Vol. 8, No. 2 February 1998

GSA TODAY

A Publication of the Geological Society of America

INSIDE

The Ediacara Biota: A Terminal Neoproterozoic Experiment in the Evolution of Life

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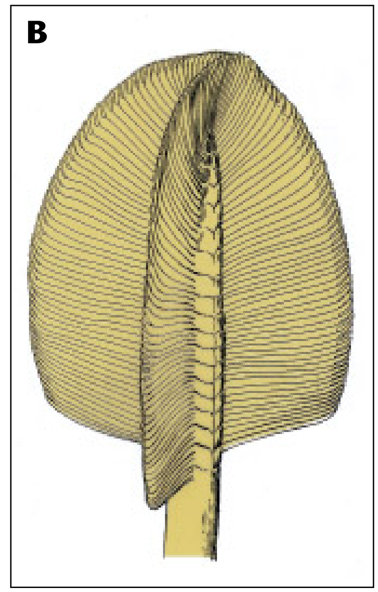

Figure 1. Photograph and artist's reconstruction of the holotype of *Swartpuntia germsi* from Namibia. For simplicity, only three petaloids are shown. Metric scale. After Narbonne et al. (1997, Figs. 6 and 8).

ABSTRACT

The Ediacara biota is a distinctive assemblage of large, soft-bodied organisms that characterizes terminal Neoproterozoic (latest Precambrian) strata worldwide. Some Ediacaran organisms apparently were the rootstock for the Phanerozoic evolution of animals; other bizarre forms may represent a failed experiment in Precambrian evolution. The Ediacara biota and its nonactualistic preservation and ecosystem characterized the final 20 m.y. of the Proterozoic, and disappeared near the beginning of the Cambrian "explosion" of shelly and burrowing animals.

INTRODUCTION

The terminal Neoproterozoic was a period of fundamental change in Earth history. Major changes included the breakup of the supercontinent Rodinia and the subsequent collision of some of the fragments that were to form Gondwana (Hoffman, 1992; Unrug, 1997), a succession of at least four global glaciations, and some of the largest known changes in the oceans and atmosphere (Knoll and Walter, 1992). It is against this backdrop that we see the appearance of abundant, large organisms, including the first definite fossil animals in Earth history, the Ediacara biota.

The Ediacara biota typifies terminal Neoproterozoic rocks worldwide (Glaessner, 1984; Fedonkin, 1992; Jenkins, 1992; Runnegar and Fedonkin, 1992). It was first described from Newfoundland and Namibia, but the name is derived from the superb assemblages of these fossils discovered at Ediacara in the Flinders Ranges of South Australia by Sprigg (1947). In contrast with the shelly fossils that characterize the Phanerozoic, the Ediacara biota consists almost exclusively of the remains of soft-bodied organisms, which are typically preserved as impressions on sandstone beds (Fig. 1). The Ediacara biota contains a few forms that might be familiar to a modern beachcomber, alongside bizarre taxa whose place in the evolution of modern life is uncertain. A few "Ediacaran survivors" have been reported from the Cambrian, but most of the archetypical forms disappeared abruptly near the Cambrian "explosion" (Grotzinger et al., 1995). The unique biology, ecology, and preservational mode of the Ediacara biota effectively marks the end of the Proterozoic Eon, and may herald the beginning of the Phanerozoic.

EVOLUTIONARY HISTORY

The Ediacara biota occupies a pivotal position in the evolution of life on Earth, between the largely microbial (especially stromatolitic) communities that characterize the classic "Precambrian" and the shelly biotas of the Cambrian and younger Phanerozoic systems (cf. Sepkoski, 1981). Prior to the appearance of the Ediacara biota, Mesoproterozoic to mid-Neoproterozoic (1600–600 Ma) benthic communities had been dominated by prokaryotic microbes along with some sheetlike and ribbonlike algae (Knoll, 1992). Evidence from molecular phylogeny suggests that microscopic animals could have evolved sometime prior to the appearance of the Ediacara biota, but the exact timing remains debatable (Wray et al., 1996; Conway Morris, 1996). The oldest known megascopic Ediacara-type remains occur in the Twitya Formation of northwestern Canada (see Fig. 3, locality 22) immediately below tillites correlated with the Marinoan-Varanger glaciation and believed to be about 600 m.y. old (Hofmann et al., 1990). The structures consist of centimeter-scale rings and discs that are

Ediacara Biota *continued on p. 2*

GSA TODAY February 1998
Vol. 8, No. 2

GSA TODAY (ISSN 1052-5173) is published monthly by The Geological Society of America, Inc., with offices at 3300 Penrose Place, Boulder, Colorado. Mailing address: P.O. Box 9140, Boulder, CO 80301-9140, U.S.A. Periodicals postage paid at Boulder, Colorado, and at additional mailing offices. **Postmaster:** Send address changes to *GSA Today,* Membership Services, P.O. Box 9140, Boulder, CO 80301-9140.

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Ediacara Biota *continued from p. 1*

similar to the simplest (most primitive?) elements of the Ediacara biota worldwide. A global rise in atmospheric oxygen in the Late Proterozoic may have been the trigger that permitted animals to achieve megascopic size at this time (Canfield and Teske, 1996).

Ediacaran biotas diversified rapidly after the end of the Neoproterozoic glaciations (Fig. 2) and are now known from some 30 localities on five continents, including at least seven distinct regions of North America (Fig. 3). The known stratigraphic range of Ediacara-style biotas is approximately 55 m.y. (ca. 600–544 Ma), but diverse and complex fossils are known only from the final 20 m.y. of the Neoproterozoic (Fig. 2). At least three stratigraphically restricted assemblages have been recognized, each more diverse than its predecessor (Narbonne et al., 1994). It was formerly believed that the Ediacara biota disappeared several tens of millions of years before the beginning of the Cambrian, but precise U-Pb dates of fossiliferous strata in Namibia indicate that the

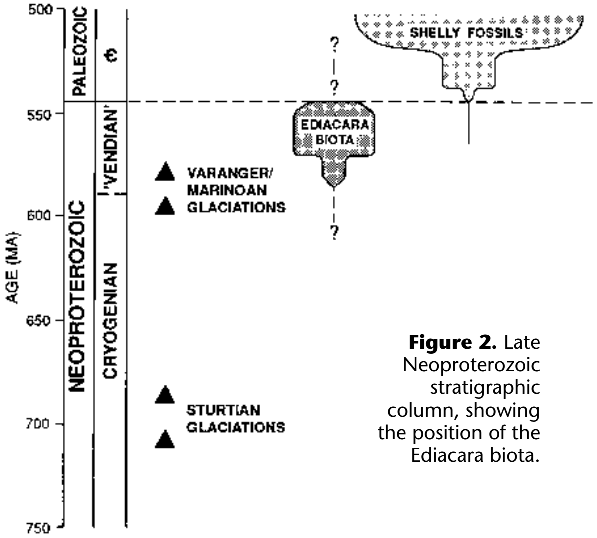

Figure 2. Late Neoproterozoic stratigraphic column, showing the position of the Ediacara biota.

Ediacara biota persisted to near the beginning of the Cambrian "explosion" (Grotzinger et al., 1995). Possible explanations for the abrupt disappearance of the Ediacara biota include elimination of a preservational "window" (Fedonkin, 1992), competition and predation by early skeletal animals (McMenamin, 1986), and global geochemical perturbations (Bartley et al., 1998).

AFFINITIES

In a little more than a decade, the affinities of the Ediacara biota have gone from being a well-documented "fact" to becoming one of the great controversies in paleobiology. Prior to the mid-1980s, virtually all workers emphasized similarities in two-dimensional structure between Ediacaran fossils and living groups of jellyfish, soft corals, annelid worms, and arthropods, and concluded that the Ediacara biota represented the direct ancestors of these modern groups. Glaessner (1984) aptly termed this "The dawn of animal life." In contrast, Seilacher (1982, 1989, 1992) believed that most of the Ediacara biota was unrelated to modern organisms, a "failed experiment" in the history of life on Earth. Seilacher suggested that Ediacaran organisms be referred to his new phylum or kingdom "Vendozoa," which consists of quilted organisms that lacked mouths and guts and received energy by absorbing dissolved organic molecules or by harboring photosynthetic or chemosynthetic symbionts. The rival classifications of Glaessner and Seilacher represent two end-member views that have generated lively debate in the literature over the past decade (Gehling, 1991; Runnegar, 1995). Seilacher (1992) subsequently restricted his original concept of the "Vendozoa" (which he now terms the "Vendobionta") and specifically removed taxa that he now regards as true animals.

In my view, any interpretation that unites the disparate fossils of the Ediacara biota into a single taxonomic group, be it jellyfish, protists, lichens, or vendozoans, should be viewed with suspicion. Ediacaran fossils range from centimeter-scale blobs to complexly segmented discs and fronds more than 1 m long. Symmetry ranges from bilateral to trigonal to tetragonal to pentameral to radial. Some were soft and jellylike; others were highly resistant to both mechanical stress and decomposition. Different taxa lived under conditions ranging from shallow, sunlit shelves to the deep seafloor. Several distinct groups can be recognized; I focus here on the three most common and familiar.

The least equivocal are the trace fossils, which are represented almost exclusively by simple subhorizontal burrows (Fig. 4). These show evidence of mobility and imply concentration of sensory organs at a "head" region. All previous workers have regarded these simple trace fossils as the work of bilaterian animals (e.g., Seilacher, 1989; Narbonne and Aitken, 1990; Fedonkin and Runnegar, 1992).

The second are the nonresistant "discs" such as *Ediacaria* and *Cyclomedusa* (Fig. 5). These were originally interpreted as jellyfish (medusoids), but considerations of the morphology and preservation of these discs have progressively eliminated taxa to the point that no undoubted "jellyfish" remain among the Ediacara biota! All appear to have been bottom-dwelling (benthic) organisms, and many seem to have been permanently attached to the sea bottom (Seilacher, 1982; Narbonne and Aitken, 1990; Gehling, 1991; Fedonkin and Waggoner, 1997). The centimeter-scale disc to hemisphere *Beltanelliformis* (Fig. 6), perhaps the most common and widely distributed Ediacaran fossil worldwide, is strikingly similar to the base of some anemones and especially to the bases of Paleozoic burrows generally attributed to anemones (Narbonne and Hofmann, 1987; Fedonkin and Runnegar, 1992). Larger discs such as *Ediacaria,* some of which are as large as a dinner plate, are more controversial. Most show no evidence as to the nature of their upper surface, but several taxa show evidence of hairlike markings extending radially from a central disc (e.g., Fig. 5A) which might alternatively be regarded as the tentacles of a polyp or the rootlike structures of a

