grand Canyon and did just that.

McKee, born in 1906 just 48 years after the first explorations of the Grand Canyon, was introduced to the canyon in Washington, D.C., where he grew up. He joined Boy Scout Troop 1, whose scoutmaster was François E. Matthes, the eminent topographer, who in 1903, made the first small-scale topographic sheets of the Grand Canyon. Matthes must have told stories of his experiences, the demands of mapping the canyon, of blazing a horse trail up narrow, rocky Bright Angel Creek, of heat that diminished the leveling bubbles in their instruments, and tales of scientific discovery by renowned canyon explorers like John Wesley Powell and Charles D. Walcott—stories that surely meted out adventure, technical know-how, and solid work ethics.

As a young man, McKee entered the U.S. Naval Academy, but again Matthes changed McKee's life. In 1927, Matthes arranged a summer internship for the self-assured McKee with paleontologist and educator John C. Merriam. President of the Carnegie Institution of Washington, Merriam was charged by the National Park Service with developing the first interpretive programs at Grand Canyon National Park. McKee arrived at the canyon on June 16, to assist paleobotanist David White and vertebrate-ichnologist Charles W. Gilmore.

Enthralled by the experience, McKee enrolled in Cornell University to study geology. Winters in Ithaca, New York, alternated with invigorating summers in the Grand Canyon until February 20, 1929, when tragedy changed his life. Park naturalist Glen Sturdevant drowned with ranger Fred Johnson while crossing the Colorado River, and McKee was given Sturdevant's job as park naturalist. When he returned permanently to the canyon, he courted biologist Barbara Hastings, who was working during summers on the canyon's North Rim. McKee frequently hiked the rigorous 21 miles across the mile-deep canyon, and up the trail blazed by Matthes, to visit Barbara. They married on December 31, 1929.

Edwin and Barbara McKee's similar interests are displayed throughout the park museum's study collections, which are filled with ethnographic artifacts and natural history specimens. Butterfly collecting was among Edwin's avocations (McKee, 1927). The McKees ran a bird-banding station (McKee, 1934) and studied the distributions of birds in the canyon. They befriended the Havasupai Indians of the canyon; their published collection of Havasupai basketry (McKee et al., 1975) records a critical period of changing Havasupai culture. Barbara stopped writing when they began their family, but she accompanied Edwin into the field as often as possible. Once, in Mexico, she satisfactorily explained to quizzical Yaqui Indian helpers on the Colorado River delta that her husband did such "strange things" as filling bags with sediment because "he gets paid to do that!"

McKee helped create the Grand Canyon Association, which continues to assist interpretive programs in the park. His popular ranger talks covered regional geology, paleontology, ornithology, mammalogy, herpetology, entomology, botany, ethnology, archaeology, and history. In 1931 he published *Ancient Landscapes of the Grand Canyon Region* which remained in print during his entire life, in 30 revised printings until 1985. He compiled the first checklists of the Grand Canyon's mammals, amphibians, reptiles, and birds. He discovered the salmon-colored Grand Canyon rattlesnake, *Crotalus viridis abyssus*, indigenous to the canyon (McKee, 1930, 1976). But it was sedimentary cross-beds, found in many of the canyon's formations but most dramatically shown in the eolian, Permian Coconino Sandstone, that particularly piqued his curiosity. He organized the Grand Canyon Cross-Bedding Club, "a group of energetic residents who liked to hike and who had some background in geology." After he taught them precise field techniques, each Sunday they hiked into the canyon

to measure cross-beds. His first significant geological paper, on the Coconino, was published in 1933.

McKee's ability to relate the minutiae of sediments and fossils to broad geography led him to be the first to apply practical methods of tracing key beds from one area to another. In his1938 monograph on the Permian Kaibab and Toroweap formations, he used these techniques in the study of sedimentary facies. These principles were masterfully applied in a 1945 monograph, with paleontologist Charles E. Resser, on the Cambrian Tonto Group. They are his most profound interpretations of geologic processes. Sediments and fossils in these strata show that rates of transgression and regression of the sea varied and periodically reversed, making problems for stratigraphic interpretation. Such well-exposed intertonguing of sequential formations led economic geologists to better understand subsurface stratigraphy. McKee's diagrams continue to be reprinted, and the principles of his work are core materials in classes on sedimentology and stratigraphy.

The National Park Service did not allow a ranger to remain more than ten years at one place. In 1938, rather than move to Yosemite National Park, Edwin quit and became assistant director for research at the Museum of Northern Arizona. His three children were in their early school years, and a decrease in his publications reflects the attention to family affairs and administration. Still he managed to study modern sediments as analogs of paleosediments, and he devised a classification of bedding structures. Later he went to the Department of Geology at the University of Arizona, Tucson, where he became department chair. In the late 1950s, he was a research geologist for the U.S. Geological Survey, in Denver, where he operated a sedimentology laboratory even after his retirement. This is a remarkable ascendancy for someone with just a bachelor's degree. In 1957, Northern Arizona University awarded him an honorary doctorate.

Thereafter, McKee studied modern and fossil sediments on every continent but Antarctica. He considered sedimentary and biologic deposits of low-gradient streams and river deltas; dune structures of the great sand seas of Africa, Asia, and Australia; structures of arid-climate pediments; and carbonate sedimentary processes of Pacific atolls. He carried out flume-sediment experiments, and he had interests in theoretical aspects of paleoclimate analysis. McKee also embraced remote sensing technology and visual reports from Skylab to study surface processes of the world's sand seas.

The Supai Group of Grand Canyon is quintessential McKee, a model of 50 years of field work and analytical methods (McKee, 1983). Chapters by McKee and by others on these four largely fluvio-deltaic, Pennsylvanian-Permian formations are topically and technologically diverse. A color photo of a Havasupai basket from the McKee collection respectfully acknowledges the Havasupai craftswomen and friends whose family names are given to geographic features and rock formations of the Supai Group.

In the field McKee was indefatigable. His sparks of industry and creativity inspired others. No McKee bibliography exists, but a partial listing (in Spamer, 1990) contains hundreds of titles in many fields. His geological work spanned the world, but Arizona's Grand Canyon was first and never forgotten.

In 1984, McKee's ashes were buried at Grand Canyon Cemetery, beside paleobotanist David White, and John H. Maxson, a geologist who traveled with McKee on the Colorado River in 1937. Barbara McKee joined him in 1998. Despite remarkably broad interests, the man who published hundreds of articles and monographs on many subjects, who was an accomplished collector of butterflies, stamps, and Havasupai crafts, has just a simple marker of water-sculpted Tapeats Sandstone from the Grand Canyon Cambrian. A small plaque gives his occupation not as geologist, but "Teacher." His exemplary legacy and the inspiration to be gained from his accomplishments are, indeed, grand lessons.

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McKee coating trilobites with ambroid, Grand Canyon, 1936. Photo NAU.PH.95.48.1107, McKee Collection, Cline Library, Northern Arizona University. Used with permission.

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and the GSA Foundation…

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GSA FOUNDATION

Memories: 1999 GeoVentures

The 1999 GSA GeoVentures offered two programs unrelated to the annual or section meetings. The 51 participants, ranging in age from 34 to 78, represented a vast range of interests and backgrounds.

GeoVentures serve professionals who enjoy their geology and the company of other geologists in a field setting. These educational programs are a special benefit created for members, but are open to guests and friends also.

GeoVentures encompass adult educational and adventure experiences of two kinds: GeoHostels and GeoTrips. Both are known for superior scientific leadership. GeoHostels are usually five-day, campus-based programs. GeoTrips, from one to three weeks, cover a wide variety of destinations.

GeoTrip

From Pacific Islands to Snake River Rapids: The Geology of Hells Canyon, Oregon and Idaho

June 17–25, 1999; 17 participants.

Leader: Tracy Vallier, Lewis-Clark State College, Lewiston, Idaho.

"The display of geology and Tracy Vallier's exposition was excellent. I have worked on modern oceanic counterparts and found it all to be a fine example of convergent plate margin geologic processes. Tracy's understanding of both realms made it all a valuable experience."

—James W. Hawkins, La Jolla, California

"Tracy Vallier's knowledge and love for Hells Canyon made this a 5-star GeoTrip. Tracy clearly knows more about the canyon than anyone and he freely shared his insider's knowledge and concerns about the canyon's future. This was a flexible trip with a variety of activities scheduled each day."

— Janet Battista, Madison, Wisconsin

"Beachwave"—Hells Canyon. *Photo by Chris Alger.*

Lewis & Clark Trail gang. *Photo by Dale Kunitomi.*

GeoHostel

Geology of the Lewis and Clark Expedition—The Three Forks of the Missouri River to the River of No Return, Montana and Idaho

July 17–22, 1999; 34 participants.

Leaders: Robert Thomas and Sheila Roberts, Western Montana College, Dillon, Montana.

"Leaders were excellent! Very good at explaining things simply, but very knowledgeably. Sign me up for Lewis & Clark, Part II!"

—J. R. Ouellette, Pawtucket, Rhode Island

Reminder: Call for Nominations

PENROSE MEDAL

To be awarded for outstanding original contributions or achievements that mark a major advance in the science of geology. Scientific contributions should be considered rather than contributions in teaching, administration, or service. Mid-career scientists who have already made exceptional contributions should be given full consideration for this award.
Nominations are due by February 1, 2000.

DAY MEDAL

To be awarded for outstanding distinction in contributing to geologic knowledge through the application of physics and chemistry to the solution of geologic problems. The intent is to recognize outstanding achievement and inspire further effort, rather than reward a distinguished career. Scientific achievements should be considered rather than contributions in teaching, administration, and service.
Nominations are due by February 1, 2000.

HONORARY FELLOWS

To be awarded to non-North Americans who live and work outside of North America and have distinguished themselves in geological investigations or in notable service to the Society. Under exceptional circumstances, North Americans have been named Honorary Fellows.
Nominations are due by February 1, 2000.

YOUNG SCIENTIST AWARD (DONATH MEDAL)

To be awarded to a young scientist (35 or younger during the year in which the award is to be presented) for outstanding achievement in contributing to geologic knowledge through original research that marks a major advance in the earth sciences.
Nominations are due by February 1, 2000.

GSA PUBLIC SERVICE AWARD

To be awarded for contributions that have materially enhanced the public's understanding of the earth sciences or significantly served decision-makers in the application of scientific and technical information in public affairs and public policy related to the earth sciences.
Nominations are due by February 1, 2000.

DISTINGUISHED SERVICE AWARD

To be awarded for exceptional service to the Society. GSA Members, Fellows, and Associates are eligible.
Nominations are due by March 1, 2000.

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

In cooperation with the Association of American State Geologists (AASG), GSA makes an annual award for the best paper on environmental geology published either by GSA or by one of the state geological surveys. The award is a $1000 cash prize from the endowment income of the GSA Foundation's John C. Frye Memorial Fund. The paper must be selected from GSA or state geological survey publications; it must be selected from those published during the preceding three full calendar years; and the nomination must include a paragraph stating the pertinence of the paper. Nominated papers must establish an environmental problem or need, provide substantive information on the basic geology or geologic process pertinent to the problem, relate the geology to the problem or need, suggest solutions or provide appropriate land-use recommendations based on the geology, present the information in a manner that is understandable and directly usable by geologists, and address the environmental need or resolve the problem. It is preferred that the paper be directly applicable by informed laypersons (e.g., planners, engineers).
Deadline for nominations for 1999 is March 31, 2000.

OFFICERS AND COUNCILORS

The GSA Committee on Nominations requests your help in compiling a list of GSA members qualified for service as officers and councilors of the Society. The committee requests that each nomination be accompanied by basic data and a description of the qualifications of the individual for the position recommended (vice-president, treasurer, and councilor).
Nominations are due by February 15, 2000.

NATIONAL AWARDS

The deadline for the William T. Pecora Award, the National Medal of Science, the Vannevar Bush Award, and the Alan T. Waterman Award is April 30, 2000.

Materials and supporting information for any of the nominations may be sent to GSA Administrative Offices, Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140. For more detailed information about the nomination procedures, refer to the October 1999 issue of *GSA Today*, or call headquarters at (303) 447-2020, ext. 188.

Statement of Ownership, Management, and Circulation
(Required by Title 39 U.S.C. 4369)

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This information taken from PS Form 3526, signed September 20, 1999 by the Publisher, Peggy S. Lehr, and filed with the United States Postal Service in Boulder, Colorado.

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h.	Copies Not Distributed		
	(1) Office use, leftovers, spoiled	978	1,146
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Innocents on the Ice; A Memoir of Antarctic Exploration, 1957. *By John C. Behrendt. University Press of Colorado, Niwot, 1998, 428 p., $29.95 hardcover, $19.95 paperbound.*

This book is really two stories in one, and both are interesting. The title relates to individuals, some military and some civilian, assigned to Ellsworth research station in Antarctica during the International Geophysical Year, 1957–1958. The 38 "innocents" had virtually no experience under the rigorous conditions of the Antarctic winter. They were nearly all in their 20s, and the commander was a veteran explorer who had considerable experience in Antarctica.

The book contents are in two forms, one being excerpts from the journal that Behrendt kept in 1956–1957, and the rest his explanation, written in the present, of some of the events described in the journal.

Behrendt describes a long traverse, in tracked vehicles, over new terrain in West Antarctica. Risks and hazards of this kind of work included the dangers of travel along the edge of the Filchner-Ronne ice shelf and the invisible crevasses that the scientists encountered frequently. The traverse yielded useful information on the shelf thickness (seismic stations were established regularly), snow accumulation (from pit studies), weather, and rock composition (samples from the mountain ranges). At this time the concept of plate tectonics was still in its infancy, and the discovery of rock strata correlative with parts of the Transantarctic Mountains, and of Africa, were (and are) of great significance.

Perhaps more interesting, to students of human nature, are the descriptions of the way the men (no women in the field at that time in the U.S. Antarctic Program) interacted. The dynamics revolved around the base leader, who also doubled as station scientist; this arrangement was unlike the practice at other U.S. stations where there was a military leader responsible for the command of the military personnel and the support of science, and a civilian station leader responsible for coordinating the science of the civilians.