Ediacara Biota *continued on p. 4*

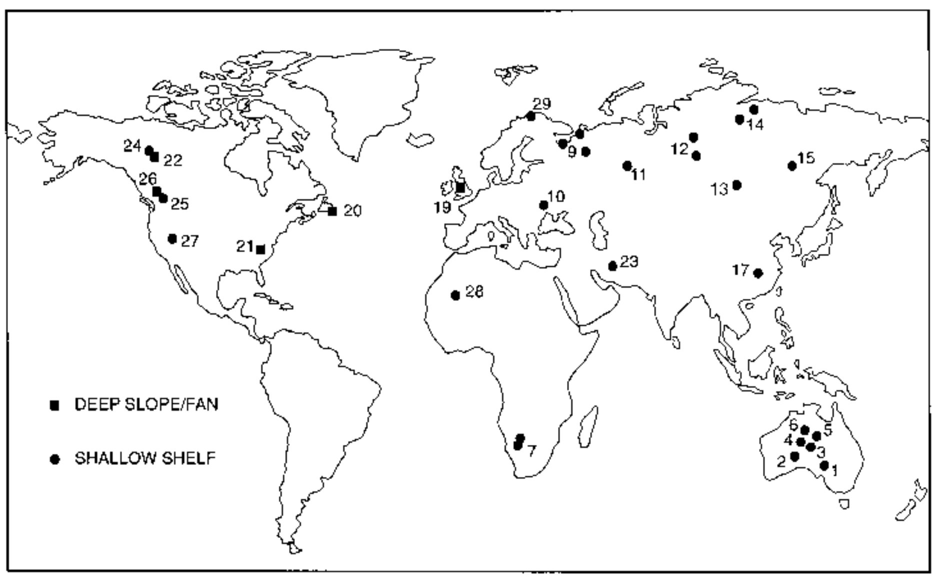

Figure 3. Global distribution of principal Ediacara-type fossil assemblages and environments. Data from Glaessner (1984, Fig. 1.8, localities 1–23), Hofmann (1987, Fig. 13, localities 24–25) and recent literature (localities 26–29). Glaessner's localities 8 (calcareous tubes), 16 (pseudofossils), and 18 (Cambrian) have been omitted, as have several low-diversity assemblages of discs and problematica described subsequently. Australia: 1—Flinders Ranges, Adelaide "Geosyncline"; 2—Officer Basin; 3 and 4—Amadeus Basin; 5—Mt. Skinner; 6—Georgina Basin. Africa: 7—Namibia; 28—Algeria (Bertrand-Sarfati et al., 1995). Europe: 9—White Sea, Russia; 10—Podolia, Ukraine; 11—Urals; 19—Charnwood Forest, England; 29—Finnmark, Norway (Farmer et al., 1992). Asia: 12—Yenisey River, Siberia; 13—Lake Baikal, Siberia; 14—Anabar and Olenuk, Siberia; 15—River Maya, Siberia; 17—Yangtze Gorge, China; 23—Iran. North America: 20—Avalon Peninsula of Newfoundland; 21—North Carolina; 22—Mackenzie Mountains, northwestern Canada; 24—Wernecke Mountains, northwestern Canada; 25—Rocky Mountains, British Columbia; 26—Cariboo Mountains, British Columbia (Ferguson and Simony, 1991); 27—Spring Range, Nevada (Horodyski, 1991; Waggoner and Hagadorn, 1997).

Figure 4. Simple burrows following a carbonaceous layer in the Wernecke Mountains, northwestern Canada. Scale in millimeters. After Narbonne and Hofmann (1987, Fig. 10a).

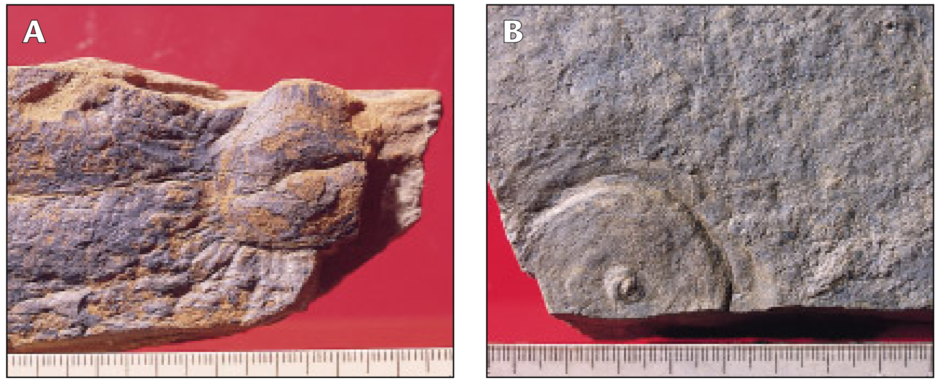

Figure 5. Ediacaran discs from northwestern Canada. Scale in millimeters. **A:** *Hiemalora* from the Mackenzie Mountains. Note pustular surface with carbonaceous coating, and radiating tentacle-like markings to left. After Narbonne (1994, Fig. 3.1). **B:** *Ediacaria (Beltanella)* with overlying stem (right side of disc) from the Mackenzie Mountains. After Narbonne and Aitken (1990, Pl. 1, Fig. 1).

Ediacara Biota *continued from p. 3*

holdfast (Runnegar, 1995). Others are attached to tubelike structures (Fig. 5B) or even complete fronds (Jenkins, 1992), and are best interpreted as holdfasts.

A third group are potential true Vendobionta (sensu Seilacher, 1992). Seilacher (1989, 1992) has shown that their distinctive quilted structure (Figs. 1, 7) is constructed of parallel, linked tubular segments in which the walls were more resistant than the ceilings. After the organism died, segments could become deflated or even imbricated. These organisms were formerly regarded as representing the ancestors of several modern groups ranging from soft corals to annelid worms (Glaessner, 1984). However, close similarity of the quilted constructional elements among architectures that range from erect multifoliate "fronds" (e.g., *Swartpuntia;* Fig. 1) to flat reclining sheets (e.g., *Dickinsonia;* Fig. 7A) implies that these taxa were more similar to each other than to any modern organisms (Narbonne et al., 1997). The Vendobionta appears to be a distinctive clade (monophyletic group) of Neoproterozoic organisms, but its taxonomic position is uncertain; suggestions range from an extinct group within the phylum Cnidaria (which also includes modern corals and anemones) to an extinct phylum or even kingdom unrelated to the subsequent Phanerozoic evolution of animals (Buss and Seilacher, 1994).

PRESERVATION

If almost all Ediacaran organisms were soft-bodied, how were they preserved so abundantly worldwide? First and foremost, Ediacara-type fossils are preserved in event beds. These soft-bodied organisms lived on the mud bottom, and their impressions were preserved when they were catastrophically covered by a bed of sand-sized debris (an event). One famous example is the felsic tuff that covers the fossil surface at Mistaken Point in Newfoundland (Fig. 8A). This tuff has been

Figure 6. The probable anemone *Beltanelliformis* from the Bernashev Member, Ukraine. Metric scale.

dated at 565 ± 3 Ma (U-Pb on zircons; Benus, in Landing et al., 1988), providing a precise date for this "Ediacaran Pompeii." The most common mode of preservation of the Ediacara biota worldwide is on the soles of storm or turbidite beds (Fig. 8B), again reflecting instantaneous deposition of sand on the muddy seafloor. Wade (1968) recognized two preservational modes that reflected resistance to decomposition. In particular, most discs decomposed prior to cementation of the overlying sand bed and thus are preserved as ridges on its sole (Figs. 5, 6), whereas most quilted fossils (e.g., *Dickinsonia*) did not decompose until *after* cementation of the sand and are preserved as indentations on the base of the bed (Fig. 7). Resistant organisms can even be preserved within and on top of storm beds (Fig. 9), but this is extremely unusual for nonresistant discs.

One might expect exquisite preservation of soft organisms under a layer of submarine volcanic ash such as at Mistaken Point, but why do some thick storm deposits and proximal turbidites faithfully preserve delicate structures on Ediacaran fossils despite the obvious evidence of high-energy conditions during deposition? The answer seems to lie in the warty, pustular texture that marks most fossiliferous Ediacaran surfaces (Figs. 4–7). Russian paleontologists refer to this as "old elephant skin," and it provides the search image for Ediacaran fossils on at least three continents; it is rarely found in beds that do not contain Ediacaran fossils, and these fossils are almost never found in beds that lack this texture. Gehling (1987)

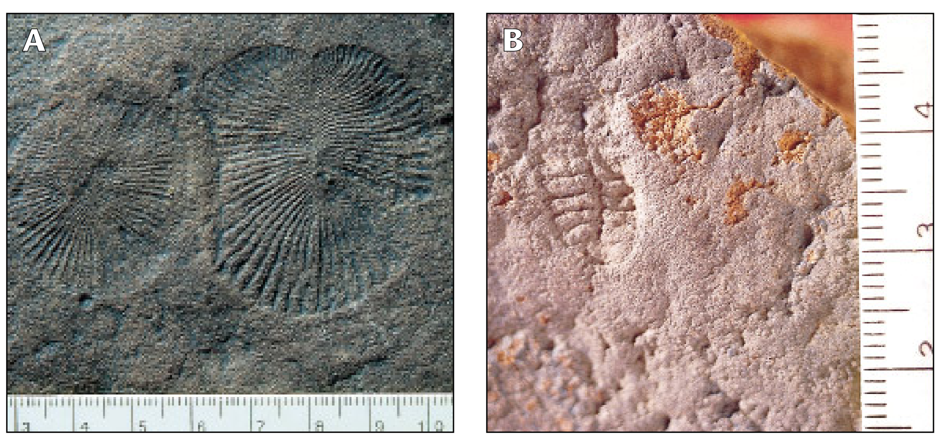

Figure 7. Dickinsoniids preserved as indentations on bed soles from Ediacara, Australia (A), and the Mackenzie Mountains, northwestern Canada (B). Metric scale. **A:** Two specimens of *Dickinsonia costata.* South Australia Museum P13760. **B:** *Windermeria aitkeni.* After Narbonne (1994, Fig. 3.2).

first recognized the similarity between these surfaces and modern microbial mats and has concluded that these mats were instrumental in stabilizing the mud surface and perhaps providing a "death mask" on the organism itself. In most cases, the distinctive texture is all that remains of the former microbial mat, but in northwestern Canada mats are preserved as black carbonaceous sheets that coat the fossil surfaces and that are locally ripped up to form intraformational conglomerates of carbonaceous sheets, some still bearing fossil impressions (Fig. 10).

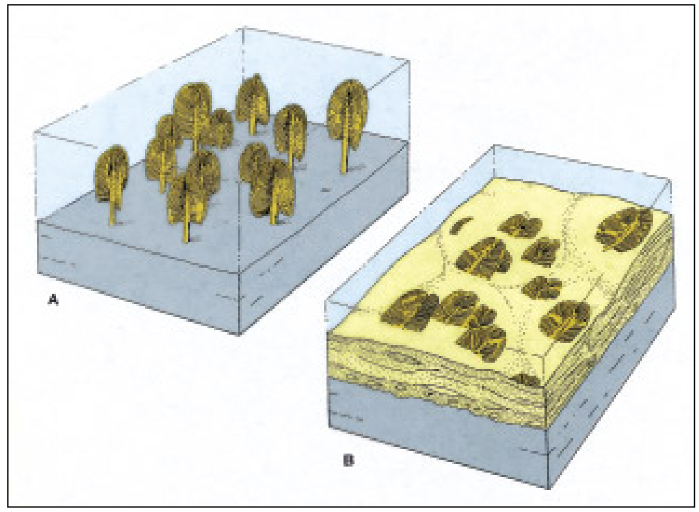

Figure 9. Living assemblage (A) and preservation (B) of *Swartpuntia germsi* from Namibia. Specimens lived on the mud bottom and are preserved within and on top of the bed of hummocky cross-bedded sandstone. After Narbonne et al. (1997, Fig. 11).

The prevalence of microbial mats throughout the subtidal realm represents a nonactualistic feature of Neoproterozoic seas (Seilacher and Pfluger, 1994; MacNaughton et al., 1997). Bioturbation, cropping, and competition resulted in severe reduction of these mats in the Early Cambrian and, thus, less likelihood of preserving soft-bodied organisms on sandstone soles. However, with a few notable exceptions (see e.g., Conway Morris, 1993), complex Ediacara-type organisms are also absent from Cambrian Lagerstätten such as the Burgess Shale, implying that the disappearance of the Ediacara biota was not solely preservational.

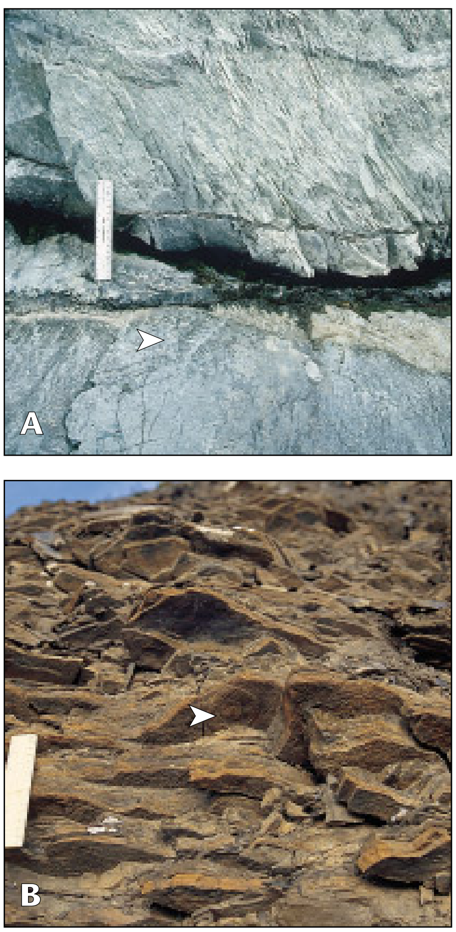

Figure 8. Preservation of Ediacaran fossils in North America. Arrows show their positions. Ruler is 15 cm long. **A:** Felsic tuff (565 ± 3 Ma) covering the fossil surface at Mistaken Point, Newfoundland. **B:** *Cyclomedua plana* on sole of a turbidite in the Sheepbed Formation at Sekwi Brook, northwestern Canada.

ECOLOGY

As discussed above, recent studies suggest that the Ediacara biota consists mainly of benthic organisms, most of which are in their original life position. Shallow-water deposition characterizes the vast majority of Ediacaran fossil sites (Fig. 3), including the classic sites in Australia, Namibia, and northern Russia (Gehling, 1988; Narbonne et al., 1997; Grazhdankin and Ivantsov, 1996). Fossiliferous sandstones in all these regions contain wave ripples and hummocky cross-stratification, but they typically lack true desiccation cracks and other evidences of emergence. Most fossiliferous strata were deposited between wave-base and storm wave-base, and were probably within the euphotic (photosynthetic) zone. A handful of deep-water occurrences of the Ediacara biota are also known (Fig. 3), principally in the Avalon Zone of eastern North America and England (Jenkins, 1992). Shallow-water features have not been found in any of these successions, and process sedimentology studies (such as those carried out at Mistaken Point in Newfoundland; Landing et al., 1988) imply that the strata were deposited on a deep-sea turbidite fan, but the subsequent tectonic history of these regions makes calculations of absolute depth impossible. Diversity is moderate to high, but only one taxon (*Charnia*) from Mistaken Point and Charnwood Forest is also known from shallow-water successions. However, it is uncertain whether the unusual composition of these assemblages reflects the deep-water setting or paleogeographic isolation of the Avalonian microcontinent during the terminal Neoproterozoic.

Figure 10. Conglomerate of carbonaceous rip-up clasts, with a specimen of *Spriggia* preserved on a clast, from the Wernecke Mountains of northwestern Canada. GSC 83030.

The Windermere Supergroup of northwestern Canada provides a unique natural laboratory to study the depth distribution of the Ediacara biota on a single lithospheric plate. Strata were deposited in shelf and slope settings on the margin of the opening proto–Pacific Ocean. Shelf facies in the Wernecke Mountains comprise mainly storm-deposited sandstones that were laid down in shallow, wave-agitated, and probably euphotic environments (Narbonne and Hofmann, 1987). In contrast, slope facies in the Mackenzie Mountains lack shallow-water features and are characterized by turbidites, contourites, and mass-flow deposits that accumulated in 1.0–1.5 km water depth on the continental slope (Dalrymple and Narbonne, 1996). Ediacara-type fossils in both regions appear to be in their original life positions. The principal difference in biota between these two environmental regimes is the extreme abundance of probable anemone *Beltanelliformis* in the shallow-water assemblages of the Wernecke Mountains and its complete absence from the deep-water assemblages in the nearby Mackenzie Mountains. This mirrors global trends—*Beltanelliformis* occurs profusely in shallow-water settings worldwide but has not yet been found in any deep-water succession. Few other differences in composition are evident, suggesting that the

Ediacara Biota *continued on p. 6*

Ediacara Biota *continued from p. 5*

depth-related zonations that characterize Phanerozoic and modern seas were not strongly developed in the terminal Neoproterozoic (Narbonne and Aitken, 1990).

In some ways, the Ediacaran ecosystem differed significantly from all modern systems. Microbial mats covered most marine surfaces and exerted a major influence on sedimentation patterns. Burrowing organisms were sparse and mostly ineffective bioturbators, and no animals seem to have been capable of preying on the largely soft-bodied and immobile Ediacaran organisms. McMenamin (1986) has referred to this as “The garden of Ediacara,” and in many ways it reflects the last vestiges of the Precambrian lifestyle that had characterized the preceding 3 b.y. of Earth history. However, the presence of anemones (Gehling, 1988) and sponges (Gehling and Rigby, 1996) among the Ediacara biota implies that ecological niches in the Ediacaran seas included microcarnivores and filter feeders. Ecological tiering included, for the first time, three feeding levels: an elevated level in the water column occupied by the fronds; a seafloor level with anemones, sponges, and a variety of other organisms; and the shallow subsurface where wormlike bilateria burrowed beneath microbial mats. These ecological innovations laid the groundwork for the massive ecological changes of the Cambrian “explosion,” and thus marked the beginning of our Phanerozoic world.

ACKNOWLEDGMENTS

Interactions and discussions with members of the IUGS Working Group on a Terminal Proterozoic System and IGCP Project 320 (Neoproterozoic Events and Resources) helped me in writing this paper. Line drawings are the work of John Glew, Rob MacNaughton, and Ela Rusak. Long-term funding has been provided by the Natural Sciences and Engineering Research Council of Canada (NSERC Research Grant 2648); the Geological Survey of Canada and Lithoprobe also provided support during critical periods. I thank Molly Miller for editorial advice and Michael Gibson and an anonymous reviewer for helpful reviews. This paper is dedicated to the memory of Bob Horodyski, who found the first Ediacaran fossils ever discovered in the western United States.

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Manuscript received November 3, 1997; revision received November 13, 1997; accepted November 14, 1997 ■

Sarewitz Leaves IEE Post

After 2½ years as director of GSA's Institute for Environmental Education (IEE), Daniel Sarewitz has accepted a position with Columbia University as a senior research fellow. He will write on science and technology policy and set up a science policy institute that will focus on social outcomes.

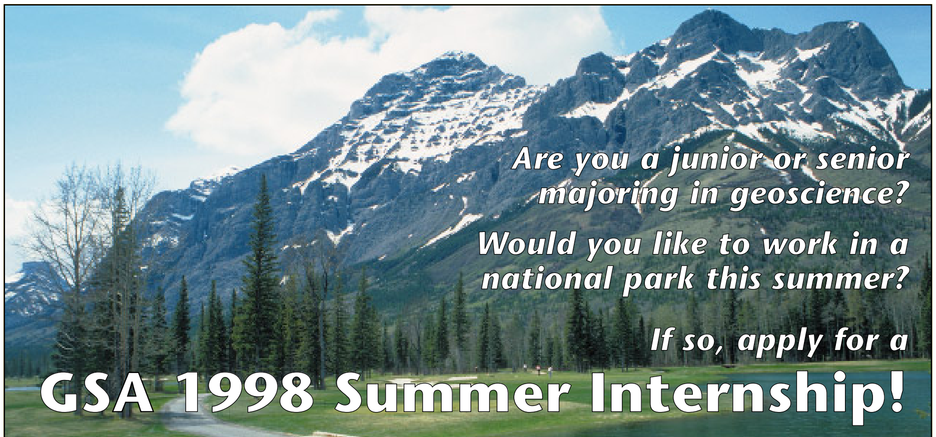
Sarewitz, who was a GSA Congressional Science Fellow in 1989–1990 and a science consultant to the U.S. House of Representatives Committee on Science, Space, and Technology, was appointed to the IEE post in 1995.

"It's been exciting working with GSA during this time of major change in our science," Sarewitz said. "You can see signs of this change everywhere—in the job market, in academia, in publications. Just look at the evolution of the GSA annual meeting over the past five years or so. Sessions about education, environment, and policy used to be very rare. Now they are an important part of the meeting."

During his IEE tenure, Sarewitz helped to implement some of these changes, by organizing media workshops, symposia, and theme sessions at GSA annual and section meetings; initiating workshops on the USGS–National Biological Service merger and on the policy relevance of predictive modeling; launching the Roy Shlemon Mentors in Applied Geology Program; guiding the GSA Congressional Science Fellow and National Park Service Internship programs; and working with the Geology and Environment Public Outreach Program to cultivate communication among geoscientists, policy makers, representatives of the private sector, and members of the general public on environment-related issues.

Sarewitz has moved to Washington, D.C., where he can keep track of meetings and other activities of congressional committees that deal with science policy. His new position begins on March 1.

IEE was formed in 1990 and was headed by GSA Fellow and benefactor Fred A. Donath, as a volunteer, for almost five years. The success of this initiative dictated establishing a full-time directorship, and that is the position for which Sarewitz was hired in 1995. The recent gift from John F. Mann, Jr. (see January 1998 *GSA Today,* p. 1) to support an Institute for Applied Geoscience will ensure that the IEE agenda remains a vital part of GSA's outreach activities. For information, contact Liz Knapp at GSA headquarters, eknapp@geosociety.org. ■



GSA is sponsoring five National Park Service undergraduate internships for the summer of 1998. Interns will work with park scientists and staff to develop interpretive programs, provide public education, and conduct research. Internships are available at the following parks: Badlands, Denali, Lake Clark, Petrified Forest, and White Sands.

Each internship carries with it a stipend of $2500, to cover transportation, food, and incidental expenses. Accommodations in the park will be provided free of charge.

Internships will be awarded on a competitive basis to five junior or senior undergraduates majoring in geoscience. Applicants must be GSA student Associates. You may join GSA at the same time you submit your application for the intern program. Detailed position descriptions and additional qualifications are listed on our Web site (www.geosociety.org/iee/parkint.htm) and in January *GSA Today*.

Apply for a GSA–National Park Service Internship by submitting:

- A one-page letter explaining your interest in and qualifications for the internship. Include (1) dates that you are available for the internship; (2) your preference (if any) for a national park placement, selected from the list of five available park positions; (3) your phone number; (4) your GSA membership number.;
- A copy of your academic transcript (unofficial is okay);
- Your resume; *and*
- One letter of reference from a faculty member in your geoscience department. (This letter may be included with your application package in a separate, sealed envelope, with the signature of the reference across the seal, or it can be mailed separately.)