The leader at Ellsworth, a retired U.S. Navy captain, used strict means of keeping things under control, and the reaction of the men was that they were being treated unfairly. They were not allowed to use the radio without permission or to contact other stations or field parties (although they did have contact with the outside world by ham radio, on a limited basis), and any messages to be sent out were approved (or censored) by the station leader. He also insisted on clearing all plans that related to the traverse. Personality differences surfaced, and some of the men began to document conversations and situations. A bizarre sidelight to Behrendt's journal and later commentary relates to an activity—aerial photo coverage of selected areas—that he speculates was sponsored by the U.S. Defense Department and Central Intelligence Agency.

The book ends with a bibliography that includes other books by and about the station leader, a short glossary, and a detailed index. Black-and-white photos of the station and traverse life supplement the text.

This book is a good description of how science (mainly geophysics) was done in the IGY under very trying field conditions, and it shows how personality problems can surface in certain situations, developing into a kind of paranoia among all concerned. We are fortunate that Behrendt has documented both.

John F. Splettstoesser
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Interpreting Pre-Quaternary Climate from the Geologic Record. *By Judith Totman Parrish. Columbia University Press, New York, 1999, 338 p., $95.*

Paleoclimatology is one of the most flourishing fields of research at present, involving both climate modeling and interpretation of geological climate indicators. Such research has recently been spurred on by our need to learn how the climate system works and to make predictions about future climate change. We also need to know about ancient climates: what they were like and how they operated in the geological past. The focus of literature published in the past few years on paleoclimates has tended to be on computer models of climate, but now Judy Parrish has redressed the balance with this book that concentrates on the geological evidence for past climates, such as the range of geological indicators used and how they can be interpreted in terms of climate, particularly for pre-Quaternary time.

The introduction of the book usefully describes how features of our climate (e.g., atmospheric circulation patterns) work and some of the principles behind using geological indicators, especially oxygen and carbon isotopes. The following chapters each deal with a sector of paleoclimate data sources. These include marine biotic indicators of paleoclimate such as foraminifera, diatoms, and nannofossils, and marine macrofossils such as trilobites, graptolites, corals, vertebrates, and even trace fossils. Lithic indicators of climate discussed include oceanic sediments such as cherts, chalks, phosphorites, clay minerals, glauconites, organic-rich rocks, reefs, and carbonate platforms, to name but a few. Eolian deposits, loess, evaporites, zeolites, volcanic ash, paleosols, coals, lake deposits, glacial indicators, and even fluvial indicators are some of the topics considered in the terrestrial and freshwater lithological realm. A wide range of biotic indicators on land is discussed, including pollen, ostracodes, terrestrial vertebrates, invertebrates, and many types of fossil plants.

As is apparent from the list above, this is an almost exhaustive coverage of geological data sources. Some topics, such as fossil plants and paleosols, are covered in some depth whereas others, such as zeolites and authigenic minerals, are dealt with only briefly. However, every section contains information about the climate relevance and references to reviews or case studies to follow up. This has resulted in an extensive and valuable reference list.

Computer models are not ignored; one chapter deals with the nature of paleoclimate models (such as general circulation models, energy balance models and Parrish's own conceptual models), how they are applied, and some of the problems with them. A simple discussion on how various climate models work, both atmospheric and oceanic, is most welcome. Case studies are presented to show how climate interpretation from geological data compares with simulations produced by models.

The strong message that comes through from Parrish is that it is not suitable to rely on just one or two data sources but as many indicators of paleoclimate as possible should be used in case studies and that they should be considered in their regional or global contexts. Her final chapter illustrates this well and presents some important case studies, such as evidence for and against an early Oligocene ice sheet on Antarctica, which brings together a host of different geological indicators, such as oxygen isotopes, plants, diatoms, glacial sediments and sea-level data, to produce a detailed and evolving story of paleoclimate.

The figures in this book are somewhat disappointing. Black-and-white and gray-scale figures are abundant (at least one per two-page spread). The quality of the illustrations is not always good—most come from published literature and they have not been redrawn but simply scanned in from original publications. This has resulted in some rather fuzzy lines and coarse detail, which has made some figures illegible. It is a shame that there are

no photographic plates or color figures; some photographs of the different features of paleosols or of fossil plants would have been helpful.

This is the only book of its kind at present; it must have been a huge task to bring all this varied information together. It will be an extremely useful reference text not just for paleoclimatologists, but for many others—both researchers and students—who would like to know how their data can be used to the full.

Jane Francis
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Soils and Geomorphology *[Third Edition]. By Peter W. Birkeland, Oxford University Press, New York, 1999, $45, paperbound.*

It was a pleasure to review the greatly expanded and updated third edition of Birkeland's book, the second edition (1984) of which won him the 1988 Kirk Bryan Award of the GSA Quaternary Geology and Geomorphology Division. That second edition was a 30% expansion of the first (1974) edition under a different title, but followed a nearly identical chapter and subchapter organization. Introductory chapters on soil profiles and nomenclature and on soil classification were followed by chapters on the processes and products of weathering (good, basic geomorphology) and a more specific chapter on the processes of soil-profile development. These five chapters are updated and modestly enlarged in the third edition.

The theme of this book is summarized in the brief chapter six, which introduces the grand concept of Five Factors of Soil Formation: climate, organisms (primarily vegetation—microbes are barely noted), topography, parent material, and time. In earlier editions, this chapter was followed by five more, each elaborating on the relationships of one of the factors to soils, with a concluding chapter on the application of soils to geomorphological studies.

This third edition breaks the mold. Chapter seven: "The influences of parent material on weathering and soil formation" nicely updates the earlier edition, but thereafter the other four factors are complexly blended. The factor of time, through the concept of soil chronosequences, is reviewed by climatic regions in chapter eight. More than half the references in the massive reference list of 245 entries for chapter eight postdate the second edition. Similarly, in chapter nine the factor of topography is reviewed with respect to climatic setting, and in chapter ten the factor of climate is reviewed in the context of Quaternary paleoclimates. The fifth factor, organisms (read "vegetation") has lost its own chapter and is imbedded in time, climate, and topography.

Although the tables of contents of the three editions look similar, the change in emphasis clearly records the growing integration of soils science, geomorphology, and Quaternary studies. Are all soils polygenetic, shaped by ever-changing climate, vegetation, and topography? This edition confronts such issues in a fresh, honest, and informed way. It should be studied by everyone in the numerous related fields.

Any review should include quibbles, if only to prove that the reviewer has been thorough. I note the frequent use of the words "difficult," "difficulty," "problematic," etc. in opening sentences of paragraphs. Usually the rest of the paragraphs are fully informative, but a naïve student might be subliminally influenced into believing that the entire subject is too complex to be understood. I found it amusing that three generations of Oxford Press editors failed to read the preface, with its thanks by the author to his family, "each [singular] of them ... in their [plural] own way ...." The extensive lists of references by chapters are now collected at the end of the book, and could easily have been consolidated into a single alphabetical list that would have saved many pages of duplicate entries.

One of the lesser used definitions of "factor" is "one who invests." This book is dedicated to the five "factors" who greatly influenced Birkeland's work. Clearly, their investments have reaped rich reward.

Arthur L. Bloom
Cornell University
Ithaca, NY 14853

Quaternary Environments *[Second Edition]. By M. Williams, D. Dunkerley, P. De Deckker, P. Kershaw, and J. Chappell. Arnold & Oxford University Press, New York, 1998, 329 p., $45, paperbound.*

The Quaternary is the remarkable period when humans first reached their major potential, including the ability to dramatically degrade the planet. This book by Australian geoscientists is an exposition on past environments, with an avowed attempt to better understand the future. *Quaternary Environments* joins only a few other such books to provide new information on paleoclimatology, glaciations, sea-level changes, and environmental reconstructions. Quaternary global change is featured in terms of climate and environmental fluctuation controlled ultimately by a wide variety of internal and external factors that are authoritatively explained.

Two introductory chapters review the overall context in a prelude to the Quaternary by introducing controls of environments by tectonism, volcanic gases, growth of Antarctic ice, vegetation and the planetary carbon cycle, and meltwater flood effects on oceanic circulation. The extent, landforms, and chronology of the world cryosphere are presented in a general analysis, with special emphasis on high-resolution ice cores. Useful explanation of Dansgaard-Oeschger temperature events, bun-

Book Reviews *continued on p. 26*

dled into sawtoothed Bond cycles, reveals slow cooling followed by rapid warming. Correlation with marine sediment-core archives shows enigmatic rapid oscillations. Flotillas of Heinrich-event icebergs are well presented in relation to global oceanic circulation.

Special attention is placed upon Milankovitch cycles as explanations for Quaternary variation, but other controls are not discounted. Sea-level changes are especially well explained, and treatment of the oceanic record is among the best. In contrast, the discussion of rivers is superficial and restricted to the Amazon, Nile, and Murray-Darling. Lakes are discussed with an Australian emphasis, but with inaccurate or outdated references on Lake Bonneville. Groundwater hardly belongs as part of a chapter title. Discussion of the causes and timing of cooling and desiccation in the late Cenozoic is generally good, although the explanation of atmospheric flow in the tropics is a bit misleading.

The section on terrestrial flora and fauna has an excellent but little known scheme for comprehensive assessment of sediments that many will find valuable. Pollen analysis and interpretation are given particularly close and useful attention. In contrast, plant macrofossils, phytoliths, tree rings, vertebrates, and beetles receive but brief mention. Fifteen pages of global synthesis of plant and animal distribution constitute a reasonable attempt to show possibilities.

In a step beyond most work on the Quaternary, the discussion of human origins, innovations, and migrations will make this book interesting to many. A brief exposition of human ancestors is related to environmental controls. Recent information on transitional forms of Homo, tool use, fire, and cultural developments is presented. Controversies over megafaunal extinctions are related to changes in sea level, climate, fire, overkill, and complex causes. Isotopic evidence (C3-C4 vegetation) of paleodiets is discussed, along with the timing and types of domestication of plants and animals, and the resulting first towns.

A final chapter on atmospheric circulation should have been moved forward or recombined, and an appendix on dating improved. Neither is especially useful as written; indeed, the section on dating is somewhat superficial and lacks some of the new isotopic and other techniques of considerable utility.

Overall, this book is a valuable addition to the shelf of any Quaternary enthusiast, especially as it has unusual emphasis on parts of the Southern Hemisphere not commonly discussed elsewhere. The term "Cainozoic" is used throughout the book. Otherwise, only a few odd usages, typographical errors, and other irregularities occur. The authors have done an excellent job of bringing together a wealth of older and new material on the Quaternary that can be endorsed for classroom use. The far-ranging scope of the book will lend itself to a wide, interdisciplinary audience.

John F. Shroder, Jr.
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Call for Submissions of Your Geological Photos

Be a part of the Geological Society of America's exciting new anthology of text and photographs, *Encounters with Earth* (a working title), edited by Eldridge Moores, Lauret Savoy, and Don Easterbrook.

GSA invites submissions of photographic images in various photographic media that examine features of Earth (from microscopic to aerial and satellite perspectives) for a new thematic, 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 photographs (current as well as historical) of a variety of Earth subjects, in combination with complementary accompanying excerpts from writings from a range of fields in addition to the geosciences. The book will be offered to the scientific community and to the general public.

Previously published as well as original writings will be selected to reflect social, scientific, artistic, literary, and cultural themes related to the Earth. They would also be selected to reflect a range of perspectives, time periods, and nationalities or ethnicities. The focus will be how the 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.

SUBMISSION REQUIREMENTS

Each photographer may submit up to 10 images. Each submission must meet the criteria described below.

◆ PHOTOS must be of high technical quality, preferably duplicate slides or transparencies and/or black-and-white prints; tell an interesting and unique geologic story; and have unusual aesthetic appeal.

◆ EACH IMAGE must be submitted either as (1) a black-and-white print (8" X 10" on smooth nonglossy paper), and/or (2) a clean color slide (duplicate transparency) AND a color print or photocopy of that image (for review purposes).

◆ ORIENTATION and NAME must be clearly marked on each slide or print (or holder/sleeve).

◆ DESCRIPTIVE TEXT should be brief (two or three sentences) for each image, 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, please 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 writings by authors who have considered in any literary form the regions or features in your photographs, please include this information (author, title of work, location of reference). (We particularly would like photographs and information on writers outside of North America.)

Send submissions as early as possible, but all must arrive at GSA no later than December 15, 1999. Please send prints or duplicate transparencies along with a stamped, self-addressed envelope with your submission for return of the photographs. Pack slides well to avoid damage; we recommend 8-1/2" x 11" slide sleeves.

Send submissions to: Geological Society of America
Encounters Photos
Attn: Naomi Horii, Managing Editor
3300 Penrose Place
P. O. Box 9140
Boulder, CO 80301-9140

For further information, contact Lauret Savoy at lsavoy@mtholyoke.edu after November 15, 1999.

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GSA Grants Support Student Research

Leah J. Carter, Research Grants Administrator

Grants for Graduate Students

The purpose of the general research grants program is to provide partial support of master's and doctoral thesis research in earth science for graduate students at universities in the United States, Canada, Mexico, and Central America. GSA strongly encourages women, minorities, and persons with disabilities to participate fully in this grants program. Applicants need not be members of GSA. Funding for this program is provided by a number of sources, including GSA's Penrose and Pardee endowments, the National Science Foundation, industry, individual GSA members through the Geostar and Research Grant funds, and numerous dedicated research funds that have been endowed at the GSA Foundation by members and families.

Applications must be on current GSA forms available in geology departments in the United States and Canada, or from the Research Grants Administrator, GSA, P.O. Box 9140, Boulder, CO 80301-9140 or lcarter@geosociety.org. Application forms, appraisals, and information are available on GSA's Web page www.geosociety.org. Evaluations from two faculty members are required on GSA appraisal forms. Applications and appraisals may be downloaded from the Web but *will not* be accepted by e-mail or facsimile. The deadline is February 1 each year for grants awarded in April. In 1999, 468 proposals were received, 212 of them were funded. A total of $395,235 was awarded.

Specialized Grants

Recipients of special named awards are selected by the Committee on Research Grants from applicants to the general research grants program; the same application forms are used, and they must also be postmarked by February 1. It is not necessary for applicants to indicate that they wish to be considered for a specialized grant. The committee considers all qualified applicants when selecting recipients for special awards.

The Gretchen L. Blechschmidt Award supports research by women interested in achieving a Ph.D. in the geological sciences and a career in academic research, especially in the fields of biostratigraphy and/or paleoceanography, and who have an interest in sequence stratigraphy analysis, particularly in conjunction with research into deep-sea sedimentology.

The aim of the John T. Dillon Alaska Research Award is to support research that addresses earth science problems particular in Alaska, especially field-based studies dealing with the structural and tectonic development, and those that include some aspect of geochronology (either Paleontologic or radiometric) to provide new age control for significant rock units in Alaska.

The Robert K. Fahnestock Memorial Award is made annually to the applicant with the best application in the field of sediment transport or related aspects of fluvial geomorphology.

The Lipman Research Award is to promote and support graduate research in volcanology and petrology.

The Bruce L. "Biff" Reed Award is for graduate students pursuing studies in the tectonic and magmatic evolution of Alaska and also can fund other geologic research.

The Alexander Sisson Award supports research for students pursuing studies in Alaska and the Caribbean.

The Harold T. Stearns Fellowship Award is awarded annually in support of research on one or more aspects of the geology of Pacific Islands and of the circum-Pacific region.

Division Grants

Nine of the 12 GSA divisions award grants for outstanding student research within the respective division's field of interest. The Committee on Research Grants will select candidates from the general research grant applicants for awards by the Geophysics (Allan V. Cox Award), Hydrogeology, Sedimentary Geology, and Structural Geology and Tectonics Divisions.

The Archaeological Geology Division awards the Claude C. Albritton, Jr. Scholarships for graduate students in the earth sciences and archaeology. Contact Reid Ferring, Institute for Applied Sciences, Box 310559, University of North Texas, Denton, TX 76203.

The Coal Geology Division awards the A. L. Medlin Scholarship Award and a Field Research Award to students who submit the best proposals of research projects in the field of coal geology. Guidelines are available from the division secretary.

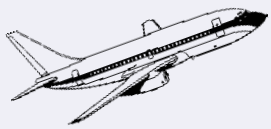
The Planetary Geology Division offers two S. E. Dwornik Student Paper Awards in the field of planetary geology annually. Contact the division secretary for information.

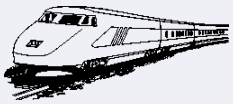
The Quaternary Geology and Geomorphology Division awards the J. Hoover Mackin and Arthur D. Howard Research Grants to support graduate student research on Quaternary geology or geomorphology. Applications are available from the division secretary, Alan R. Nelson, U.S. Geological Survey, Box 25046, MS 966, Federal Center, Denver, CO 80225. The deadline for applications is February 1 for grants awarded in April.

The Engineering Geology Division offers the Roy J. Shlemon Scholarship

GSA Student Associate Member
TRAVEL GRANTS

The GSA Foundation has awarded $4,000 grants to each of the six GSA sections. The money, when combined with equal funds from the sections, is used to assist GSA undergraduate Student Associates, as well as graduate Student Members, traveling to GSA meetings. For information and deadlines, contact your section secretary.





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(402) 472-7546, rfd@unl.edu

Northeastern—Kenneth Weaver,
(410) 554-5532, kweaver438@aol.com

South-Central—Rena Bonem,
(254) 710-6806, Rena_Bonem@baylor.edu

Southeastern—Harold Stowell,
(205) 348-5098, hstowell@wgs.geo.ua.edu

Award and the Engineering Geology Division Award to students who submit the best proposals for research projects in the field of engineering geology. Contact Robert A. Larson, at 6416 Woodley Avenue, #5, Van Nuys, CA 91406; e-mail: ralarson@ecom.net.

The Geoscience Education, History of Geology, and International Divisions do not currently award grants for student research.

Section Grants for Undergraduate and Graduate Students

Recipients for graduate research grants from the South-Central Section are selected from applicants to the GSA general research grants program who are recommended by the Committee on Research Grants to the Management Board of the section for final selection. Eligibility is restricted to graduate students attending a college or university within the geographic area of the section.

The South-Central Section also awards grants to undergraduate students; applications are available from the section secretary, Rena M. Bonem, Department of Geology, Baylor University, P.O. Box 97354, Waco, TX 76798-7354. The deadline for Fall applications is October 15, 1999 and for Spring is March 15, 2000.

The North-Central Section awards grants to undergraduate students within the geographic boundary of the section. For further information contact the section secretary.

The Southeastern Section awards grants for both undergraduate and graduate student members of GSA who are enrolled in institutions within the geographical boundaries of the section. Application forms can be obtained from the section secretary, Harold H. Stowell, Department of Geology, Box 870338, University of Alabama, Tuscaloosa, AL 35487-0338. The deadline is February 1 for grants awarded in April.

The Northeastern Section offers research grants for undergraduate students who are enrolled at institutions within the section and are Student Associates of GSA. Contact the section secretary, Kenneth N. Weaver, Maryland Geological Survey, 2300 St. Paul St., Baltimore, MD 21218-5210, for application forms. Applications must be postmarked by February 7 for grants awarded in April.

The remaining two sections—Rocky Mountain and Cordilleran—do not currently offer research grants. ■

South-Central Section Awards 1999 Grants

The South-Central Section has awarded grants to two graduate students who applied to the GSA Research Grants program. The awardees are: Edward A. Zarecky, Baylor University, for "The Effects of Land Use on the Spatial Distribution of Historical Overbank Sedimentation in Mill Creek Watershed, Blackland Prairie, Central Texas"; and C. Norman Hansen, University of Texas, for "Urban 'Karst': The Impacts of Utility/Service Conduits/Ducts, and Trenches on Urban Groundwater Systems."

GSA Offers Awards in Geomorphology and Micropaleontology

Two GSA awards for support of research are a testimony to the generosity of the late W. Storrs Cole. The Gladys W. Cole Memorial Research Award provides support for the investigation of the geomorphology of semiarid and arid terrains in the United States and Mexico. It is to be given to a GSA Member or Fellow between 30 and 65 years of age who has published one or more significant papers on geomorphology. Funds cannot be used for work already accomplished, but recipients of a previous award may reapply if additional support is needed to complete their work. The amount of this award in 2000 will be $11,000.

The second award, the W. Storrs Cole Memorial Research Award, was established to support research in invertebrate micropaleontology. This award will carry a stipend of $9,000 in 2000 and will be given to a GSA Member or Fellow between 30 and 65 years of age who has published one or more significant papers on micropaleontology.

Additional information and application forms may be requested from the Research Grants Administrator, Geological Society of America, P.O. Box 9140, Boulder, CO 80301, e-mail lcarter@geosociety.org. Applications are now available on GSA's Web site www.geosociety.org. Applications will not be accepted by e-mail or facsimile.

All applications must be postmarked on or before *February 1, 2000*. Actions taken by the Committee on Research Grants will be reported to each applicant in April.

These are two of GSA's most prestigious awards; all qualified applicants are urged to apply.

GEOLOGICAL SOCIETY OF AMERICA
BULLETIN
VOLUME 111, NUMBER 11, NOVEMBER 1999

GEOLOGY

VOLUME 27
NO. 11
P. 961–1056
NOVEMBER 1999

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Positions Open

REMOTE SENSING/GIS
DEPARTMENT OF GEOLOGY
IDAHO STATE UNIVERSITY

We seek an earth scientist to fill a full-time, non-tenure-track Research Faculty position in Remote Sensing and GIS applications. A Ph.D. and U.S. citizenship are required. Excellent salary provided for three years, in anticipation of attracting ongoing extramural funding. Research duties include active participation in the university's Center for Integrated Environmental Analysis and the establishment of strong cooperative research ties with scientists in the ISU Geology Department and the Idaho National Engineering and Environmental Laboratory. Teaching duties include supervision of Geology M.S. students and 1–2 classes per year in specialty area. The successful candidate will have broad geologic interests and demonstrated proficiency in the application of Idrisi, IMAGINE, or ENVI software to solving geologic problems. See www.isu.edu for additional information. Send CV, statements of academic philosophy and research interests, and names of 3 referees to Search Committee, Department of Geology, Idaho State University, Pocatello, ID 83209-8072. Applications will be reviewed beginning December 1, 1999. ISU is an EO/AA Employer.

IOWA STATE UNIVERSITY
Stratigrapher/Sedimentologist

The Department of Geological and Atmospheric Sciences invites applications for a tenure-track position in stratigraphy/sedimentology at the assistant professor level that will begin in mid-August 2000. The position is to complement existing programs in environmental geology, hydrogeology, structural geology/tectonics, economic geology, geophysics, petrology, and geochemistry. Opportunities exist for close interaction with other faculty on campus having strengths in ecology, geology, meteorology, and soil science.

The successful candidate will be expected to develop a vigorous research program, supervise graduate students, attract external funding, and participate actively in our graduate (M.S. and Ph.D.) and undergraduate teaching programs. He or she will teach modern field methods at our undergraduate field camp in Wyoming with the long-term goal that the candidate will serve as its director. Preference will be given to individuals with a strong background in the application of one or more of the following fields: sequence stratigraphy, basin analysis, clastic or carbonate petrology, sedimentary tectonics, and sedimentology.

Applicants should send a letter of application, a statement of research and teaching interests, curriculum vitae, transcripts, and the names, addresses, e-mail addresses, phone and fax numbers of at least three references to: Search Committee Chair, Department of Geological and Atmospheric Sciences, 253 Science I, Iowa State University, Ames, IA 50011-3212. Applicants should hold a Ph.D. in geosciences at the time of appointment. To ensure consideration, applications should be received by December 1, 1999. Information about the Geological Sciences Group can be found on the Web at: http://www.geology.iastate.edu. Iowa State University is an Equal Opportunity/Affirmative Action Employer and encourages applications from women, minorities, and other protected groups.

TENURE-TRACK POSITION IN GEOMORPHOLOGY
UNIVERSITY OF NEW MEXICO

The Department of Earth & Planetary Sciences is accepting applications for a tenure-track faculty position in geomorphology beginning in fall 2000. We anticipate hiring at the assistant professor level. Applicants must have a Ph.D. by the time of the appointment, research focus in fluvial and hillslope processes, with applications to climatic and/or tectonic geomorphology, demonstrable skills in GIS, and a strong field emphasis. A strong record of research and publication is essential. The successful candidate is expected to develop and maintain an active research and teaching program, to advise and direct graduate student research, and is encouraged to collaborate with other faculty in a collegial fashion in related fields that include soil geomorphology, paleoclimatology, hydrology, sedimentology, tectonics, and volcanology. Teaching responsibilities include undergraduate- and graduate-level courses in field-based and quantitative geomorphology, including GIS, and introductory earth science courses. The Department of Earth & Planetary Sciences has 20 full-time faculty and excellent laboratory and computational facilities (details on our web site: epswww.umn.edu).The spectacular geologic setting of New Mexico serves to enhance both teaching and research that takes place within the Department.

Applicants should submit a CV, graduate transcripts, copies of selected publications, a statement of teaching and research experience and interests, and the names and contact information of four referees to: Dr. Maya Elrick, Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116. Applications must be received by December 17, 1999. The University of New Mexico is an equal opportunity/affirmative action employer.

ASSISTANT PROFESSOR TOWSON UNIVERSITY

The Department of Physics, Astronomy, and Geosciences at Towson University seeks to fill an entry level tenure-track position for an Assistant Professor beginning fall of 2000. The successful candidate will join in the expansion of the Geosciences major. Expertise in fields related to environmental geology such as aqueous geochemistry and groundwater hydrogeology is desired. A strong commitment to undergraduate teaching and research participation is essential.

Responsibilities include teaching introductory geology courses, aqueous geochemistry and groundwater hydrogeology. The ability to develop other upper level courses such as petrology or geophysics is a plus. This position will support continued growth of the Geosciences major and an interdisciplinary program in Environmental Science. Other courses may be developed for either major. A viable research program involving undergraduates is expected. Teaching experience is desirable. A Ph.D. is required at the time of appointment. Salary is competitive. To learn more about this position, please visit www.towson.edu/geosciences.

Towson University is located in suburban Baltimore. The community offers many intellectual and recreational opportunities. Abundant opportunities for the establishment of research collaborations exist in the Baltimore/Washington metropolitan area as well.

Applicants should send a curriculum vitae and statements of teaching philosophy and research interests, as well as arrange to have three letters of reference sent to: Dr. Jonathan Filer, Geology Search Committee Chair, Department of Physics, Astronomy, and Geosciences, Towson University, Towson, MD 21252. Review of applications will begin on January 14, 2000.

Towson University is an equal opportunity/affirmative action employer and has a strong commitment to diversity. Women, minorities, persons with disabilities, and veterans are encouraged to apply.

FACULTY POSITION IN
ENVIRONMENTAL BIOGEOCHEMISTRY
UNIVERSITY OF WISCONSIN-MADISON

The Department of Geology and Geophysics, UW-Madison, invites applications for a tenure-track faculty position in the area of Environmental Geochemistry at the assistant professor level. We are particularly interested in individuals with expertise in environmental geochemistry, low-temperature aqueous geochemistry and environmental biochemistry. Ph.D. required at the time of appointment. The successful candidate will be expected to develop a vigorous research program, including supervision of graduate students. Teaching duties will include undergraduate and graduate courses. Preference will be given to candidates whose expertise would lead to interactions with existing groups in the department, especially those in hydrogeology, sedimentology, surficial processes, mineralogy, economic geology, isotope geology, and geomicrobiology.

Applicants should submit a resume, statement of research and teaching interests, copies of up to five publications, and the names and addresses of at least three references to Professor Jillian Banfield, Geochemistry Search Chair, Dept. of Geology and Geophysics, UW-Madison, 1215 W. Dayton, Madison, WI 53706-1692.

Application deadline November 15, 1999. For additional information see http://www.geology.wisc.edu.

UW-Madison is an equal opportunity/affirmative action employer and encourages applications from women and minorities. Unless confidentiality is requested in writing, information regarding the applicants must be released upon request. Finalists cannot be guaranteed confidentiality.

SEDIMENTARY GEOLOGIST
THE UNIVERSITY OF AKRON

The Department of Geology at The University of Akron invites applications for a tenure-track assistant professor position in the general area of sedimentary geology, starting August 28, 2000. The preferred candidate will have a strong field-orientation with a specialty in carbonate or clastic sedimentary petrology, sedimentology, or stratigraphy. A Ph.D. in geology or a related field is required, and previous teaching/research experience is desirable.