Send applications to: National Parks Internship Program,
Geological Society of America,
3300 Penrose Place, P.O. Box 9140, Boulder, CO 80301

All application materials must be *received* **at GSA headquarters by March 1, 1998.**

The five successful applicants will be notified no later than *April 15, 1998.* For more information, call (303) 447-2020 ext. 195, or e-mail bbrown@geosociety.org

The 1998 GSA–National Park Service Internship Program is supported by generous gifts from John F. Mann, Jr., and the Shell Oil Company Foundation. This program is administered by the John F. Mann, Jr. Institute for Applied Geoscience.

1998 National Research Council Summer Internship Program

The application period is now open for the 1998 summer internship program of the National Research Council. Interns work at the NRC offices in Washington, D.C. Graduate or postdoctoral candidates in the physical, biological, and social sciences or any field of engineering are invited to submit the application available at http://www2.nas.edu/nrc-ip. The deadline is *March 1, 1998.* For more information, contact NRC-IP@nas.edu or write to: Deborah Stine, National Research Council, 2101 Constitution Ave., NW, Washington, DC 20418.

You Show Me Yours, and I'll Show You Mine

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The *National Science Standards* (1996) place great emphasis on creating environments in which all students can learn. Inherent features of the Internet's World Wide Web (hypertext links coupled with its interactive and distributed nature) lend themselves to serious experimentation to evaluate the potential of the Internet as one way to create these environments. It is encouraging that an overwhelming majority of the developers of geosciences Internet-based course resources are willing to share materials. Faculty with an interest in learning how their colleagues are using the Internet have a wealth of material through which to browse, examine content, and obtain ideas for developing their own resources.

The widespread willingness to "share by showing" Internet-based resources is impressive. This nearly universal practice can have a twofold impact. First, the instructor has access to a veritable wealth of information from which to select resources for his or her evolving course pages (for example, see the Virtual Geosciences Professor, http://www.uh.edu/~jbutler/anon/anonfield.html). Second, the instructor can gain insight into how other instructors are conducting similar courses. This is a win-win situation as both faculty and students ultimately may derive benefit.

G. Van Dusen "The Virtual Campus—Technology and Reform in Higher Education," ASHE-ERIC Higher Education Reports, v. 25, no. 5, 1997) observed that many institutions seem to follow the "Yuppie toy model" in making decisions to purchase and use electronic technology. However, the institution with the most toys might turn out to be the loser and not the winner. Van Dusen argues that the "institution that approaches the virtual campus concept with the attitude that the new technologies are merely better tools that can be used to help the institution effectively and efficiently achieve its educational mission will be far more successful in the long run." The question is, therefore, What is an efficient and cost-effective way for a faculty to learn whether or not the Internet can help their institution do this?

Getting Started

The best way to begin exploring the potential of the Internet in helping to create learning environments is to find out how colleagues are using Internet-based resources in their courses. A good starting point for such an exploration is the World Lecture Hall listings, at http://www.utexas.edu/world/lecture/index.html. Instructors are encouraged to publish Internet addresses of their course materials at this University of Texas at Austin–sponsored site, which has been in existence for at least three years. Given the interdisciplinary nature of the geosciences, the current contents for science and mathematics are summarized in Table 1.

Table 1. World Lecture Hall Science and Mathematics Internet Course Resources

Discipline	No. of listings
Biochemistry	13
Biology and botany	64
Chemistry	55
Computer science	133
Geography	20
Geosciences	38
Mathematics	28
Physics	52
World Lecture Hall science	403

The World Lecture Hall staff make no attempt to add resources that were not nominated by the developer(s), so there is a bias in their listings. I have been keeping track (by systematically reviewing departmental Internet pages) of the number of course resources in the geosciences since the fall semester of 1995.

For First Time Readers, http://www.uh.edu/~jbutler/anon/use.html provides a brief introduction of links to geoscience courses and course resources that have been identified during the past two years. At the beginning of the fall 1997 semester, there were 623 of these resources being produced by geoscience faculty at 135 departments in the United States and Canada. Thus, only about 6% of these resources have been nominated for listing in the World Lecture Hall. (A resource is defined as having features that take at least a minimal advantage of the distributive nature of the Internet; thus, a typed syllabus and course outline would not qualify.)

Although the number of geoscience courses with Internet-based course resources continues to increase, it can be argued that much of the growth is due to a relatively small number of faculty producing more and more of these resources over time. Whether the Internet is adopted by a larger percentage of the geoscience faculty remains to be seen. The value added by Internet-based course resources will be the value these resources add to the learning environment.

To Share or Not To Share

Having committed to experimenting with the Internet, the developer will be faced with a decision as to whether to share the resources with the rest of the world or to restrict access. Systematic Surveys of the World Wide Web (http://www.uh.edu/~jbutler/anon/use.html) lead to the conclusion that more than 95% of the available resources are open to the public. Several universities (University of Illinois, http://www.geology.uiuc.edu/, and the University of Texas at El Paso, http://www.geo.utep.edu/class_notes/Class_Index.html, for example) restrict access to some of their course resources to enrolled students. UT at El Paso, however, provides an e-mail link for other instructors to request access. Others, like the University of Wyoming (http://geoweb.uwyo.edu/) restrict access to individual student pages (where instructors record performance on quizzes and examinations) and course notes. Still others, like the MIT Physical Geology Tutor (http://cfd4.mit.edu/PGTdemo/), restrict access to illustrations to on-campus users.

The number of formal courses delivered via the Internet in a "distance education format" is increasing. Even some of these are available for inspection by other students and faculty; for example, Environmental Problem Solving at Indiana University–Purdue University at Indianapolis (http://www.geology.iupui.edu/classes/g130/coned/index.htm).

Clearly, there is a need to protect the intellectual properties of both the developer and the textbook publisher and to forbid access to student records. Each developer will face these and related questions and issues when it is time to move html (hypertext markup language) files and images to a server.

Each user of resources produced by someone else needs to be aware of the concepts of "fair use" and "protection of intellectual property." The University of Texas at Austin has prepared a Crash Course in Copyright (http://www.utsystem.edu/OGC/IntellectualProperty/cprtindx.htm), which provides a good starting point.

Learning from Colleagues

During more than 30 years of teaching at the university level, I have partici-

SAGE Remarks *continued on p. 10*

SAGE Remarks *continued from p. 9*

pated in many discussions about how to evaluate teaching. In discussing “classroom visits,” it was usually decided that negative issues outweighed the positive. Many of my colleagues will talk freely about their research project(s) but are notably reticent about discussing how they plan their courses and what approaches they use to cover selected topics.

Much of what I have learned about constructing courses and presenting content has come about since I became an active “Internet Voyeur”—and I believe that my students are the true beneficiaries of my reeducation.

In selecting course resources and courses to feature here, I had to omit some really exciting resources. Readers are urged to find ways to share knowledge of what works (and doesn’t!) with colleagues within and across discipline boundaries.

Although the examples are discipline-based, the general philosophy of the instructor or producer as to layout, presentation style, techniques for visualization of fundamental concepts, etc. should have a wider appeal. I list these examples in increasing order of complexity (which is in no way meant as a criticism, as the technically simplest pages still have utility for those who developed them and for their students). There is something to be gained from each of these that can be transferred to a particular level of Web awareness and preparedness. I hope that you will view these resources as examples that might be worthy of emulation.

Electronic Syllabus

I used to distribute about 50 pages of handouts per student in a semester in my Physical Geology course. At about 50 students and $0.10 per page, I spent about $250 for a small course. If my colleagues gave out an average of 50 handouts per student, the cost would be about $5,000 for the 1,000 students who take Physical Geology each semester.

When I first introduced my students to the Internet in Physical Geology (http://www.uh.edu/~jbutler/physical/physical.html), many of them used the terminals at the University of Houson library. Many quickly learned that the library was not charging for printing, and printed the entire set of pages! Many individuals are simply more comfortable with a printed version—even if they know that they can access the same materials on the Internet at any time. I have simply passed the cost on from my department to the library!

A good first use of the Internet might be to distribute materials needed by students in a course or set of courses. As an example of how effective even very simple html course pages can be, take a look at Calculus I—Math 151 (http://calclab.math.tamu.edu/docs/math151/), at Texas A&M University. Material that an instructor usually hands out to a class—a syllabus, schedule, important dates, past exams, and suggested homework problems—are published. Why not take the word-processing version of your syllabus, for example, save it as a text file, and add the html tags to make it into a file that you can distribute on the Internet?

I like the OnLine Survey (http://www.isc.tamu.edu/~mpilant/math151-survey.html) that the faculty have designed: “In an effort to improve instruction across the Engineering Math sequence, we would like to know something about each of the students in this class. Please take time to answer the following questions. Using this information, background and goal profiles of students who take this course will be developed.… These profiles will help us to evaluate curricular changes in Calculus … and to compare current students to previous students in Math 151. The information you provide will be kept strictly confidential; there will be no identification of individual students.”

Most colleges and universities give students the opportunity to critique the courses that they take—but usually at the end of the course. Rarely do faculty take the opportunity to survey students about their attitudes toward education in general or a course in particular, or about their level of preparation for a course while it is in progress.

I recently gave my students in Physical Geology the opportunity to participate in a Preparation and Background Survey (http://www.uh.edu/~jbutler/physical/physsurvey.html). All of the homework exercises are published on the Internet, so the student must use the Internet to access and complete the assignments. In order to assess how many students were routinely accessing the course pages, I added a “blinking” link at the top of the course home page. Students could receive 10 “extra points” if they responded within 5 days; they were admonished to let the other students discover the survey for themselves. After one week, 24 (50%) of the students had responded. The correlation between class rank (out of some 300 available points) and response to the survey was disappointing but anticipated—75% of the students in the upper half of the class responded within the allotted time as compared to 25% in the lower half of the class.

Learning About the Internet on the Internet

Once the decision has been made to incorporate Internet resources in a course, it is imperative to assess the level of Internet familiarity of each student. Some Internet Tours (for example, http://www.uh.edu/~jbutler/anon/anoninternettour.html) can be made available to a class, or you may wish to develop your own “Introduction to the Internet” as a part of the exercises that you develop; for example, Searching for Specific Information (http://www.uh.edu/~jbutler/physical/exercise6.html). At last count there were more than 20 courses dealing with gaining familiarity with the Internet listed at the World Lecture Hall site.

Electronic Data Processing (http://www.nd.edu/~rbarger/capp380syl.html) is taught by Robert N. Barger at Notre Dame. This course was designed to accomplish the following. “Students will study computer ethics and will learn some UNIX utilities and such Internet applications as e-mail, listserv, telnet, ftp, newsgroups, archie, gopher and veronica, talk, search engines, and the World Wide Web (including HTML and JavaScript). Learning activities will be done on-line. Exams will be given on-line. Homework assignments, ethics case analyses, and a Web page project will also be done on-line.”

Results of Current Students’ Previous Use of Computer Applications and Languages (and their philosophic world views), at http://www.nd.edu/~rbarger/survey.html, allow students to compare their background with others in the class. This might prove beneficial, especially in large survey courses where students often are not sure what the prerequisites are and whether they are really prepared.