A commitment to excellence in both teaching and research is required. Teaching responsibilities will include graduate courses in his/her specialty, sedimentation and stratigraphy, general studies courses, and participation in field camp. An interest in working into the directorship of field camp is desirable. The successful candidate will develop an externally funded research program and supervise graduate student research at the M.S. level.

Salary will be commensurate with the candidate's level of experience. Startup funds available. Send letter of application along with a statement of research and teaching interests, complete vitae, and names, addresses, phone numbers, and e-mail of 3 referees to: Dr. Annabelle Foos, Dept. of Geology, The University of Akron, Akron, OH 44325-4101.

The Department of Geology has 12 faculty with diverse research interests and has excellent field and laboratory equipment. Major equipment includes: an electron microprobe, automated X-ray diffraction system, cathodoluminoscope, ICP, AA, Giddings, soil probe, and SUN workstation laboratory. Visit http:// www.uakron.edu/geology/ for additional information. The University of Akron is an Equal Opportunity Employer. Application deadline: January 15, 2000.

ASSISTANT PROFESSOR
QUATERNARY PROCESSES
CALIFORNIA STATE UNIVERSITY LOS ANGELES

The Department of Geological Sciences at California State University, Los Angeles invites applications for a full-time, tenure-track assistant professor position in the area of Quaternary processes. We are seeking an individual with applied and theoretical expertise in active fault geomorphology, soil formation processes, geomorphic processes, coastal environmental processes, and Quaternary dating techniques. The position will start in Fall 2000 at an initial salary commensurate with qualifications and experience.

Applicants must have a Ph.D. in geology, demonstrated potential for effective teaching using a variety of methodologies, demonstrated ability and/or interest in working in a multicultural environment, and potential for scholarly and creative activity. Duties will include teaching at the undergraduate and graduate level, directing graduate students, maintaining an active research program, participating in University service, and student advising.

Applicant documentation should include the following: letter of application describing research and teaching interests, curriculum vitae, three letters of recommendation, and transcript from institution awarding highest

Classifieds *continued on p. 32*

Classifieds *continued from p. 31*

degree. Review of applications will begin on January 15, 2000. Address applications, required documentation, and/or requests for information to: Dr. Kim Bishop, California State University, Los Angeles, 5151 State University Drive, Los Angeles, CA 90032-8203, www.calstatela.edu.

Cal State LA is an equal opportunity/Title IX employer. Upon request, reasonable accommodation will be provided to individuals with protected disabilities.

UNIVERSITY OF IOWA
POSITION IN QUATERNARY GEOLOGY AND SOILS

The Department of Geoscience, University of Iowa, invites applications for a tenure-track Assistant Professor in Quaternary geology and soils. We seek an outstanding teacher and researcher who can attract external funding and who will complement ongoing research in Quaternary geology, environmental geology, surficial processes, and other areas in the Department and in related departments and programs on campus. Teaching responsibilities will involve three courses per year including a rotation in one of our general education courses (Introduction to Environmental Science). Upper-level undergraduate/graduate courses will include Modern and Ancient Soils, Glacial and Pleistocene Geology, and other appropriate subjects depending on the candidate's expertise. All applicants should have the basic qualifications, which are a Ph.D. in hand by August 16, 2000 and a record of teaching and research in Quaternary geology and soils. Additional expertise in geoarchaeology, Quaternary geochronology, quantitative methods, or other sub-fields is desirable. Women and minorities are encouraged to apply. Applicants should send a complete resume (including a bibliography and statement of teaching and research interests) and have three letters of recommendation sent to: Dr. Richard G. Baker, Search Committee Chair, Department of Geology, University of Iowa, Iowa City, Iowa 52242-1379 (Phone: 319-335-1827; fax: 319-335-1821; e-mail dick-baker@uiowa.edu). Screening begins December 1, 1999. The University of Iowa is an affirmative action-equal opportunity employer.

ASSISTANT PROFESSOR
DEPARTMENT OF GEOLOGY
BALL STATE UNIVERSITY, MUNCIE, INDIANA

Tenure-track position with interest in global environmental geology, low temperature geochemistry, and/or paleoclimatology available August 18, 2000. Responsibilities: teaching courses in geochemistry and environmental field methods or paleoclimatology along with courses in general education, such as physical, environmental geology, and/or oceanography; developing a program of research; advising student research at the graduate and undergraduate levels. Minimum qualifications: doctorate completed by August 1, 2000; college teaching and/or professional experience with teaching interest in geochemistry. Preferred qualifications: doctorate in geology, college teaching and/or professional experience; demonstrated teaching abilities and effective interaction with other faculty and students on individual projects and research; records supporting quality of teaching, research, and/or professional performance; interest in teaching several of the following: geochemistry, environmental field methods, paleoclimatology, and general education courses such as physical, environmental geology, and/or oceanography; interest in teaching and perhaps directing the summer five-week field mapping course currently taught in Montana and Wyoming; experience and knowledge in earth science education methods; research area that would enhance the department's course offerings and research. Send statement of teaching and research interests, including how research might be developed to include students, especially undergraduates; vitae; names of at least three references; and transcript of highest degree earned to: Chairperson of Search Committee, Department of Geology, Ball State University, Muncie, IN 47306. Review of applications will begin November 15, 1999, and will continue until the position is filled. Additional information about the position may be obtained by communicating through the department website (www.bsu.edu/geology).

Ball State University is an equal opportunity, affirmative action employer and is strongly and actively committed to diversity within its community.

ASSISTANT PROFESSOR
IN VERTEBRATE PALEONTOLOGY

The Department of Geoscience at the University of Iowa invites applications for a full-time, tenure-track Assistant Professorship in vertebrate paleontology, preferably one specializing in the Late Cenozoic. The appointment will begin in August 2000. We seek an outstanding researcher and teacher whose approach is both quantitative and specimen-based, and who will work with other faculty to improve our strong graduate program in paleontology and quaternary geology. In addition to developing an active, externally-funded program of research, the successful candidate will be expected to teach three courses per academic year. These will include: (1) an upper-level undergraduate/ graduate course in vertebrate paleontology, (2) a general education course related to fossil vertebrates, and (3) a graduate seminar in paleontology. He/she will also be expected to contribute both to our Paleontology Repository as well as to new departmental initiatives in the environmental sciences and climate change. Applicants should have a Ph.D. in hand by August 16, 2000. Women and minorities are especially encouraged to apply. Applicants should send a complete resume (including a bibliography and statement of teaching and research interests) and have at least three letters of recommendation sent to: Search Committee Chair (Vertebrate Paleontology), Department of Geoscience, University of Iowa, Iowa City, IA 52242-1379 (phone: 319/335-1818; Fax: 319/335-1821). Screening of candidates begins December 1, 1999, and will continue until the position is filled. The University of Iowa is an affirmative action – equal opportunity employer.

PETROLOGY
BOWLING GREEN STATE UNIVERSITY

The Department of Geology invites applications for a tenure-track position at the Assistant Professor level starting August 2000. We seek a petrologist with specialization in some area of economic geology, which may include ore deposits, environmental remediation, or industrial minerals. The successful applicant will be expected to combine a commitment to excellence in undergraduate- and graduate-teaching with a productive research program including external funding. Teaching duties will include field geology, petrology in a team-taught mineralogy/petrology/geochemistry course, introductory geology, and advanced courses in the candidate's specialty. The successful candidate will teach in the Summer (field geology) with a commensurate reduction in teaching in either the Fall or Spring semester.

Department facilities include AAS, XRD, CL, USGS-type fluid inclusion stage, mineral kinetics and rock mechanics lab, geochemistry labs, complete rock preparation facilities, extensive field equipment including coring equipment and field vehicles, and exceptional computing facilities including UNIX workstations. A Ph.D. is required at the time of employment. Applications, including a complete resume, statements of research and teaching interests, and three current original letters of recommendation, should be sent to: Chair, Faculty Search Committee, Department of Geology, Bowling Green State University, Bowling Green, OH 43403. A transcript will be required at the time of hire. Completed applications must be postmarked by December 31, 1999. Bowling Green is an AA/EO employer, and encourages applications from minorities, women, veterans, and persons with disabilities. The Department is responsive to the needs of dual-career couples. For more information, please visit our website at: http://www.geoserv01.bgsu.edu.

UNIVERSITY OF NEBRASKA
COFFMAN CHAIR IN SEDIMENTARY GEOLOGY

The Department of Geosciences of the University of Nebraska-Lincoln invites applications for an associate or full professor appointment as the Mr. and Mrs. J. B. Coffman Chair in Sedimentary Geology. We seek an outstanding geoscientist with a solid record of scholarly achievements who is well versed in quantitative approaches to sedimentary geology. The successful candidate will be expected to conduct a vigorous program of research and to participate in teaching and other academic activities appropriate for a senior faculty member at the University of Nebraska-Lincoln.

The University of Nebraska-Lincoln is a AAU, Research-I land-grant institution with a distinguished tradition of research in all the major disciplines. It has approximately 23,000 students and is designated as the principal research and graduate institution in the state.

The Department of Geosciences currently includes 14 full-time faculty and seven part-time faculty shared with other UNL units, and has strong collaborative associations with the State Museum, Conservation and the Survey Division, and the School of Natural Resource Sciences. The Department has a solid undergraduate program and approximately 40 graduate students (Masters and Ph.D.). For further information about the Department, see our web site at http://www.unl.edu/geology/geohome.html. Questions concerning the position or the Department of Geosciences can be addressed to the Department Chair (Norman D. Smith) by telephone (402-472-2663) or email (nsmith3@unl.edu). Applicants should send a letter of interest, current resume, and the names and addresses of at least four references to: Professor David Loope, Chair, Coffman Chair Search Committee, Dept. of Geosciences, 214 Bessey Hall, Lincoln, NE 68588-0340.

The review of applications will begin December 6, 1999, and continue until the position is filled. The University of Nebraska-Lincoln is committed to a pluralistic campus community through Affirmative Action and Equal Opportunity and is responsive to the needs of dual career couples. We assure reasonable accommodation under the Americans with Disabilities Act; contact David Loope at 402-472-2647 for assistance.

ASSISTANT PROFESSOR / UNIVERSITY OF OREGON
ENVIRONMENTAL GEOCHEMISTRY

The Department of Geological Sciences and the Environmental Studies Program invite applications for an entry-level tenure-track position to begin in Fall 2000. We seek an individual who applies geochemical or isotopic techniques to fundamental problems in environmental geology, e.g., paleoclimate, hydrogeology, global change, or environmental degradation.

The successful candidate will be expected to develop an academically-oriented research program and to contribute teaching to both the Environmental Studies Program and the Department of Geological Sciences. Founding of an analytical lab is also encouraged.

Completion of the Ph.D. is required. Applicants should send a curriculum vitae, statement of research and teaching interests, including discussion of potential contributions, to both Environmental Studies and Geological Sciences, and the names, postal and email addresses, and telephone numbers of three suitable referees to: Geochemistry Search Committee, Department of Geological Sciences, 1272 University of Oregon, Eugene OR 97403-1272. We will begin reviewing completed applications December 1, 1999, and will continue until the position is filled.

The University of Oregon is an equal opportunity/affirmative action institution committed to cultural diversity and compliance with the Americans with Disabilities Act.

TENURE TRACK FACULTY POSITION
IN GEOSCIENCES, UNIVERSITY OF VIRGINIA

The Department of Environmental Sciences at the University of Virginia invites applications for a tenure-track assistant professorship in geosciences. The Department is an interdisciplinary community of process-oriented scientists representing atmospheric sciences, ecology, geosciences and hydrology. The department offers B.A., M.S., and Ph.D. degrees. We strongly encourage prospective candidates to review our departmental web site (http://www.evsc.virginia.edu/) prior to applying.

We encourage applications from scientists whose research and teaching strengths and interests show promise for capitalizing on the unique interdisciplinary nature of our department, and to build upon our existing strengths in low temperature geochemistry and geomorphology in particular. Examples include, but are not limited to, landscape-scale geomorphic processes, field-oriented coastal and estuarine sedimentary processes, geochemical processes in soils and sediment, environmental geochemistry and geochronology.

The successful candidate will be expected to develop outstanding programs in research and teaching at both the undergraduate and graduate levels and to participate in teaching our undergraduate core course in Physical Geology. Applicants must show demonstrated excellence in their research and a strong commitment to quality teaching.

Applicants should include one-page statements on their research and teaching interests and experience, a curriculum vitae, and names and contact information of three references. The application deadline is December 15, 1999. Applications should be sent to: James N. Gal-

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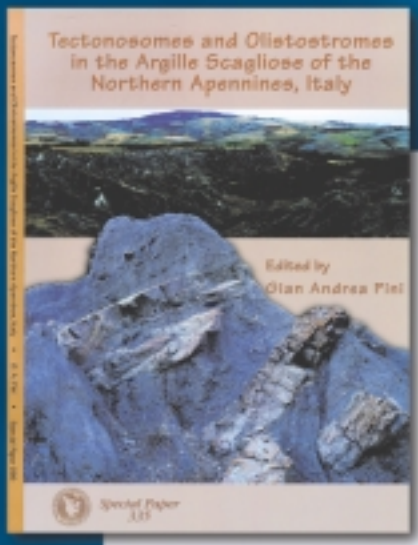
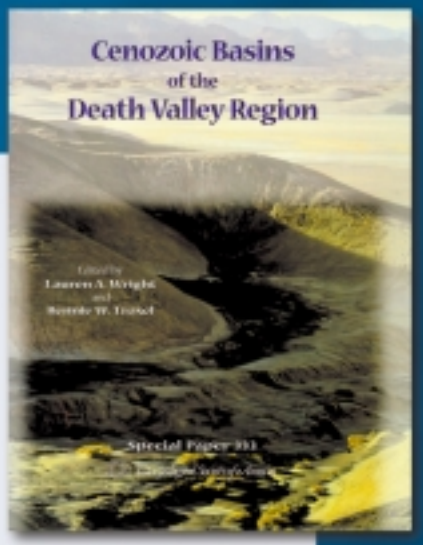


Tectonosomes and Olistostromes in the Argille Scagliose of the Northern Apennines, Italy

by G. A. Pini, 1999

Every geologist interested in melanges and in the evolution of orogenic belts will find this profusely illustrated volume valuable. A summary of the geology of the northern Apennines familiarizes the reader with this classic orogen. Field and laboratory studies reveal new information on the origin of the *argille scagliose* — scaly clays — in their type area in the northern Apennines of Italy. These stratally disrupted rocks, with prevailing block-in-matrix fabric, have been regarded for more than a century as gravitationally induced, chaotic assemblages. This 73-page volume includes a discussion of criteria for subdividing the *argille scagliose*, at both map and outcrop scales, into either strongly deformed stratigraphic units—tectonosomes, or sedimentary bodies emplaced by mass flow—olistostromes. Evidence shows that olistostromes mostly were derived from the tectonosomes. Debris flows and avalanches and, possibly, mud diapirism have contributed to the final character of the olistostromal bodies.

SPE335, 73 p., ISBN 0-8137-2335-3, $25.00, Member price $20.00



Cenozoic Basins of the Death Valley Region

edited by L. A. Wright and B. W. Troxel, 1999

The first symposium on the Cenozoic basins of the Death Valley region included 16 papers that provide a major updating on the structural and stratigraphic features and chronology of the principal basins. The 26 authors address the role of each basin in the tectonic evolution of the Death Valley extended terrane. Featured are: the transition from broad paleotopography of Oligocene and early Miocene time to the environment of the present basins and ranges; evidence for the magnitude and timing of displacement on the major strike-slip and normal faults that have shaped Death Valley and the surrounding region; the interrelated late Cenozoic histories of the Tecopa basin and the basins of central and southern Death Valley; and analysis of gravity anomalies in detecting the three-dimensional geometry of the basins and the thickness of the unexposed parts of the basinal successions.

SPE333, 392 p., ISBN 0-8137-2333-7, $55.00, Member price $44.00

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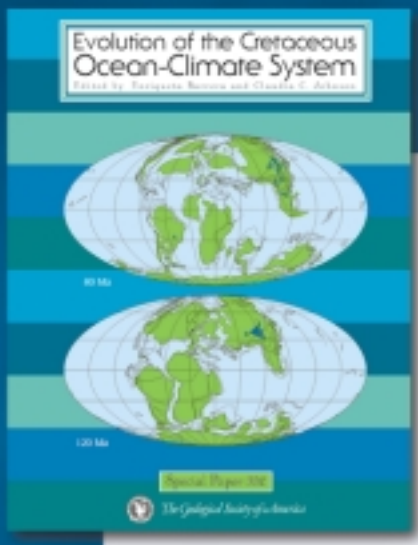

Evolution of the Cretaceous Ocean-Climate System

edited by E. Barrera and C. C. Johnson, 1999

The *Evolution of the Cretaceous Ocean Climate System* is the latest GSA volume focusing on an integrated systems approach to understanding the Cretaceous greenhouse world. This state-of-the-science research brings together the latest interpretations of data and models from both the marine and continental realms. Syntheses and specialized papers by more than 21 contributors highlight significant events or processes in the evolution of Cretaceous ocean-climate and biological systems, from a regional to a global scale. In the forefront of Cretaceous research, the volume will stimulate ongoing vigorous debate among concerned scientists from such diverse disciplines as marine biology, sedimentology, and tectonics.

SPE332, 446 p., ISBN 0-8137- 2332-9, $84.00, Member price $67.20

Sales:

P.O. Box 9140
Boulder, CO 80301-9140

The Geological Society of America

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loway, Professor and Chair, Department of Environmental Sciences, Geosciences Search Committee, University of Virginia, Clark Hall, Charlottesville, VA 22903. Tel. 804-924-0561.

We encourage applications from under-represented groups. The University of Virginia is an Equal Opportunity/Affirmative Action Employer.

UNIVERSITY OF FLORIDA

The Department of Geology invites applications for a tenure-track assistant professor position in the general area of organic geochemistry to begin with the 2000-2001 academic year. Possible areas of specializaiton include: biogeochemistry, environmental geology, astrobiology, paleoceanography, etc. Preference will be given to quantitative, process oriented scientists who will develop vigorous, innovative research programs, and who have a strong commitment to teaching. More information on the Department is available at web.geology.ufl.edu. Applicants should send a letter of interest, including a statement of research and teaching goals, a curriculum vitae, and the names and addresses of three references by December 15, 1999 to: Dr. Paul A. Mueller, Department of Geological Sciences, 241 Williamson Hall, Box 112120, University of Florida, Gainesville, FL 32611, (352)392-2231, fax 352-392-9294 (mueller@geology.ufl.edu).

The University of Florida is an equal opportunity-employer; qualified women and minorities are especially encouraged to apply.

TWO FACULTY POSITIONS
CALIFORNIA STATE UNIVERSITY, FULLERTON
GEOPHYSICIST AND HYDROGEOLOGIST

The Department of Geological Sciences, California State University, Fullerton, invites applications for two tenure-track positions that will be filled at the rank of Assistant Professor, starting August, 2000. Applicants must have a primary interest in teaching and achieving excellence in teaching and a commitment to developing an externally-funded research program that includes undergraduate and graduate students. Responsibilities will include limited involvement in professional activities, outreach, and university and community service. Additionally, the successful applicant will have the following credentials and capabilities:

Geophysicist: a Ph.D in geology or geophysics (degree must be in-hand by August 15, 2000); expertise in the use of geophysical methods to solve geologic problems; an interest and potential for developing intradepartmental collaborative research.

Teaching responsibilities will include, but not be limited to, physical geology, earth's interior, applied geophysics, earthquake seismology, and graduate courses in the new faculty member's area of expertise.

Hydrogeologist: a Ph.D. in geology or hydrogeology (degree must be in-hand by August 15, 2000); a field-based orientation with experience in groundwater modeling; industrial experience and/or a potential for developing working relationships with local hydrogeology consulting firms.

Teaching responsibilities will include, but not be limited to, physical geology, hydrogeology and field hydrology, and graduate courses in the new faculty member's area of expertise. The successful applicant will be expected to teach our summer hydrology field camp at Mammoth Lakes, California. In addition, the department is interested in someone with experience in G.I.S. and/or remote sensing.

Salary and benefits for both positions will be competitive and commensurate with the appointee's qualifications.

CSU Fullerton is a large university dedicated to the preeminence of learning. Located 22 miles southeast of metropolitan Los Angeles, Fullerton is a full-service city renowned for its unique mix of residential, commercial and industrial, educational, and cultural environments which provide residents with an outstanding quality of life. The Department has seven full-time faculty with expertise in stratigraphy, volcanology, igneous petrology, Quaternary geology, structural geology, engineering geology, and earth science education. The nearby Los Angeles Basin, Peninsular and Transverse Ranges, Mojave Desert, Sierra Nevada, and Basin and Range geological provinces provide abundant opportunities for field-based research. We have about 50 undergraduate majors and will be implementing a masters degree program soon. Additional information is available through our web page at http://geology.fullerton.edu/geology/.

To apply, please send the following: (1) a detailed curriculum vitae; (2) a letter telling us about yourself and detailing how you meet the qualifications outlined above; (3) a statement about teaching that includes a discussion of relevant course work and/or experience in preparation for teaching, a list of courses you would feel comfortable teaching, and a statement of your teaching philosophy; (4) a statement of your future research plans and goals; and (5) the names, addresses, phone numbers, and e-mail addresses of at least three references familiar with your teaching and research potential.

Send application to: Dr. Brady Rhodes, Chair, Search Committee, Department of Geological Sciences, California State University, P.O. Box 6850, Fullerton, California 92834-6850. Applications will be accepted until November 15,1999. Applications received after this date will be reviewed only if the position is not filled from the original pool of applicants.

California State University, Fullerton is an Affirmative Action/Equal Opportunity Employer. All personnel policies conform with the requirements of Executive Order 11246, the Americans with Disabilities Act (ADA) of 1990, Title IX of the Higher Education Amendments of 1972 and other federal regulations regarding nondiscrimination.

ASSISTANT PROFESSOR
IN EARTH SCIENCE EDUCATION
UNIVERSITY OF NORTHERN COLORADO

Assistant Professor in Earth Science Education. Requires a doctorate (or ABD) and expertise in science education and the earth sciences. Successful K-12 teaching experience is highly desirable. Review of applications begins December 1, 1999. Applications after this date may be accepted. Contact Dr. William Nesse, Department of Earth Sciences, Campus Box 100, University of Northern Colorado, Greeley, CO 80639, (970) 351-2830, wdnesse@bentley.unco.edu, http://www.met.unco.edu/.

TENURE-TRACK FACULTY POSITION
EDINBORO UNIVERSITY OF PENNSYLVANIA

The Department of Geosciences at Edinboro University seeks applications for a Tenure-Track Assistant Professor (Instructor) position for a person with expertise in soils, paleolimnology and/or Quaternary geology beginning August 2000. Responsibilities: Teach Stratigraphy and Sedimentation, introductory geology courses and upper level courses in area of expertise. Qualifications: Ph.D. in geology expected (ABD considered). Preference given to applicant who can integrate field experiences and applied technology into teaching, and develop a research program involving undergraduates. Demonstration of teaching skills is an interview requirement. Salary and benefits are competitive.

In accordance with the terms of the collective bargaining agreement between the State System of Higher Education and APSCUF, you may be assigned to perform work at off-campus sites and/or provide instruction through distance education.

Specifiy Position #170-0872 and submit a letter of application, resume, copies of transcripts and names/addresses/telephone numbers of three current references to Dr. Eric Randall, Dean of Science, Management and Technologies, Department GSA, Edinboro University of PA, Edinboro, PA 16444. Application Deadline: January 15, 2000. Visit our home page at http://www.edinboro.edu/cwis/geosci/htdocs/geohome.html. AA/EOE/M/F/V/D.

GEOPHYSICIST
ILLINOIS STATE GEOLOGICAL SURVEY

The Illinois State Geological Survey seeks an associate scientist with a minimum of 4 years experience following a master's degree or a new Ph.D. in geophysics, geology, or related field. Master's degree with 10 years related experience or a Ph.D. with 8 years is preferred. This scientist will provide geophysical expertise (especially shallow, land-based seismic reflection data acquisition, processing, and interpretation) to a three-dimensional geologic mapping program in glacial terrain of the Great Lakes states. A significant component of this position includes working with an interdisciplinary team of geoscientists in mapping 1:24,000-scale quadrangles. Previous experience in acquiring and interpreting geophysical data to characterize glacial sediments and writing scientific reports on research conducted is required. The successful candidate will also be expected to participate in other Survey research and service programs including, for example, groundwater and engineering geology, geologic hazards, neotectonics, and geology of rivers, lakes, and wetlands. A broad background in applying various geophysical techniques to solve problems in (or to map) shallow, unconsolidated sediments is essential. Salary commensurate with education and experience. Closing date: 12/15/99. For application form, please contact walston@isgs.uiuc.edu or 217-244-2401, Human Resources, Illinois State Geological Survey, 615 East Peabody Drive, Champaign, IL 61820. www.isgs.uiuc.edu. AA/EEO/ADA Employer.

ASSISTANT PROFESSOR
SOUTHERN METHODIST UNIVERSITY
DEPARTMENT OF GEOLOGICAL SCIENCES

The Department of Geological Sciences at Southern Methodist University invites applications for a tenure-track position in surficial processes, including geomorphic, sedimentary, and/or neotectonic approaches. We seek creative applicants with an excellent understanding of fundamental physical principles and processes and a demonstrated ability to apply that understanding to important problems in the earth sciences. The department has strong programs in geology and geophysics and is looking for an individual who will complement strengths in geochemistry, petrology/tectonics, planetary dynamics, and terrestrial paleontology. We anticipate making the appointment at the assistant professor level with the appointment to begin in August, 2000. Applicants must have a Ph.D. in a relevant specialization at the time of appointment. The successful candidate must have a firm commitment to excellent teaching at all levels and must establish an externally funded research program in his or her field of expertise. The committee will begin its review of the applications on or about December 1, 1999. To ensure full consideration, application should be postmarked by December 1, 1999, but the committee will continue to accept applications until the position is filled. Candidates should submit their curriculum vitae, names and addresses of three references, and a written statement of teaching and research interests to: Dr. Lee McAlester, Chair, Department of Geological Sciences, P.O. Box 0395, Southern Methodist University, Dallas, TX 75275-0395. Email: geol@mail.smu.edu. Web Site: http://www.geology.smu.edu.

The Committee will notify applicants of its employment decision after the position is filled. SMU will not discriminate on the basis of race, color, religion, national origin, sex, age, disability, or veteran status.

ENVIRONMENTAL GEOCHEMIST
MARY WASHINGTON COLLEGE

The Department of Environmental Science and Geology seeks applications for a full-time, tenure-track position, at the rank of Assistant Professor, to begin in the fall of the 2000-2001 academic year. The Department seeks an individual with expertise in low-temperature geochemistry with special emphasis on environmental applications. Research experience on marine or estaurine environments would be considered highly desirable. The successful candidate will also be expected to teach courses in physical, historical, and marine geology. The ability to offer an introductory course in paleontology would be an asset. A completed Ph.D. is required for this position. The Department strongly encourages faculty to mentor undergraduate students who wish to engage in independent research projects.

Applicants should send a one-page letter of application, statements of teaching and research interests, detailed c.v., undergraduate and graduate transcripts, and the names and addresses of three references to Office of Human Resources, Chair of the Search Committee, Department of Environmental Science and Geology, Mary Washington College, Box 615, Fredericksburg, VA 22401-5358. Deadline for receipt of applications is December 15, 1999 by 5:00 p.m. Postmarks will not be honored. Visit the department web page at http://www.departments.mwc.edu/eesg/www/. Mary Washington College is a member of the council of Public Liberal Arts Colleges (COPLAC), a national alliance of leading liberal arts colleges in the public sector. Mary Washington College is deeply committed to affirmative action and encourages minorities and women to apply.

MINERALOGIST / GEOSCIENCE EDUCATION
UNIVERSITY OF WISCONSIN–MILWAUKEE

The Department of Geosciences at the University of Wisconsin-Milwaukee anticipates opening a position in Mineralogy/Geoscience Education at the level of tenure-track Assistant Professor or tenured Associate Professor. Applicants must hold a Ph.D. in geology, and have

demonstrated research experience in mineralogy and/or geoscience education. Post-doctoral experience is desirable. The successful candidate is expected to conduct an active research program, and teach undergraduate courses in mineralogy, (on an interim basis) introductory petrology, and related subject areas. Information is available on-line regarding the Department at http://www.uwm.edu/dept/geosciences/.