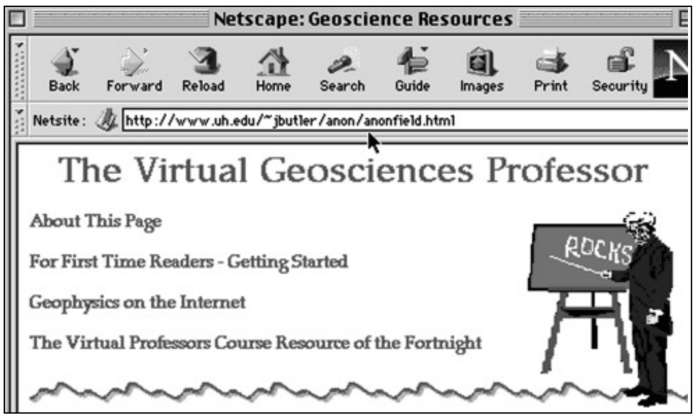
I particularly like Barger’s emphasis on Internet ethics and the Ethics Case Histories (http://www.nd.edu/~rbarger/cases.html). Everyone who uses the Internet should be familiar with the concept of fair use, and it helps to have case histories to refer to.

Discipline-Based Internet Initiative

One of the first geosciences Internet-based resources for a course that I encountered was developed by the Department of Earth and Ocean Sciences at the University of British Columbia. This effort was underwritten as part of a university and province–wide commitment as described in *Newsletter of Computing and Communication* (http://www.cc.ubc.ca/ccandc/mar95/mrn.html), March 1995. Michelle Lamberson has been with the project from its inception. Her article in May/June 1995 *Newsletter of Computing and Communication* (http://www.cc.ubc.ca/ccandc/may-june95/geoweb.html), puts into perspective their current effort, Course Web Pages in Earth and Ocean Sciences (http://www.eos.ubc.ca/courses/courses.html)—23 courses with extensive Internet resources in fall 1997. Lamberson received the first EduCom Medal to be awarded by the Geological Society of America (October 1997), a wellearned recognition for not only her work but also the commitments that the Department of Earth and Ocean Sciences have made to their faculty and students.

If faculty are contemplating an extensive Internet effort, or would like to see how such a project could be organized, the Earth and Ocean Sciences Web Resources Page (http://www.science.ubc.ca/~eoswr/project/) clearly highlights the importance of having the right kind of help at the unit level.

Earth and Ocean Sciences at UBC has devoted most of its funds to people—Michelle Lamberson and a group of enthusiastic students who work with faculty. The faculty provide the goals and objectives and produce the content. The students provide the skills for getting the materials on the Internet. Lamberson serves as the interface between student workers and the faculty. Take a look at Developer Tools, (http://www.science.ubc.ca/~eoswr/) or, perhaps better yet, have your Information Technology Office look at that site. It really helps if your organization recognizes the need for tools and gadgets that can be shared across the university.



Internet-Based Text

The materials listed above are best considered as Internet-based course resources, as they were designed to complement materials distributed in specific courses. Perhaps the next step would be the development of a hypertext book such as the MIT Biology Hypertext Book (http://esg-www.mit.edu:8001/bio/7001main.html). This effort is produced by the Experimental Study Group at MIT (http://esg-www.mit.edu:8001/home/home.html).

The current version of the hypertext book has 11 Chapters (http://esg-www.mit.edu:8001/bio/chapters.html) with the look and feel of a classroom lecture featuring a blackboard and an overhead projector. References to other Internet resources are minimized. (This is something that each producer must consider. How easy do you want to make it for the readers to "surf"? How critical are the these links to the purpose of the pages you are producing? Should the links be interspersed throughout the text or lumped together at the end as other resources? Clearly, the MIT group favored minimizing possible distractions.)

Each set of Review Questions (http://esg-www.mit.edu:8001/bio/chem/problems.html) is immediately followed by a link to the Solutions (http://esg-www.mit.edu:8001/bio/chem/solutions.html). A Searchable Index (http://esg-www.mit.edu:8001/bio/search.html) provides a mechanism for locating specific information in this hypertext text.

For seven chapters there are Practice Problems (http://esg-www.mit.edu:8001/bio/problems.html), which, in my opinion, are the real heart of these pages. Many modern textbooks provide questions, but few provide answers accompanied by suggestions as to where to go when you need to know. The philosophy behind the self-quizzes is explained as follows: "This is a diagnostic quiz to show whether or not you learned what you needed to learn from the readings. When you have answered all of the questions, you turn in the quiz electronically (by pressing the button). This is purely a diagnostic exercise to help both yourself and your tutor know where weak points in comprehension are. Once the answers have been submitted, you may jump to the Self-Quiz answers and check your answers against the solution key. If you got a question wrong, are uncertain about a certain question, or don't know what a word means, the Self-Quiz answers come with a searchable index so that you can immediately get to the material you need to review."

Alternative to an Internet-Distributed Text

As developed at MIT, the hypertext involved several steps. First, an instructor prepared a word-processing document containing the text. Second, overheads and other graphics were scanned and converted to images. Third, the documents from the first two steps were combined and an html document produced.

One of the frustrating aspects is that many of the features of the word-processing documents, such as tables and lists, are not automatically retained when converted to html files. You can reformat a table, but it may not have the same look as it did in its original form. I suggest that everyone contemplating the preparation of course resources should at least review Portable Document Files (PDF).

The free Adobe Acrobat Reader (http://www.adobe.com/prodindex/acrobat/readstep.html) allows the user to view, navigate, and print PDF files across all major computing platforms. Acrobat Reader is the free viewing companion to Adobe Acrobat 3.0 and to Acrobat Capture software. Adobe will allow you to link to their site where your users can Download a Free Copy of the Reader (http://www.adobe.com/prodindex/acrobat/distribute.html).

Geochemistry (http://www.geo.cornell.edu/geology/classes/GEO455.HTML), taught by William White at Cornell, provides an excellent illustration of how appropriate course material can be distributed as PDF files. In addition to the text, a syllabus, problem sets and solutions and geochemistry-related web links are available on the Internet.

Note that if you intersperse pictures, plots, and other graphical displays in your word-processing documents, your PDF files will retain the look and feel of the hard-copy original.

Distance Education Course?

Another development that I have been watching is the Introduction to Geophysical Exploration (http://magma.Mines.EDU/fs_home/tboyd/GP311/), which is produced by Tom Boyd and Phil Romig at the Colorado School of Mines. This is a joint effort between Boyd and Romig and the Society of Exploration Geophysicists, a case of professional organization investing in the learning environment of students who are potential future members and contributors to the discipline.

The authors provide their Philosophy of Teaching and Learning (http://www.mines.edu/fs_home/tboyd/GP311/INFORMATION/MOTIVATION/motiv.html). The parallel they draw between learning and playing baseball is intriguing, regardless of your discipline: "The framework of the prototype learning environment we are developing has many parallels to the way youngsters learn to play baseball. In developing this analog, consider first a program for baseball instruction based on the model that is currently used by most universities to teach engineering and science. One could easily envision a baseball undergraduate being required to take courses in calculus, differential equations, physics, fluid mechanics, the history of baseball, baseball and society, baseball theory, and various specialty courses (pitching, base running, hitting,

SAGE Remarks *continued on p. 12*

SAGE Remarks *continued from p. 11*

etc.). If students were lucky enough to attend a university that emphasized field work, the baseball curriculum would also include a six-week field program where students either took field trips to watch professional players practice their art, or, in some rare instances, actually played the game."

Their course consists of four modules. The principles underlying the modules are described as follows: "[T]he learning philosophy that we are incorporating in this program is characterized by one that includes Multiple Opportunities for Mastery, Autonomously Paced Learning, and Personalized Instruction. Our program includes each of these in the following ways. (1) Multiple Opportunities for Mastery. In the process of designing surveys and interpreting data, students use modeling software as many times as necessary to discover the relationships between geological parameters and physical phenomena. In the final report associated with each module, students must demonstrate mastery of these concepts by writing the set of rules that describe those relationships. (2) Autonomously Paced Learning. Each module is a project that can be done at a pace appropriate to the student's situation. The coordinator is a coach who answers questions rather than giving lectures, so interaction can occur at any time. The efficiency of this function will also be enhanced by the establishment of the FAQ file. (3) Personalized Instruction. Students submit their own survey designs and receive data sets customized to that design. In addition, they can submit a new survey design at any time. When they interact with the coordinator, it is in regard to their unique survey design and data set."

In the Gravity Module (http://magma.Mines.EDU/fs_home/tboyd/GP311/MODULES/GRAV/main.html), the subject matter is introduced in the form of course notes, and both on-line and off-line references are provided.

I took a course with a similar name a long time ago. The objectives may have been the same, but the level of student involvement leading to understanding is orders of magnitude greater in the Boyd and Romig course. Students gain more of an understanding of principles when they apply them directly to solving a specific and realistic problem rather than hand-cranking out the answer to a small part of a problem. Users of this module design a sampling strategy, bid on the project, manage a budget, and incorporate information gained from a variety of sources to solve a real problem.

All of the modules include Java applets that truly encourage playing the "what if" game. For example, the Gravity Module involves determining the location of abandoned tunnels in the shallow subsurface. The user specifies the tunnel width and depth, the density contrast between the tunnel and the surrounding rock, the number of readings at each station, the station spacing, etc. A gravity profile is constructed as a function of the values input by the user. It is highly instructive to hold all but one of these values constant and allow the other to vary. For example, what happens to the magnitude of the gravity anomaly if the tunnel width increases? If the density contrast decreases ? If the depth of the tunnel increases?

Boyd and Romig elected to modify the way the course is presented. They still meet with the class in two three-hour sessions per week, but now the students control what happens in class by the questions they ask. Lecturing per se has been

SAGE Remarks *continued on p. 13*

LETTERS TO THE EDITOR

Edwards Aquifer Revisited

We appreciate the critique of our article by our colleagues Woodruff, Rose, and Abbott (*GSA Today,* v. 7, no. 11, November 1997), and we wish to respond by making three points.

First, our statement, "It is not always recognized … that although the Edwards aquifer is present in the San Antonio area, the Edwards Limestone is not" (Sharp and Banner, 1997), was intended to emphasize the fact, no more and no less, that stratigraphic and hydrostratigraphic units are not identical! The rationales for these differences are given by Maxey (1964) and Seaber (1988). We submit that this distinction is not always appreciated by the geological community, let alone the general public. We infer from our colleagues' letter that this point has been made and that they agree, even though old terms will continue to be used (and misused).

Second, in modern hydrogeology, precise mapping of geological strata is desirable because hydraulic properties of aquifers commonly can be related to or inferred from the lithologic and geologic characteristics of such strata. Recent detailed stratigraphic maps by scientists from the U.S. Geological Survey, the Texas Bureau of Economic Geology and the Barton Springs/Edwards Aquifer Conservation District of the Edwards aquifer (e.g., Small et al., 1996) are noteworthy in this regard. The public and governmental agencies demand specifics, especially in urbanizing areas. For instance, they demand to know what the effects will be of this development, this water supply plan, or this potential contamination threat on the yield and water quality of specific well fields or specific springs. Our ability to make such assessments demands more precision, not less.