To be considered, a curriculum vitae with a research plan, an outline of teaching philosophy, and three letters of recommendation must be mailed to Mark Harris, Chair, Department of Geosciences, University of Wisconsin-Milwaukee, P.O. Box 413, Milwaukee, WI 53201 (fax: 414-229-5452; E-mail: mtharris@uwm.edu), postmarked by November 15, 1999. The University of Wisconsin-Milwaukee is an Equal Opportunity/Affirmative Action Employer.

FACULTY AND STAFF POSITIONS
MONTCLAIR STATE UNIVERSITY NJ

The Earth and Environmental Studies Department invites applications for a tenure-track, Assistant or Associate Professor position starting September 2000 and a full-time Laboratory Specialist position starting as early as December 1999.

Faculty position requires research and teaching expertise in one or more of the following areas: environmental geology (other than hydrogeology), coastal and estuarine environmental management, waste and pollution management and/or environmental remediation. Excellence in teaching, the pursuit of a funded research program, and contribution to the development of an interdisciplinary environmental management doctoral program is expected. Candidates should have completed a doctorate in an appropriate field prior to September, 2000. A well-established record of research and teaching will be required for appointment at the associate rank.

Laboratory Specialist duties include coordinating use and maintenance of: department laboratories (including GIS teaching and research laboratories); field and laboratory equipment; collections and supplies. Duties also include training and supervision of student assistants. A bachelor's or master's degree with 2–5 years of relevant experience and knowledge of ArcView and ArcInfo GIS software are required.

The department of 12 full-time faculty offers geoscience, geography and environmental studies in graduate and undergraduate degrees and is well-equipped for applied field research with digital seismic, ground penetrating radar, resistivity, GPS surveying, and tide/current monitoring equipment. Separate teaching and research computer labs support GIS, remote sensing and groundwater modeling software. Other labs support X-ray diffraction, analytical geochemistry, hydrologic modeling, rock and sediment preparation and SEM. Further information about the department and positions can be obtained on our Web page at http://www.csam.montclair.edu/earth/eesweb.

Applicants for either position should send cover letter, curriculum vitae and three letters of recommendation. Faculty applicants should also include a statement of professional goals, research interests and teaching philosophy. Apply to: Faculty Search Committee (V#21) or Staff Search Committee (V#045), c/o Dr. Jonathon M. Lincoln, Chair, Earth and Environmental Studies Dept., Montclair State University, Upper Montclair, NJ 07043. Screening begins immediately and continues until the positions are filled. Montclair State University is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply. Subject to available funding.

LOW TEMPERATURE / AQUEOUS GEOCHEMIST
THE COLORADO COLLEGE

The Department of Geology announces a tenure-track position for a low temperature/aqueous geochemist. Appointment will be at the assistant professor level to begin August 2000. Ph.D. is required.

A primary responsibility will be to design an innovative 2nd-year course in Geochemistry/Mineralogy that includes components of crystal chemistry and silicate structures, an introduction to optics, and water-rock interactions. Teaching responsibilities will also include LT or Aqueous Geochemistry, Introductory Geology, and Hydrogeology. Other courses will depend on candidate's areas of expertise and interest.

Ability to establish a research program and to supervise undergraduate research is essential. Interaction with the Environmental Sciences program is desirable, as is participation in other interdisciplinary programs such as Southwest Studies, American Ethnic Studies, and Women's Studies. Candidates who can contribute to the diversity of the Colorado College curriculum and community are particularly encouraged to apply and to indicate how they might make such contributions.

Applicants must be committed to high-quality innovative undergraduate teaching, including field-oriented courses. The Block System of education at Colorado College, in which professors teach, and students take, only one course at a time for 3-1/2 weeks. lends itself to field- and project-based teaching. The Department has five tenure-track faculty and four staff positions, a large group of dedicated majors, and excellent field, laboratory, and computer facilities for teaching and research.

Send curriculum vitae and a statement of teaching and research interests, and have three letters of reference sent, to: Eric Leonard, Chair, Department of Geology, Colorado College, Colorado Springs, CO 80903. Closing date for applications is December 21, 1999.

The Colorado College welcomes members of all groups, and reaffirms it commitment not to discriminate on the basis of race, color, age, religion, sex, national origin, disability, or sexual orientation in its educational programs, activities, and employment policies. Equal Opportunity Employer.

FACULTY POSITION
DEPARTMENT OF GEOLOGY & GEOPHYSICS
UNIVERSITY OF CALIFORNIA AT BERKELEY

The Department of Geology & Geophysics invites applications for a tenure-track professorship, effective July 1, 2000. Areas of interest identified by the department include: petrology and volcanic processes; aqueous and environmental geochemistry; sedimentary environments and processes; biogeochemistry and geomicrobiology.

Other fields of specialization will also be considered. We anticipate filling this position at the Assistant Professor level, but appointment at higher levels may be considered for exceptional candidates. Applicants should send their curriculum vitae, statements of research and teaching interests, reprints or preprints of up to three publications, and contact information (including e-mail addresses) for at least three references to: Search Committee, Department of Geology & Geophysics, University of California at Berkeley, 307 McCone Hall, Berkeley, California 94720-4767, no later than January 11, 2000. The University of California at Berkeley is an Equal Opportunity / Affirmative Action Employer.

ASSISTANT PROFESSOR
DEPARTMENT OF GEOLOGY
UNIVERSITY OF KANSAS

Full-time, tenure-track, academic year appointment beginning August 18, 2000. The Department of Geology seeks a hydrogeologist who can interact with the strong physical and chemical hydrogeology activities at the University of Kansas and build strength in the microbial hydrogeology area. Duties include: Teaching hydrogeology and general geology courses; developing an active research program; advising graduate students; and providing service to the Department, the University, and the profession. Required qualifications: Ph.D. degree in geology or closely related field with emphasis in hydrogeology; ability to establish a research program in microbial hydrogeology; ability to teach introductory geology courses, hydrogeology, and contaminant transport; effective communication skills; eligibility to work permanently in the U.S. Preferred qualifications: research experience in contaminant transport and microbial hydrogeology; evidence of research beyond the Ph.D.; demonstrated ability and competence in teaching. Application materials include: a letter of application outlining research and teaching interests; a complete resume; names, addresses, and telephone numbers of at least three persons who can be contacted for letters of reference, and transcripts of graduate work. Review of completed applications will begin January 17, 2000 and will continue until the position is filled. EO/AA employer. For a complete position announcement, or application contact: Carl D. McElwee, Department of Geology, University of Kansas, 120 Lindley Hall, Lawrence, Kansas 66045-2124, 785-864-2728, E-mail: cmcelwee@ukans.edu. For additional information about the Department of Geology and the University of Kansas, visit our web site at www.geo.ukans.edu. This position is contingent on budgetary approval.

ASSISTANT PROFESSOR
PETROLOGY OR THERMOCHRONOLOGY
UNIVERSITY OF KANSAS

The Department of Geology at the University of Kansas invites applications for a tenure-track position of Assistant Professor in the field of petrology or thermochronology. The appointment will begin on August 18, 2000, with a later starting date possible. We are seeking an individual with expertise in tectonic applications of geochemistry, thermochronology, or geochronology. Duties include teaching at the undergraduate and graduate levels, developing and maintaining an active program of research, working with other faculty members to develop a stronger program in tectonics, and providing professional service to the Department, the University, and the profession.

Applicants must have a completed Ph.D. degree by the starting date. Candidates may be required to demonstrate eligibility to work in the U.S. A letter of application, a complete resume, graduate-school transcripts, and names and contact information of at least three persons who can be contacted for letters of reference, should be sent to J. Douglas Walker, Search Committee Chairman, Department of Geology, University of Kansas, 120 Lindley Hall, Lawrence, Kansas 66045-2124 (tel: 785-864-2735; fax: 785-864-5276; e-mail jdwalker@ukans.edu). Upon receipt of a letter of inquiry, we will send a detailed description of the position. Review of completed applications will begin January 15, 2000, and will continue until the position has been filled. EO/AA employer. The University is committed to increasing the ethnic and gender diversity of its faculty, and we strongly encourage women and minority candidates to apply. This position is contingent on budgetary approval.

DEPARTMENT CHAIRMAN
GEOLOGY, GEOGRAPHY AND PHYSICS
UNIVERSITY OF TENNESSEE AT MARTIN

The Department of Geology, Geography and Physics invites applications for a tenure-track position at the rank of Associate or Full Professor to serve as Chair of the department beginning July 1, 2000. The Department is a multi-discipline unit with ten faculty members supporting service courses and a Geosciences major with concentrations leading to degrees in Geology, in Geography, and in Travel/Tourism (approximately 40 majors). The Department also offers a minor in Physics. The Department invites candidates for the position of Department Chair from any of the disciplines represented in the Department. The Department Chair will be expected to teach half-time. A background to teach introductory geology courses and upper division courses of mineralogy and igneous/ metamorphic petrology is preferred (other courses will depend on expertise and demand). The successful candidate will be expected to provide evidence of teaching and administrative experience with a strong commitment to undergraduate education. Administrative duties include: budget development and oversight, personnel evaluation for faculty and staff, curriculum management and communicating administration policies and decisions. Other expectations associated with the university mission include assignments such as: research (involving undergraduate students where possible), advising departmental majors and pre-professional students, serving on committees and public service. The Search Committee will begin review of applications on December 3, 1999, and the search will continue until the position is filled. Application should include a letter of application, curriculum vitae, copies of transcripts and a list of references. Mail application to: Professor W. T. McCutchen, Chair of Search Committee, Department of Geology, Geography, and Physics, University of Tennessee at Martin, Martin, TN 38238 (E-mail: tmccutchen@utm.edu, Telephone 901-587-7437). UTM is an EEO/AA/Title VI/ Title IX/ Section 504/ADA/ADEA Employer. We are particularly interested in receiving nominations from women and minority candidates.

FACULTY POSITIONS IN ATMOSPHERE, OCEAN, CLIMATE DYNAMICS AT YALE UNIVERSITY

The Department of Geology and Geophysics at Yale University announces a search for several ladder faculty positions in the general area of atmosphere, ocean, and climate dynamics. We seek both junior and senior applicants with records of creative research in subject areas that improve understanding of modern atmospheric and oceanic processes and/or the evolution of the earth's climate on geologic time scales. Areas of special interest

Classifieds *continued on p. 38*

SAGE REMARKS

Using the Method of Multiple Working Hypotheses as a Framework for Teaching Introductory Geoscience Courses

John Field*, *Green Mountain College, Poultney, VT 05764, jfield@greenmtn.edu*

The method of multiple working hypotheses ("The Method") was first presented by Chamberlin (1890) as a means of conducting scientific investigations without bias. By considering multiple hypotheses simultaneously, Chamberlin (1890) believed that an investigator would not favor a single idea that would tempt him or her to ignore contradictory evidence. While some question whether strict adherence to The Method is still practical in modern scientific investigations (Johnson, 1990), Spencer (1997) urges its use in undergraduate geology education. The value of The Method in general education courses was in some respects recognized by Chamberlin (1890) himself when he wrote, "the general application of this method to the affairs of social and civic life would go far to remove those misunderstandings, misjudgments, and misrepresentations which constitute so pervasive an evil in our social and political atmospheres" (p. 759 in the 1965 reprint). These words from over a century ago are remarkably consistent with an oft-stated goal of general education courses today: to develop an open-minded citizenry capable of critically analyzing diverse, sometimes contradictory, sources of information to reach informed decisions on important environmental, political, and social issues.

Recognizing the potential of The Method to develop informed, open-minded, critical thinkers, I use it as a framework for teaching introductory geology courses. Through this approach, students see that the information presented in class is not just a steady stream of isolated facts and truths handed down, but rather knowledge acquired through a standardized scientific procedure and supported by careful and repeated observations. I believe this approach better prepares science students to undertake unbiased scientific investigations in upper division courses (as well as in their careers) and allows nonscience students to appreciate how The Method (read open-mindedness) is of value in resolving problems in their everyday lives.

*Former address: Department of Geology, Western Washington University, Bellingham, WA 98225.

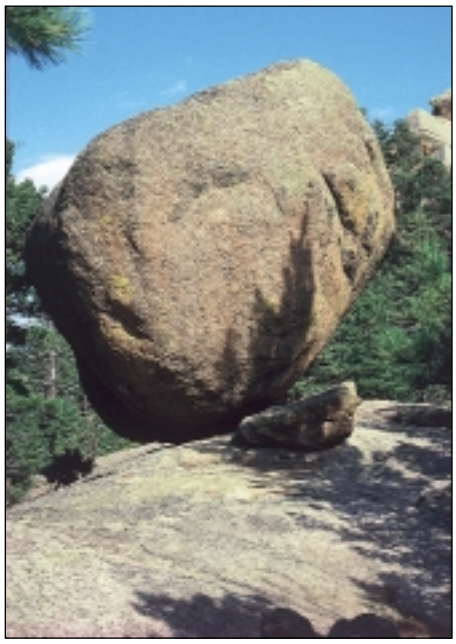

Figure 1. Photograph of large boulder near Pine, Colorado, used to generate multiple working hypotheses.

MULTIPLE WORKING HYPOTHESES ACTIVITY

I actively engage students in The Method through an interactive slide presentation that takes about 50 minutes. It begins with a slide of a large boulder perched precariously on a ridge top (Fig. 1). After I ask, "How did this form, or how did it get there?," the students generally respond with a long list of ideas, some more reasonable than others; e.g., it's a glacial erratic, a flood, landslide, windblown, or tsunami deposit, dinosaur poop (offered by a fourth grade class); it was erupted from a volcano, formed because of weathering or erosion, carved by humans, placed by giants or aliens from space. The list of multiple hypotheses provides an excellent departure point for a discussion on the nature and philosophy of science. I point out that their ideas are nothing more than guesses, or what scientists call hypotheses. I encourage students to come up with as many ideas as possible, and I greet each idea, crazy or not, with enthusiasm, because without outrageous hypotheses, some great scientific discoveries would not have been made. I inform the students that Wegener's hypothesis of continental drift and Bretz's idea that great floods created the channeled scablands of eastern Washington were initially greeted with great disdain and considered preposterous despite the evidence to support them. After listing student hypotheses on the board, I point out that the further investigation of some ideas is beyond the realm of science. The role of science is to discount certain ideas while garnering support for others. Hypotheses that cannot be tested or disproved are beyond the realm of scientific investigation (e.g., aliens from space). Before continuing the activity, I ask the students to bear in mind that the best explanation for the boulder's formation may be a combination of their ideas or an idea that has not yet been broached.

The next step in The Method is to collect data that support or refute the multiple working hypotheses under consideration. Although students are unable to make direct observations of the boulder, they are able to make observations vicariously by asking questions about it. When I do this activity with younger children, their initial questions tend to be about size. College students first focus on questions of location and composition. After the students learn that the boulder is about 25 ft (8 m) high, composed of granite, and found on a ridge top in the front range of the Colorado Rockies near Denver, I ask them if any hypotheses can be ruled out by this information. Students eliminate hypotheses such as a volcanic eruption, asteroid impact, and dinosaur poop, because of the inconsistent composition and/or size of the boulder.

With several viable hypotheses still remaining, students are encouraged to ask targeted questions that will either support or eliminate the remaining hypotheses. Eventually, a student asks the critical question: Is the boulder directly attached to the rock below? After informing the students that I believe the boulder is attached, I ask them which hypotheses this fact contradicts. I tell them that if one fact is inconsistent with the hypothesis, then the hypothesis can no longer be supported and must be disregarded or modified. This underscores the importance of multiple working hypotheses, because, as Chamberlin said, a scientist who is committed to a single hypothesis is reluctant to let go of this "intellectual child." Assuming that the boulder in Figure 1 is indeed attached to the rock below, the students then consider which hypotheses must be disregarded. Students realize that the boulder could not have been transported by a glacier, in a flood, or by rolling down the hill in a landslide. This single piece of information strongly supports the explanation that the boulder formed by in situ weathering and erosion. Once a single hypothesis is identified as the most likely explanation, a scientific investigation can continue to gather additional information

Figure 2. Boulder formed by in situ weathering in northern Portugal. Note congruence of the boulder with intersecting joints.

Figure 3. Trace fossils in the Middle Ordovician Bays Sandstone near Fincastle, Virginia.

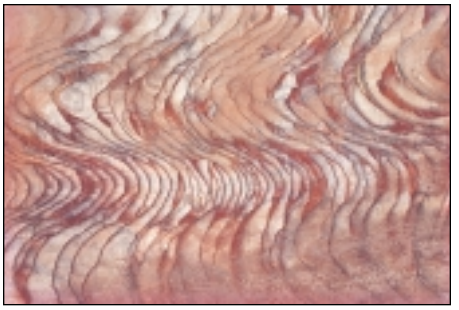

Figure 4. Liesegang banding exposed on sandstone cliffs in Petra, Jordan.

to further support that idea or answer related questions.

By showing students slides of additional large boulders formed in other ways (e.g., rock fall and glacial erratic) and quickly repeating the steps above, I impress upon the students that similar looking features will yield similar hypotheses to explain their formation. To identify the formation process for each boulder I've shown them, the students repeatedly return to the same critical question of whether the boulder is attached to the material below. I emphasize that as the answers to this and other key questions vary, so too do the conclusions that are reached—sometimes providing important clues to such phenomena as changes in climate, earthquake activity, and flood magnitude.

I end the activity by showing students a final boulder (Fig. 2), asking them to guess how it formed. Responses vary and are similar to the list of familiar hypotheses. Many of the students are surprised to discover that this boulder was also weathered in place. This emphasizes that you can never immediately be sure of something's origin, and you must follow The Method to accurately determine its origin.

I can provide copies of these and other slides to anybody interested in doing this activity, but you may have difficulty answering student questions, because of unfamiliarity with the location and character of the boulders. However, I believe this activity will work equally well with any picture or sample that elicits wonder, amazement, and a long list of possible hypotheses on how the feature formed. I have also used slides of trace fossils (Fig. 3) and Liesegang banding (Fig. 4).

FRAMING LECTURES AROUND THE METHOD OF MULTIPLE WORKING HYPOTHESES

After completing the above activity and variations on other science-process activities (Field, 1997) during the first week of class, I present much of the introductory geology content within the context of The Method. I constantly ask students to volunteer multiple explanations for natural phenomenon and patterns before explaining in detail the observations that support particular, sometimes multiple, explanations. These explanations are what we often accept as well-established theories or laws but that are rarely presented within a historic context that reveals the supporting observations and competing hypotheses of the time. I typically begin teaching a new topic or concept by having students make some initial observations of a particular phenomenon using slides, maps, or hand samples, and then I ask them a question designed to elicit multiple hypotheses (Table 1). While not all topics lend themselves to this approach, and no course should be so singular in focus, framing lectures around The Method does enliven what students often perceive as very dry material. For example, I cover material on the composition of Earth's interior by disproving my own outrageous hypothesis that it is composed of gold. While this hypothesis is consistent with initial observations that Earth's interior is denser than the crust, it becomes less and less tenable as seismic and astronomical information is presented that indicates the constraints on the density and composition of the crust. So that students will freely hypothesize explanations for observed phenomena, I prefer that they read the textbook after the relevant class rather than before, so their explanations for certain features are unfettered by information presented in the text.

ADVANTAGES

I believe that emphasizing the concept of multiple working hypotheses throughout an introductory geology course has the multiple benefits of increasing student involvement and interest in class while improving student appreciation for and understanding of science. Given the recent national attention on educational reform efforts, the value of The Method in science education is clearer

SAGE Remarks *continued on p. 38*

TABLE 1. OBSERVATIONS AND QUESTIONS USED TO FRAME SOME KEY INTRODUCTORY GEOLOGY TOPICS AND CONCEPTS AROUND THE METHOD

Concept	Observation	Question
Mineral composition, molecules	Mica peels into very thin sheets	What are minerals made of?
Crystal size	Igneous rock samples of varying grain size	Why does grain size vary?
Magmatic differentiation	Igneous rock samples of varying composition	Why are some rocks black (mafic), others gray (intermediate), and still others white (felsic)? Why aren't all igneous rocks the same?
Volcano types	Slides, videos of different volcanic eruptions	What controls how explosive a volcano is?
Metamorphic rocks	Slides, samples of gemstones	How do gemstones form, and why are they so rare?
Physical and chemical weathering	Grusified granite crushed by hand	What makes the rock rotten? What breaks it apart naturally?
Soils	Comparison of crushed rock and soil	How is rock transformed into soil?
Deserts, climate	Map showing distribution of world's deserts	Why are deserts found where they are?
Earth's interior	Earth's interior is denser than the crust	What is the composition of Earth's interior? Could it be composed of gold?
Continental drift*	Similar fossils on different continents	How did similar fossils end up on different continents?
Subduction*	Cross section of Benioff zone	Why do earthquake depths increase away from oceanic trenches?

*These are only two examples of a wealth of observations and questions related to the theory of plate tectonics.

SAGE Remarks *continued from p. 37*

than ever. As Chamberlin (1890) noted, multiple methods of instruction are needed to deal with varied learning styles, and "pedagogical inquiry in the past has very largely concerned itself with the inquiry, 'What is the best method?' rather than with ... 'What are the special values of different methods...?'" (p. 757 of the 1965 reprint). A focus on The Method in introductory geoscience courses should enable our students to more effectively resolve problems related to science, civic life, and educational reform.

Acknowledgments

The activity described above is an outgrowth of one done with a hand sample of Liesegang banding by W. D. Lowry, now professor emeritus at Virginia Tech. I thank him for this idea and my inspiration for geology that emerged from his introductory geology class.

References Cited

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CLASSIFIED ADVERTISING

Classifieds *continued from p. 35*

include atmosphere/ocean modeling; climate-system modeling; coupled air-sea interaction; dynamical meteorology and oceanography; glaciology; hydrology; remote sensing; and the physics, dynamics, and chemistry of clouds. New appointments at Yale in these areas will contribute to a broad emphasis in the Department on paleoclimatology, paleo-environments, and global change. Additional appointments in the Department will be made in areas of active tectonics and geomorphology, geochemistry, paleontology, and solid-earth geophysics. Closing date for applications is November 30, 1999.

We encourage applicants from historically disadvantaged ethnic, racial, and gender categories. Yale University is an equal-opportunity employer. Applicants should send a curriculum vitae, a statement of professional goals, and the names and addresses of three or more referees to: AOCD Search Committee, c/o Professor Danny Rye, Chair, Department of Geology and Geophysics, Yale University, P.O. Box 208109, New Haven, CT 06520-8109.

FACULTY POSITION IN GEOCHEMISTRY AT YALE UNIVERSITY

The Department of Geology and Geophysics at Yale University is starting a new multidisciplinary hiring initiative in earth science, which will include several ladder faculty appointments in the general area of geochemistry, starting as early as January, 2000. We invite applications from both junior- and senior-level candidates who will develop internationally recognized research programs in collaboration with present and future Yale geoscientists. The positions will include teaching at both undergraduate and graduate levels. All subfields will be considered, including, but not limited to: biogeochemistry, earth surface chemical processes, experimental geochemistry, mantle geochemistry, organic geochemistry, radiogenic and stable isotopes, and theoretical geochemistry. Closing date for applications is November 30, 1999.

We encourage applicants from historically disadvantaged ethnic, racial, and gender categories. Yale University is an equal-opportunity employer. Applicants should send a curriculum vitae, a statement of professional goals, and the names and addresses of three or more referees to: Geochemistry Search Committee, c/o Professor Danny Rye, Chair, Department of Geology and Geophysics,Yale University, P.O. Box 208109, New Haven, CT 06520-8109.

FACULTY POSITION IN SOLID-EARTH GEOPHYSICS AT YALE UNIVERSITY

The Department of Geology and Geophysics at Yale University is starting a new multidisciplinary hiring initiative in earth science, which includes a major expansion in solid-earth geophysics. To this end, we intend to fill several ladder faculty positions in solid-earth geophysics, either at the junior or senior level, starting as early as January 2000. We invite applicants who will develop internationally recognized research programs in collaboration with present and future Yale geoscientists. The positions will include teaching at both undergraduate and graduate levels. All subfields of solid-earth geophysics will be considered, including, but not limited to: geodesy, geodynamics, geomagnetism, mineral physics, rock and earthquake mechanics, and seismology. Closing date for applications is November 30, 1999.

We encourage applicants from historically disadvantaged ethnic, racial, and gender categories. Yale University is an equal-opportunity employer. Applicants should send a curriculum vitae, a statement of professional goals, and the names and addresses of three or more referees to: Solid-Earth Geophysics Search Committee, c/o Professor Danny Rye, Chair, Department of Geology and Geophysics, Yale University, P.O. Box 208109, New Haven, CT 06520-8109.

FACULTY POSITION IN ACTIVE TECTONICS AND GEOMORPHOLOGY AT YALE UNIVERSITY

The Department of Geology and Geophysics at Yale University announces a ladder faculty position, at either the junior or senior level, in the general area of active tectonics and geomorphology, starting as early as January, 2000. This position is part of a broad multidisciplinary hiring initiative in earth sciences at Yale, including the areas of the dynamics of the oceans, atmospheres, and climate; geochemistry; solid-earth geophysics; and paleontology. For the active tectonics and geomorphology search, we are particularly interested in finding candidates who relate the evolution of landforms to the forcing caused by tectonic and climate processes.

We also welcome applications from related fields, including but not limited to: geodynamics of landscape evolution, paleoseismology, structural geology, and tectonics. The successful candidate is expected to develop an internationally visible research program, and to teach at both the graduate and undergraduate levels.

The closing date is November 30, 1999. We encourage applicants from historically disadvantaged ethnic, racial, and gender categories. Yale University is an equal-opportunity employer. Applicants should send a curriculum vitae, a statement of professional goals, and the names and addresses of three or more referees to: Geomorphology Search Committee, c/o Professor Danny Rye, Chair, Department of Geology and Geophysics, Yale University, P.O. Box 208109, New Haven, CT 06520-8109.

FACULTY POSITION IN PALEONTOLOGY AT YALE UNIVERSITY

The Department of Geology and Geophysics at Yale University is starting a new multidisciplinary hiring initiative in earth science, which includes the strengthening of its program in paleontology. To this end, we intend to fill a ladder faculty position in paleontology, at either the junior or the senior level, starting September 2000. We invite applicants who will develop an internationally recognized research program in collaboration with present and future Yale geoscientists and bioscientists. The position will include teaching at both the graduate and undergraduate levels. All subfields of paleontology will be considered, including, but not limited to, biogeochemistry, biostratigraphy, event stratigraphy, evolutionary processes, functional morphology, macroevolution, origin of major groups/body plans, marine paleoecology, mass extinctions, paleobiogeography, paleoenvironmental analysis, systematics, or taphonomy. Closing date for applications is January 15, 2000.

We encourage applicants from historically disadvantaged ethnic, racial, and gender categories. Yale University is an equal-opportunity employer. Applicants should send a curriculum vitae, a statement of professional goals, and the names and addresses of three or more referees to: Paleontology Search Committee, c/o Professor Danny Rye, Chair, Department of Geology and Geophysics, Yale University, P.O. Box 208109, New Haven, CT 06520-8109.

VISITING FACULTY POSITIONS IN EARTH SCIENCES AT YALE UNIVERSITY

The Department of Geology and Geophysics at Yale University announces the opening of several visiting faculty positions. Applicants from all areas of earth science and all career levels are welcome to apply. The visiting positions are part of a major hiring initiative in earth sciences at Yale focused on rebuilding the size and strength of the department. We are looking for individuals who would enjoy contributing and interacting in a broad multidisciplinary department that includes active programs in atmospheres, oceans and climate; geochemistry; petrology; solid-earth geophysics; paleontology and evolutionary theory; and tectonics. The successful applicant would be expected to conduct an active research program, to interact with students and faculty, and to teach one course or seminar per semester with the topic to be negotiated. The duration and scope of the visit are negotiable as well. Applications will be considered as they arrive.