Finally, we agree that scientists should not confuse the public. We aren't sure how many nonscientists will read the statement by Woodruff et al. that "the Edwards aquifer may not always be [present]." However, those who do should not be concerned that the Edwards aquifer will disappear on a human time scale. Such statements can (and will) be quoted out of context and will mislead the public because "in Texas, water is for fighting." It is, in fact, difficult to conceive of a drought so severe and prolonged or a regional contamination event so catastrophic that this aquifer would not continue to supply water of usable quality to wells, springs, or a combination thereof. The Edwards aquifer may become abused and overexploited, and it may not be able to meet everyone's desired water needs in the future. The aquifer will, most likely, be impacted by the effects arising from the continued rapid rate of urbanization, but the Edwards aquifer won't disappear.

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Letters *continued on p. 14*

SAGE Remarks *continued from p. 12*

replaced by the Internet resources, and class time is devoted to face-to-face interactions between students and faculty.

This course, however, could be taken by a mature student as an independent study. I can imagine a geophysicist sitting on a drilling rig in the North Sea. It is windy and cold outside, but inside her office, the Internet provides a connection to a highly interactive learning environment.

Glimpse of the Future?

One of the truly impressive educational sites on the Internet is the Illinois Mathematics and Science Academy—IMSA (http://www.imsa.edu/welcome/whatis.html), "an educational laboratory for designing and testing innovative programs and methods to share with other teachers and schools in Illinois and beyond—programs and methods to transform mathematics and science teaching and learning. Included in the laboratory is the state's three-year public residential educational program for 650 Illinois students (grades 10–12) talented in mathematics and science."

Scientific Visualization (http://www.imsa.edu/edu/astro/ils/mat/scivis.html) permeates the course resource pages at ISMA. Three courses that should especially be examined are Astrophysics (http://www.imsa.edu/edu/astro/index.html), Geophysics (http://www.imsa.edu/edu/geophysics/), and Modern Physics (http://www.imsa.edu/edu/topics/).

Student Performance Self-Assessment (http://www.imsa.edu/edu/geophysics/assessment/stnd1form.html) is an integral part of the IMSA programs. These self-assessments provide feedback to the instructors throughout the course—not just at the end.

In Getting Information About the Earth (http://www.imsa.edu/edu/geophysics/geosphere/tectonics/exercise1.html), for example, emphasis is on understanding and not on mechanics. All IMSA exercises are constructed in a similar fashion and conclude with a written report incorporating a description of the method, data gathering, data reduction, images, and interpretation.

What if students with this background and extensive practice in problem solving enrolled in your department? Would your programs be challenging? Would students who have learned to use the Internet as just another tool in learning be interested in your programs?

Summing Up

It is encouraging that an overwhelming majority of the developers of Internet-based course resources are willing to share them. The Internet itself provides the best medium for evaluating the impact of the Internet in constructing learning environments. A few hours of exploration can introduce inquiring instructors to the variety of uses that their colleagues are experimenting with.

The National Science Standards (1996) (http://www.nap.edu/readingroom/books/nses/html/overview.html) note that "good teachers of science create environments in which they and their students work together as active learners. … Just as inquiry has many different facets, so teachers need to use many different strategies to develop the understandings and abilities described in the Standards." The Internet appears to be one way to create these environments. ■

GSA ON THE WEB

Visit the GSA Web Site at **http://www.geosociety.org.** ***From our home page you can link to many information resources. Here are some highlights:***

On our **Membership** page you'll learn about the GSA Employment Service, find out how to become a GSA Campus Representative, or learn how to get forms to join GSA as a professional or as a student. You'll also find information here on how to nominate a GSA Member to Fellowship standing.

Try out the **Meetings** site for a first look at the 1998 Annual Meeting in Toronto, with links to key Toronto Web sites.

From the **Publications** heading, you can visit the GSA Bookstore, where you'll find prices on DNAG publications slashed by 50% (and GSA Member discount still applies). You'll find two Treatise volume revisions, an Explore Kilauea multimedia CD-ROM, a new Reviews in Engineering Geology volume, and several new Memoirs and Special Papers. There's a general page with information for contributors, detailed information on preparing manuscripts for GSA books, information on copyright, a free geologic time scale, and more. Don't forget the *GSA Data Repository*—you can download valuable supplementary materials relating to articles in *GSA Bulletin* and *Geology.* As always, you'll find abstracts of all articles in those journals posted monthly.

In the **Education** section, read about GSA's educational programs, including PEP (Partners for Education Program), and the Earth and Space Science Technological Education Project (ESSTEP). Find out about GSA's environment and public policy activities in the **Institute for Environmental Education** section, including updates on the GSA Congressional Science Fellowship program, the Roy J. Shlemon Applied Geology Mentor Program, and the new program on "Prediction in the Earth Sciences."

Under **Foundation** you will find information on the GSA Foundation and the current annual giving campaign, a list of trustees and officers, and several ways to make a planned gift.

See the **Administration** section for information on GSA Medals and Awards, research grants, and other general information about GSA. You can also link to the pages for GSA Sections and Divisions for specific information on each of these.

Letters *continued from p. 13*

Contract Mapping

I certainly agree with Rowley, Dixon, and Stevens (*GSA Today,* October, 1997, p. 17–19) about the importance of 7.5 minute quadrangle scale geologic mapping. I was glad to see my old friend Jack Harrison quoted in their letter. I spent time in Montana with Jack, as he went about trying to achieve his target of a quadrangle mapped per day in the Belt Supergroup. I'm not so sure Jack would have agreed with them that the USGS always lived up to its basic mapping mission. Like many other economic geologists he and I were aware that our profession's frequent calls for basic geologic mapping by the Survey were often ignored in favor of others of the Survey's programs.

But now that the Survey's staff of experienced mappers is diminished, what's wrong with contracting some of the mapping to competent independent geologists? Through long use of USGS geologic maps, most of us are familiar with the conventions used and quality required. Support services such as isotopic analyses could still be provided by the Survey as needed.

I understand that the Geologic Mapping Act is one of the sources of revenue wanted by federal and state geologic surveys. However, my partner and I are probably not alone in desiring some of this work. As Ph.D. geologists with extensive experience, we believe we could provide geologic maps at a competitive cost, ready for final drafting by the USGS. We'd even be willing to submit a map on spec, to show that we can work within the Survey's system.

If Rowley, Dixon, and Stevens want support for the Geologic Mapping Act, perhaps they should consider spreading out its benefits a little. Support from geologists for renewal would be much broader based.

John Trammell
Grand Junction, CO 81506

Upside of CO_2 Increase

In the November issue of *GSA Today* Bruce Molnia summarized Vice President Gore's view on glaciers and global warming: human activity (primarily, pumping "greenhouse gases," mostly carbon dioxide, into the atmosphere by burning of fossil fuels) is causing global warming, and governments must intervene to prevent drastic consequences that will be detrimental to mankind. At the end of his report Molnia admitted that the vice president's evaluation is controversial, and he promised to report further on the "debate."

However, a large body of scientific knowledge already is available such that Gore's opinions can be refuted easily without waiting for further debate. The issue is crucial, considering the Kyoto, Japan, conference to draw up a global treaty to limit emissions of greenhouse gases; if implemented, such a treaty would seriously hamper economic activity worldwide, with a commensurate increase in human misery.

Recent increase in the carbon dioxide content of the atmosphere, likely but not certainly attributable to human activity and significant back only as far as 1940, does not correlate with a global warming trend commonly cited as beginning in the early 1800s but largely finished before 1940. Following nearly two centuries of global warming, none of the disasters now being declared as the inevitable consequence of that warming have materialized. The geologic record indicates past climate fluctuations vastly more severe than that perceived for the present; in past geologic eras human activity obviously could not have been a factor. Incidentally, many respected scientists question the validity of recent global warming as proposed by environmentalists.

During the past two decades more carbon dioxide from combustion of fossil fuels has been poured into the atmosphere than in any earlier two decades, and in the recent period, the actual global temperature has decreased slightly (see, for example, Kerr in *Science*, 1995, v. 267, p. 612).

Data published recently in *Sky and Telescope* (Baliunas and Soon, December 1996) indicate a close correlation between the solar magnetic cycle and global temperature (data recorded for the past 250 years; length of cycle correlates with temperature deviation from the mean).

A significant benefit of increased carbon dioxide is that plant growth worldwide has burgeoned. For example, timber growth in the United States has increased 25% in the past 40 years (Forest Statistics of the United States, 1987; *Access to Energy*, 1993, v. 21, nos. 3 and 4). This increase is corroborated by a study of tree-ring growth which indicates that average tree-ring width, steady from about A.D. 300, has suddenly increased substantially since the mid-20th century (Graybill and Idso, *Global Biogeochemical Cycles*, 1993, v. 7, p. 81–95). The significance of plant growth increase as a result of increased atmospheric carbon dioxide is important because of its potential effect on increased food crop harvests worldwide.

In light of these facts, it seems to me irresponsible to argue that global warming is assured, and that it will modify Earth's environment to the detriment of humanity.

Daniel R. Shawe
Lakewood, CO 80226 ■

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About People

GSA Member **Vicki Cowart**, Colorado Geological Survey, Denver, has received the Distinguished Public Service to Earth Science award from the Rocky Mountain Association of Geologists.

GSA Fellow **Bilal U. Haq**, National Science Foundation, Arlington, Virginia, will receive the SEPM (Society for Sedimentary Geology) Francis P. Shepard Medal for 1998.

The Carnegie Foundation for the Advancement of Teaching named GSA Member **Barbara J. Tewksbury**, Hamilton College, Clinton, New York, as 1997 New York Professor of the Year, and Member **Kenneth Verosub**, University of California, Davis, as 1997 California Professor of the Year.

CALL FOR NOMINATIONS REMINDERS

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, councilor). Deadline for nominations for 1998 is **FEBRUARY 18, 1998.**

Distinguished Service Award

The GSA Distinguished Service Award recognizes individuals for their exceptional service to the Society. GSA Members, Fellows, Associates, or, in exceptional circumstances, GSA employees may be nominated for consideration. Any GSA member or employee may make a nomination for the award. Awardees will be selected by the Executive Committee, and all selections must be ratified by the Council. Awards may be made annually, or less frequently, at the discretion of Council. This award will be presented during the annual meeting of the Society. Deadline for nominations for 1998 is **MARCH 2, 1998.**

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 1998 award will be presented at the autumn AASG meeting to be held during the GSA Annual Meeting in Toronto, Canada.

Nominations can be made by anyone, based on the following criteria: (1) paper must be selected from GSA or state geological survey publications, (2) paper must be selected from those published during the preceding three full calendar years, (3) 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 1998 is **MARCH 30, 1998.**

National Awards

The deadline is **April 30, 1998,** for submitting nominations for these four awards: William T. Pecora Award, National Medal of Science, Vannevar Bush Award, Alan T. Waterman Award.

Materials and supporting information for any of the nominations may be sent to GSA Executive Director, Geological Society of America, P.O. Box 9140, Boulder, CO 80301. For more detailed information about the nomination procedures, see the November 1997 issue of *GSA Today,* or the Web (www.geosociety.org/admin/awards.htm), or call headquarters at (303) 447-2020, extension 140.

Rock Stars

INTRODUCTION

Bernard of Chartres, an 11th-12th century philosopher and teacher, said that we are like dwarfs on the shoulders of giants, so that we can see more than they and for a greater distance, not by any virtue of our own but because we are carried high and raised aloft by their stature.

All of us have our geological heroes, those giants on whose shoulders we stand. To encourage recognition of these luminaries and to provide inspiration for students and young professionals, the GSA History of Geology Division presents Rock Stars, brief profiles of our geological giants. If you have any comments on profiles, please contact Robert N. Ginsburg, University of Miami, RSMAS/MGG, 4600 Rickenbacker Causeway, Miami, FL 33149-1098, E-mail: rginsburg@rsmas.miami.edu.

—Robert N. Ginsburg, History of Geology Division

Karl Gilbert at age 19 (from Davis, 1926).

Model Survey Geologist: G. K. Gilbert

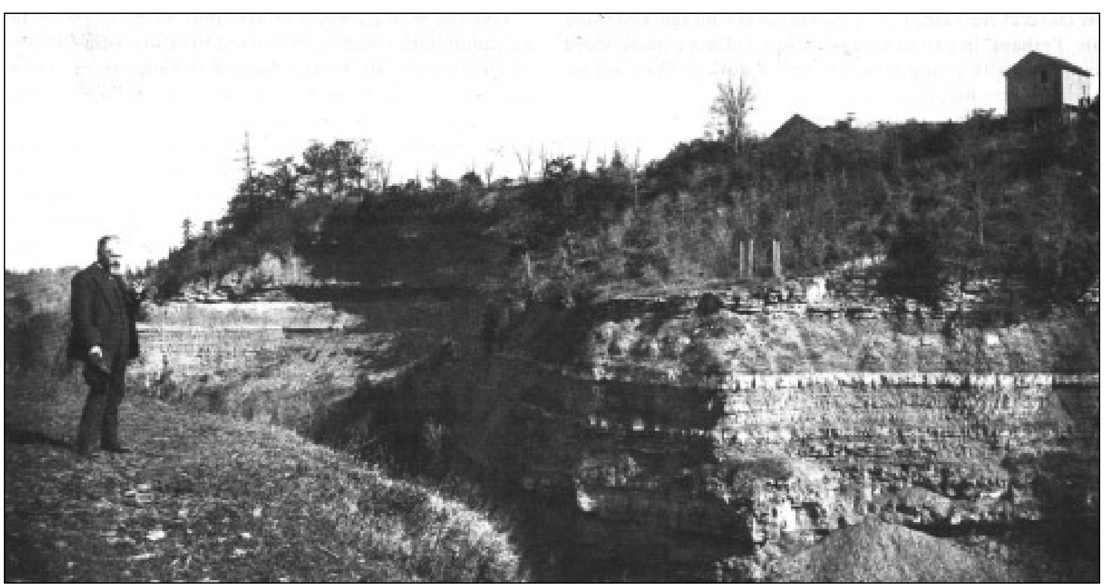
Joanne Bourgeois, University of Washington, Seattle, WA 98195

It would have been hard to predict that a rather sickly, quiet boy from Rochester, New York, would become one of the most famous geologists to explore the American West, crossing Death Valley by foot and mule, fighting upstream through the Grand Canyon, crisscrossing the basins and ranges of Utah, Arizona, and New Mexico. Not only did G. K. Gilbert survive these many adventures (as well as the 1906 San Francisco earthquake), but his scientific reports based on this and other field work are some of the best geologic papers ever written. It seems that Gilbert's geologic career started as a series of fortuitous events, but a look at his early life reveals certain qualities that may have inclined him toward the profession.

Grove Karl Gilbert, called Karl, was born in 1843 into a tightly knit family who loved to spend the evening solving puzzles and riddles, and doing other mental gymnastics. His father was something of a family maverick, a self-taught portrait painter who barely eked out a living; thus Karl's family was too poor to afford much in the way of entertainment outside the home, which they called the "Nutshell." Karl seems to have had no problem entertaining himself, though—in addition to puzzle-solving, he liked to read, including popular magazines, and was particularly fond of boating; with a friend, he built several small boats, which they took on the Genesee River near Rochester. A quiet, intelligent child, Karl was very curious, and early on, he developed excellent powers of observation. His superb physical intuition is evident in this recollection of childhood boating experiences:

> When I was a boy I noticed that by rocking a skiff I gave it a forward motion. That led to the trial of other impulses, and I found that by standing near the stern and alternately bending and straightening my legs so as to make the skiff rock endwise, I could produce a forward velocity of several yards a minute. If I stood on one side of the medial line, the skiff moved in a curve. The motions I caused directly were strictly reciprocal, the departures from initial position being equaled by the returns. The indirect result of translation was connected with reactions between the water and the oblique surfaces of the boat.

Karl finished high school at the age of 15 and, because he showed academic promise, went on to the University of Rochester, with some financial sacrifice from his family. His clothes were quite shabby and his social life restricted, but



Gilbert along the Genesee River near Rochester, New York. (Photo published in Yochelson, 1980, courtesy of USGS Photographic Library.)

he seems to have borne cheerfully and with an even temper whatever hardships came his way. He enrolled in the classical curriculum, centering on mathematics, Greek and Latin, and rhetoric and logic. Because he was fairly frail, a condition set by his father for his attending college was a program of regular outdoor exercise, and this may have inclined Karl toward geology, which was one of the minor subjects he took. His professor was Henry A. Ward, founder of Ward's Natural Science Establishment, which at that time was called Cosmos Hall. Ward collected geological and zoological specimens and supplied them primarily to museums and schools.

Karl graduated from college in 1862. Probably because he was physically weak and also perhaps because he was disinclined toward conflict, he did not enlist for military duty in the Civil War, nor was he drafted, though his name came up twice. He had debts to pay off from college, so he took a job teaching public school in Jackson, Michigan, where his older sister lived. But Gilbert had so much trouble handling unruly schoolboys that he quit even before the school year ended!

Age 19, out of a job, and with no particular idea of what to do, Karl returned to the family home in Rochester. Soon he found work at Ward's Cosmos Hall, where for the next five years (1863–1868) he catalogued samples, and, as he gained experience, collected specimens and helped mount exhibits in museums. He was left in charge of a mastodon excavation on the Mohawk River when the excavation director, James Hall, wrenched his hip. Because the skeleton was incomplete, in addition to directing the excavation, Gilbert had the opportunity to visit and study other mastodon skeletons in Boston; later he studied other fossil exhibits in New York. On these trips he had opportunities to meet with professional geologists. Also during this time, he studied mathematics, anatomy, and geology at home in the evenings.

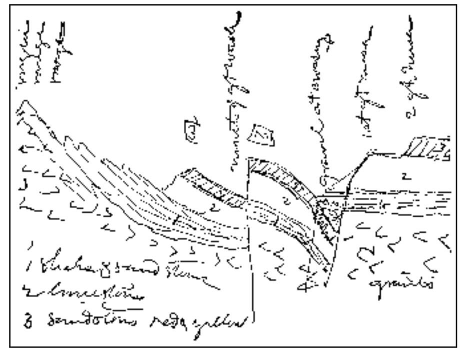
Although much of his Cosmos Hall work involved fossils, Gilbert was more interested in physical geology than in paleontology. In general, he was more attracted to processes and principles than to "facts" and catalogues. But he realized that careful, detailed description of physical evidence and a creative imagination were necessary to solve the geologic puzzles that confronted him. While excavating the mastodon, he became fascinated with potholes in the river bed, and conducted a detailed survey of 350 of them in order to determine their origin and the rate of retreat of the associated waterfall. He published both a popular account of the mastodon excavation and a technical report on the potholes, his first two publications. Gilbert later recalled that his potholes study was what attracted him to further work in geology.

Gilbert learned in the spring of 1869 that a second geological survey of Ohio was being organized, and, quite boldly, decided to go in person to ask then-governor Rutherford B. Hayes for a survey job. Upon being told that only Ohioans would be hired, he persisted by visiting J. S. Newberry, director of the survey (and a professor at Columbia School of Mines), who told Gilbert the same thing, but offered him a volunteer position, at $50/month expenses. Gilbert accepted this excellent opportunity in July 1869 and was an impressive enough worker that the next year he was offered a salaried job. His duties included conducting field work, drawing fossil plants and fish (at which he excelled), and writing reports. Newberry also employed Gilbert to help him prepare college lectures, and introduced him to several eminent geologists.

Newberry had experience on some early western surveys, so in 1871 Lieutenant G. M. Wheeler asked him to recommend a geologist for a geographical survey west of the 100th meridian; Gilbert was a natural choice. This survey was one of four competing surveys (Hayden, King, Powell, Wheeler) conducted in the early 1870s, which eventually were merged into the U.S. Geological Survey (USGS) in 1879. The Wheeler survey was ambitious, focused on military and engineering goals, and full of adventures and mishaps; Gilbert gladly moved to the Powell survey in late 1874. Gilbert had met John Wesley Powell in Washington, D.C., while working on the Wheeler reports. Gilbert and Powell became close intellectual comrades, freely exchanging ideas and support over the course of their careers. They were two of the six geologists originally hired onto the USGS, and Powell became its second director (1881–1894).

Gilbert's detailed field notebooks indicate that he was in general good-natured and even-tempered in the field, putting up with many hardships; for example: "Today my mule gave out with hunger & fatigue & I had to walk several miles, but she finally recovered so as to bring me into camp at nine o-clock, which was but an hour later than the rest." Gilbert drew cartoon sketches of his mule and of his observations, later redrawing certain views to use in scientific publications. He even put a sketch of his mule in one of his reports from the Powell expedition.

Gilbert's years on the Wheeler and Powell surveys resulted in several classic studies. He recognized the block-fault nature of the Basin Range (his term) and laccolithic nature of the Henry Mountains. The latter study also includes an essay on land sculpture emphasizing dynamic equilibrium among various parameters—slope, runoff, bedrock, etc. Then, as head of the Great Basin Division of the USGS, Gilbert studied Lake Bonneville, producing a synthesis of physiography, structure, paleoclimatology, sedimentology, and geophysics. Subsequently, after some time as head of the Appalachian Division and in other administrative duties, Gilbert returned to the West to study problems caused by hydraulic gold mining in the Sierras. This work resulted in two more classic studies—one of sediment transport, and another we would today call an "environmental impact" analysis.



Gilbert's 1871 field sketch of geology at the mouth of Colorado Canyon, near the Arizona-Nevada border (reproduced in Davis, 1926, from Gilbert's notebook).

Best known for applying quantitative techniques to physiographic problems, his well-written and well-reasoned publications show insight into a broad range of fields—survey techniques, glacial geology, lunar studies, earthquakes, method and philosophy of science. An extremely generous man, he was influential from individual to administrative levels; quite self-effacing, he was eager to give others credit. Nevertheless, he is the only person to have been appointed president of the Geological Society of America *twice* (1892 and 1909), one measure of his esteem.

Puzzle-solving, curiosity, keen observation, drawing skills, creativity, ability to get by on a low budget—these were family-established traits that set G. K. Gilbert on the road to a career in geology. Add to those his physical intuition, classical and mathematical training, cheerfulness and generosity, and a stamina that went beyond his natural condition, probably driven by his developed interest in geology. The result was a long and distinguished career of a man who was well respected—and perhaps more important, well liked—by those who knew him. ■

For Further Reading

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GSAF UPDATE

Valerie G. Brown, Director of Development, GSA Foundation

From the Ground Up

Chapter I: Thank You and Farewell!

At the 1997 annual meeting of the GSA Foundation Board in October, four senior trustees retired after distinguished service to the Board, presiding over a period of significant expansion of Foundation activities and assets.