We encourage those from historically disadvantaged ethnic, racial, and gender categories. Yale University is an equal-opportunity employer. Applicants should send a curriculum vitae, a statement of objectives for the visit, and the names and addresses of three referees to: Visiting Faculty Search Committee, c/o Professor Danny Rye, Chair, Department of Geology and Geophysics, Yale University, P.O. Box 208109, New Haven, CT 06520-8109.

SAINT LOUIS UNIVERSITY TENURE TRACK POSITION

The Department of Earth and Atmospheric Sciences has a tenure track position at the assistant professor level to be filled for the Fall of 2000.

We are looking for a geoscientist who can conduct a vigorous research program and teach at both the graduate and undergraduate levels. We prefer someone whose research is in the areas of tectonics or tectonophysics, but welcome applicants whose interests may be in related fields. Our geoscience faculty has expertise in tectonics, seismology, gravity, crustal structure and fluids, sedimentary processes, igneous petrology and paleontology. Candidates must possess a Ph.D. at the time of appointment. Breadth of teaching at the undergraduate level and the ability to motivate students are obvious assets.

Our department emphasizes a strong connection between geology and geophysics and offers excellent atmospheric science programs; it also benefits from an extensive and well-maintained computer network. The university has recently implemented a multi-million-dollar initiative to enhance research facilities and provide opportunities for cutting-edge research. The campus provides an attractive urban environment. Visit our web site at http://www.eas.slu.edu to see more about the programs and activities in our department and at Saint Louis University.

Applicants should submit a statement of teaching and research interests, a curriculum vitae, and the names, addresses (including email), and telephone numbers of four references to: The Chairman, Department of Earth and Atmospheric Sciences, Saint Louis University, 3507 Laclede Avenue, St. Louis, Missouri 63103. For further details contact: 314-977-3131 or search@eas.slu.edu. Applications will be received up to December 31, 1999, or until the position is filled.

Saint Louis University, a Catholic, Jesuit institution dedicated to education, research and healthcare, is an affirmative action, equal opportunity employer and encourages applications from women and minorities.

ASSISTANT PROFESSOR, SCHOOL OF GEOLOGY
OKLAHOMA STATE UNIVERSITY

The Oklahoma State University School of Geology invites applications for a tenure-track faculty position in hydrogeology. The appointment will be at the level of assistant professor, beginning Fall, 2000. A Ph.D. degree is required at the time of appointment. Applicants must show the ability and commitment to excellence in instruction and research.

We are seeking an individual who demonstrates the potential for developing a successful research program relating to hydrogeology. Candidates must be proficient in groundwater flow modeling. Sub-specialties in hydrogeology, such as contaminant transport, applications of geophysics, and aqueous geochemistry, are especially attractive. Teaching of undergraduate and graduate courses is required. Preference will be given to those candidates who have previous undergraduate teaching experience, and have published refereed articles in his/her discipline. The successful candidate will be expected to develop a research program that will generate funding to support the program and graduate student involvement. The candidate must be able to teach introductory geology along with courses related to his/her specialty. He/she will be expected to supervise M.S. graduate students and collaborate with faculty to enhance existing department program emphases.

For full consideration, candidates should submit a letter of application, including a description of research interests and his/her approach to teaching; a curriculum vitae; academic transcripts, and the names, addresses, e-mail addresses, and phone numbers of three references are also required. For full consideration, applications must be received by December 1, 1999; however, applications will be accepted until the position is filled.

Please send all materials to: Assistant Professor Search, Hydrogeology, School of Geology, Oklahoma State University, 105 Noble Research Center, Stillwater, OK 74078-3031.

For more information on the OSU School of Geology, please visit our Web site at www.okstate.edu/geology/geology.html.

OSU is an affirmative action/equal employment opportunity employer, commited to multicultural diversity.

TENURE-TRACK FACULTY POSITION
IN GEOLOGICAL ENGINEERING
UNIVERSITY OF MISSOURI—ROLLA

The Department of Geological and Petroleum Engineering at the University of Missouri-Rolla seeks applications for the Fred Hasselmann Chair in Geological Engineering. Candidates should have a well established reputation of industrial and/or academic experience and possess the communication and management skills necessary to provide departmental leadership. 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 qualificaitons to become registered is strongly desired. The successful candidate should possess a strong commitment to undergraduate and graduate level teaching and should have a demonstrated research record including the successful pursuit of external funding and publication. Preferred areas of expertise include groundwater hydrology and contaminant transport, applied geomorphology and engineering geology and geotechnics.

Interested candidates should submit a resume, a statement of teaching and research accomplishments and the names and addresses of three individuals from whom letters of reference may be solicited. The deadline for receipt of applications is February 1, 2000. Application materials should be directed to Human Resource Services, Reference Number: R51861, University of Missouri-Rolla, 1202 North Bishop, 1870 Miner Circle, Rolla, MO 65409-1050. The University of Missouri-Rolla is an equal opportunity and affirmative action institution, and welcomes applications from qualified women, minorities, and persons with disabilities.

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BOOKS: Geology and History of Geology. Used, out-of-print, and rare. Free catalog. Patricia L. Daniel, BS, MS, Geology. 618 W. Maple, Independence, KS 67301, ph: (316) 331-0725, fax: 316-331-0785, E-mail: pldaniel@horizon.hit.net, website: www.hit.net/~pldaniel.

Opportunities for Students

Master's/Ph.D. Fellowship Available, Baylor University. The Department of Geology at Baylor University is pleased to announce the creation of the Wendlandt Fellowship, available to an outstanding incoming graduate student in the Fall of 2000. The fellowship is supported by an annual stipend of $14,000 plus full tuition. More detailed information on the fellowship and on available graduate programs can be obtained at: www.baylor.edu/~Geology/studentinfo.html. In addition to the Wendlandt Fellowship, there are also a number of teaching assistantships available at $12,000/yr + tuition (Master's) or $15,000/yr + tuition (Ph.D.'s). For information or application, please contact Dr. Thomas Goforth, Baylor University Dept. of Geology, PO Box 97354, Waco, TX 76798-7354; (254) 710-2361; e-mail: tom_goforth@baylor.edu.

Graduate Student Opportunities, University of Missouri—Rolla. A recent large endowment to the Department of Geology & Geophysics, University of Missouri, Rolla allows us to offer very competitive financial support to qualified graduate students. Programs leading to the M.S. and Ph.D. degrees include: aqueous & environmental geochemistry, igneous petrology & geochemistry, sedimentary petrology & geochemistry, sedimentology & biostratigraphy, economic & petroleum geology, and applied exploration & environmental geophysics. The Department is well equipped and situated in a modern facility. For information about programs, faculty and admissions please access the Department's home page at: http://www.umr.edu/~geo-geop/ or write to: Graduate Advisor, Department of Geology & Geophysics, University of Missouri-Rolla, Rolla, MO 65409-0410.

Graduate Traineeship: Entering Award consisting of 9-month traineeship for graduate study in conjunction with interdisciplinary Research Training Group (RTG) in ecology, geology, archaeology, geography, and soils to enhance training in "Paleorecords of Global Change." Only citizens, nationals, or permanent residents of the U.S. qualify for stipends. Application deadline January 4. For application contact Sue Julson, RTG, University of Minnesota, Ecology, Evolution and Behavior, 1987 Upper Buford Circle, St. Paul, MN 55108. Phone: (612) 624-4238; Fax: 612-624-6777; E-mail: julso001@tc.umn.edu. Web: http://lrc.geo.umn.edu/RTG/. An Equal Opportunity Educator and Employer.

Research Assistantship / Hydrology / N.M. Tech. Graduate research assistantships are available for students interested in working on projects related to a recently-funded NSF Science & Technology Center on Sustainability of Water Resources in Semiarid Regions, of which the Hydrology Program at New Mexico Tech is a lead participant. This center was formed to address the growing problems of increasing water demand and declining water quality in the southwestern United States. The objective of the Center is not only to obtain new scientific insights into the hydrological system, but also develop and present the scientific results in such a way that they can actually be applied to the resolution of water resource problems in the near future.

We encourage applications from students seeking M.S. or Ph.D. degrees who are interested in the following research topics: Basin-scale water and salinity balance; employing isotopic and environmental tracer techniques; land-atmosphere interactions; using surface and remote sensing observations and numerical models; vadose zone processes and groundwater recharge.

Research will be focused on the hydrology of the Rio Grande Basin. Interaction with water users and managers in the basin is an important part of the planned research. Model simulations will be completed using the advanced computing facilities at Los Alamos National Lab.

We are currently accepting applications for assistantships beginning in both Spring and Fall Semesters, 2000. For additional information, contact Fred Phillips, email: phillips@nmt.edu, Department of Earth & Environmental Science, New Mexico Tech, Socorro, NM 87801, http://www.ees.nmt.edu/hydro/homepage.html.

Graduate Student 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 geochemistry, 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).

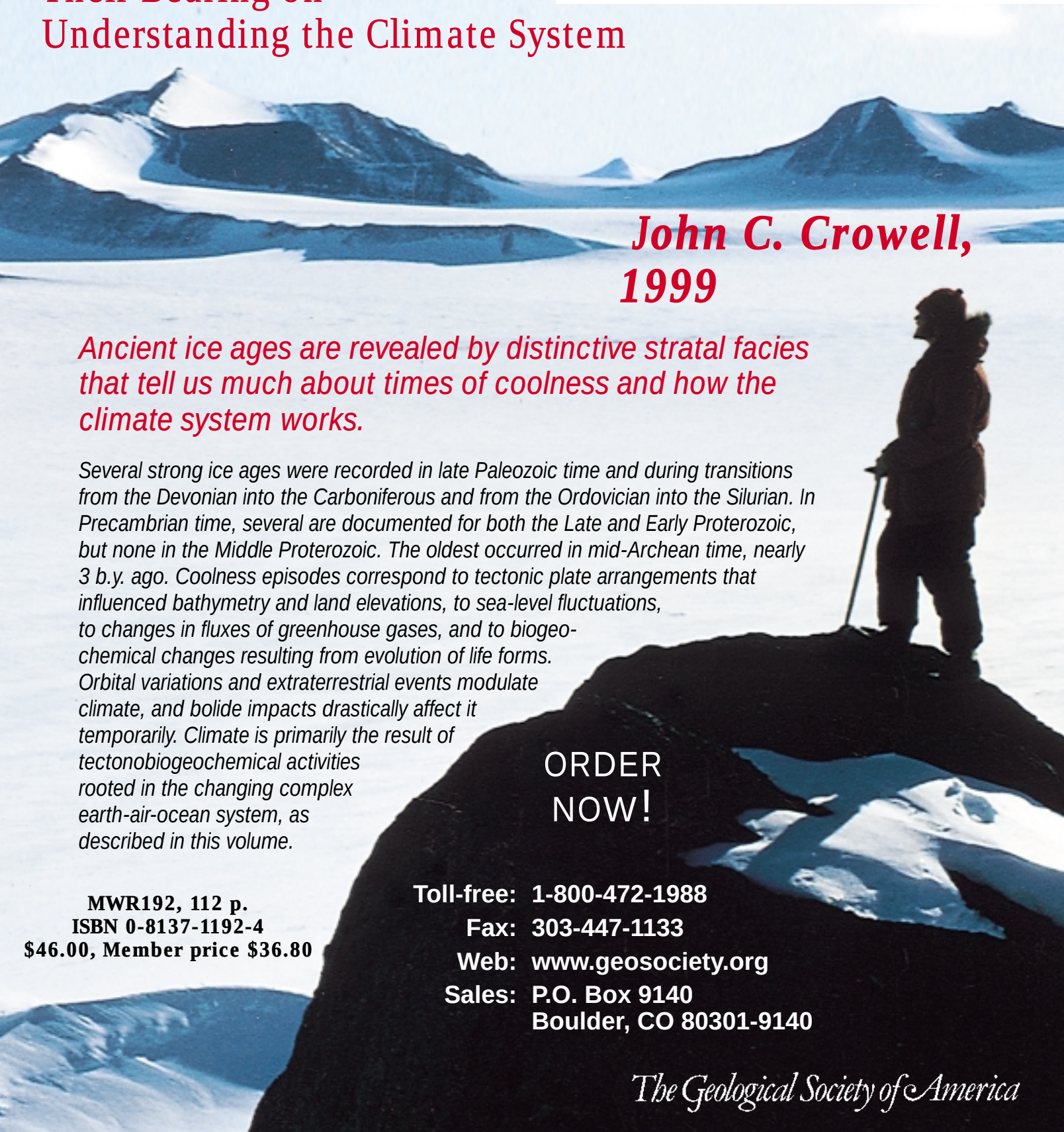
Department of Geosciences, University of Arizona, announces the availability of Sloan Scholarships for minority Ph.D. students in the geosciences. The Alfred P. Sloan Foundation and the Department of Geosciences are committed to increasing the number of African-Americans, Hispanic-Americans, and Native-Americans receiving Ph.D.s in the geosciences. Sloan scholars receive fellowship support, three summers of research support, a research allowance, and peer and faculty mentoring. Additional support through other fellowships, and teaching or research assistantships is also available. Inquiries and requests for applications to: Graduate Program, Department of Geosciences, The University of Arizona, Tucson, AZ 85721. Or gradapps@geo.arizona.edu and http://www.geo.arizona.edu.

The Graduate Program of Hydrologic Sciences at the University of Nevada, Reno, invites applications for three student positions beginning July 1, 2000. Each position carries an annual stipend of $14,000 including tuition and fees. These positions require serving as a teaching assistant for one semester with the remaining time being spent on a research fellowship. One student will be selected in each of the following areas: ground water, surface water, and enviornmental geochemistry. In addition, the Division of Hydrologic Sciences (DHS) of the Desert Research Institute announces the Sulo and Aileen Maki Fellowship in Hydrologic Sciences. The Fellowship is available for incoming doctoral candidates who are pursuing a degree program in aspects of hydrologic sciences at either the University of Nevada, Reno, or the University of Nevada, Las Vegas. The Fellowship will provide a $15,000/year stipend for three years. The successful applicant must select a DHS faculty member as their advisor.

Completed application packages, including expressed interest in one of the aforementioned appointments, are due January 10, 2000 and should be mailed to: Graduate Program of Hydrological Sciences, 1000 Valley Road, Reno, NV 89512-0180. Potential applicants are encouraged to browse http://www.hydro.unr.edu for more information on the program and positions. ■

Pre-Mesozoic Ice Ages:

Their Bearing on Understanding the Climate System



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