Phil LaMoreaux's wide experience and acquaintance proved to be as meaningful as his and his wife Bunnie's outstanding generosity to GSA.

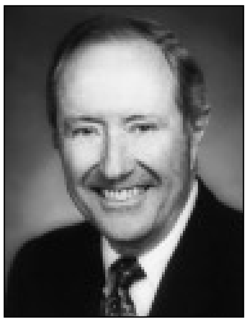
Charlie Mankin will long and deservedly be honored for his leadership as chair of the Foundation and for his commitment to the success of the Second Century Fund Campaign.

Haydn Murray also augmented his Board presence by additional participation in the formation and planning of the Second Century Fund Campaign.

Brian Skinner played two lead roles, as a trustee and as interim chair of the Second Century Fund Campaign Committee; he will remain active as the Foundation representative to the GSA Committee on Investments.

Both the Foundation and GSA have been extraordinarily fortunate to have benefited from the time, dedication, and support of these wise and generous friends.

Chapter II: Welcome!



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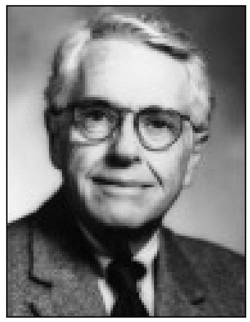

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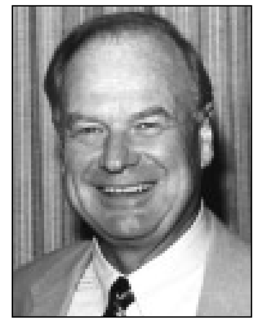


Suttner

We are equally fortunate in introducing the four new trustees, who are eager to contribute their expertise to the Foundation's ongoing engagement with GSA's mission and programs.

Bob Fuchs has already made contributions beyond calculation as Foundation president since 1992, ensuring the successful launch of the Second Century Fund Campaign. This followed nine years as GSA's treasurer, during which he also maintained an entrepreneurial stake in resource exploration and development. Bob's extensive experience as a professional geologist and as a mainstay of GSA's operations give him a unique insight into furthering the Foundation's agenda.

Dave MacKenzie is returning to active duty after having served GSA through the 1970s as a Councilor, a Bulletin Associate Editor, and a member of the Annual Meeting, Publications, and Headquarters Advisory committees. Dave has also had a notable career as a petroleum geologist. After three years in Europe and the Mediterranean with American Overseas Petroleum, Ltd., he joined Marathon Oil Company, headquartered in Littleton, Colorado. Although he "retired" in 1986 as manager of Oil and Gas Exploration based in London, he continues to work as a consultant. Dave's historical knowledge of GSA will bring an essential perspective to the board's discussions.

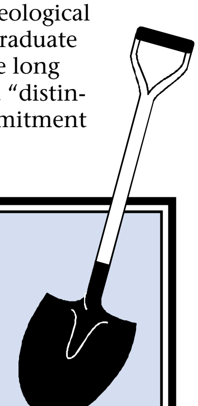
Catherine Skinner assumes the board's "Skinner Chair in Geological Science and Organizational Advancement." As a scientist, Catherine has achieved considerable renown for her unusual combination of expertise in mineralogy and human biology. Her special interest in the process of mineralization both in geological and biological systems has been manifest in many important publications. Additionally, her institutional experience with the full-time faculty of Yale University and the visiting faculties at Harvard, Cornell, and the University of Adelaide have given her significant exposure to the materialization of gift support.

Lee Suttner is transiting from several years as a leader of the Second Century Fund Campaign Committee. Lee's numerous professional and scientific activities, publications, and awards include service to GSA as a member of Council and a mainstay of programs and conferences. At Indiana University, he currently holds dual posts as chair of the Department of Geological Sciences and as associate dean of Research and Graduate Studies in the College of Arts and Sciences. In the long list of his activities, the words "outstanding" and "distinguished" appear frequently, attesting to the commitment he brings to all that he does. ■

Digging Up the Past

1955 USGS Field mapping, Four Corners area: seeing those type sections for real instead of textbook pictures — WOW!

—James Minard



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WASHINGTON REPORT

Bruce F. Molnia

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.

House Science, a Study, and a Senate Bill

"The United States has been operating under a model developed by Vannevar Bush in his 1945 report to the President entitled 'Science: The Endless Frontier.' It continues to operate under that model with little change. This approach served us very well during the Cold War, because Bush's science policy was predicated upon serving the military needs of our nation, ensuring national pride in our scientific and technological accomplishments, and developing a strong scientific, technological, and manufacturing enterprise that would serve us well not only in peace but also would be essential for this country in both the Cold War and potential hot wars…With the collapse of the Soviet Union, and the de facto end of the Cold War, the Vannevar Bush approach is no longer valid. Appealing to national pride in the sense that 'Our science is better than your science' is no longer meaningful to the American public. The needs of our military mission today are far different, and the competitions we are engaged in now are less military and largely economic. Science today is an international enterprise, and we must assume a leadership role in guiding international science policy…I know that Vern [House Science Vice Chairman Ehlers] has discussed science policy with many academic and scientific leaders from across the country and has received a positive response from the scientific community. I believe it would be a powerful role for Vern to lead, with your advice and support, the House in developing a new, sensible, coherent long-range science and technology policy."

— excerpt of House Speaker Newt Gingrich's letter to Science Chairman F. James Sensenbrenner, Jr., February 12, 1997

"These are important discussions and I am pleased that this Committee is taking the leadership in setting science policy for the next Century."

— Rep. George Brown at the start of a year-long study of U.S. science, October 23, 1997

In my opinion, the House Committee on Science is the most powerful overseer of science in the U.S. government. It is a standing committee, part of the permanent legislative structure of the House of Representatives. Originally established by Rule X of the House, the committee's jurisdiction is defined in Rule X, Section (1)(n), and includes:

1. All energy research, development, and demonstration, and projects therefor, and all federally owned or operated nonmilitary energy laboratories;
2. Astronautical research and development, including resources, personnel, equipment, and facilities;
3. Civil aviation research and development;
4. Environmental research and development;
5. Marine research;
6. Measures relating to the commercial application of energy technology;
7. National Institute of Standards and Technology, standardization of weights and measures and the metric system;
8. National Aeronautics and Space Administration;
9. National Space Council;
10. National Science Foundation;
11. National Weather Service;
12. Outer space, including exploration and control thereof;
13. Science scholarships;
14. Scientific research, development, and demonstration, and projects therefor. These activities are divided between the Committee's four subcommittees: Basic Research, Technology, Space and Aeronautics, and Energy & Environment.

In the 105th Congress, the committee, composed of 25 Republican members and 21 Democratic members, is chaired by F. James Sensenbrenner, Jr. (R—WI); former Chairman George E. Brown, Jr., (D—CA) is its ranking minority member. The other Republican members (listed by seniority) are: Sherwood L. Boehlert, New York; Harris W. Fawell, Illinois; Constance A. Morella, Maryland; Curt Weldon, Pennsylvania; Dana Rohrabacher, California; Steven Schiff, New Mexico; Joe Barton, Texas; Ken Calvert, California; Roscoe G. Bartlett, Maryland; Vernon J. Ehlers, Michigan; Dave Weldon, Florida; Matt Salmon, Arizona; Thomas M. Davis, Virginia; Gil Gutknecht, Minnesota; Mark Foley, Florida; Thomas W. Ewing, Illinois; Charles W. Pickering, Mississippi; Chris

Washington Report *continued on p. 21*

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continued from p. 19

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Washington Report *continued from p. 20*

Cannon, Utah; Kevin Brady, Texas; Merrill Cook, Utah; Phil English, Pennsylvania; George R. Nethercutt, Jr., Washington; Tom A. Coburn, Oklahoma; and Pete Sessions, Texas. The other Democratic members are: Ralph M. Hall, Texas; Bart Gordon, Tennessee; James A. Traficant, Jr., Ohio; Tim Roemer, Indiana; Robert E. Cramer, Jr., Alabama; James A. Barcia, Michigan; Paul McHale, Pennsylvania; Eddie Bernice Johnson, Texas; Alcee L. Hastings, Florida; Lynn N. Rivers, Michigan; Zoe Lofgren, California; Michael F. Doyle, Pennsylvania; Sheila Jackson Lee, Texas; Bill Luther, Minnesota; Walter H. Capps, California; Debbie Stabenow, Michigan; Bob Etheridge, North Carolina; Nick Lampson, Texas; Darlene Hooley, Oregon; and Ellen Tauscher, California.

The study requested by Gingrich will be headed by Committee Vice Chairman Vern Ehlers. Introducing the study, Sensenbrenner said: "This is an important project to help assure America's position of continued scientific excellence in the future, and I am pleased that Vice Chairman Ehlers, being a scientist himself, has agreed to lead the study."

On October 23, 1997, the Science Policy Study began with an address by Speaker Gingrich, a press conference, and a luncheon hosted by the Council on Competitiveness. This was followed by a roundtable discussion with about 35 prominent scientists and science policy makers, representatives of the Executive Branch, and several members of the Science Committee, including George Brown. Upon being introduced, Ehlers stated: "I am gratified with the personal participation of Speaker Gingrich, Chairman Sensenbrenner, and Ranking Democrat George Brown. Their personal interest indicates the priority this Congress is placing on scientific research and technological development." Roundtable participants included: Bruce Alberts, president of the National Academy of Sciences; John A. Armstrong, National Science Board; Lewis M. Branscomb, Harvard University; Allan Bromley, Yale University; Rita R. Colwell, University of Maryland; Kenneth W. Dungan, chair of the American Association of Engineering Societies; Robert J. Eagan, Sandia National Laboratories and president of the Federation of Materials Society; Clifford Gabriel, Office of Science and Technology Policy; R. C. Greenwood, chancellor of the University of California, Santa Cruz; William R. Hambrecht, chairman of the Council on Competitiveness; Sherrie Hans, The Pew Charitable Trusts; William Happer, Princeton University; Arthur Jaffe, president of the American Mathematical Society; Anita K. Jones, University of Virginia; Rowena Matthews, University of Michigan; Shirley M. Malcom, American Association for the Advancement of Science; William A. Nierenberg, director emeritus of Scripps Institution of Oceanography; Debra van Opstal, vice president of the Council on Competitiveness; Roger A. Pielke, Jr., National Center for Atmospheric Research; Roland W. Schmitt, president of the American Institute of Physics; Charles V. Shank, director of Lawrence Berkeley National Laboratories; Kenneth I. Shine, president of the Institute of Medicine; H. Guyford Stever, University of California; Harold E. Varmus, director of the National Institutes of Health; Charles M. Vest, president of Massachusetts Institute of Technology; Admiral James D. Watkins, president of the Consortium for Oceanographic Research and Education; Deborah Wince-Smith, Council on Competitiveness; William A. Wulf, president of the National Academy of Engineering; John Yochelson, president of the Council on Competitiveness; and John A. Young, retired president and CEO of Hewlett-Packard Company.

On December 8, 1997, at an Early Career Scientists Roundtable, participants were told that the goal of the study is to make a new science policy that is "long-range" in that it will last 25 years or more. Thus, it was important to get input from young scientists who are only a few years into their careers and will be living with the new policy for much of their professional lives. The attendees were urged to continue participation in the project after the roundtable, and to contact other young scientists to solicit their views about this topic. Participants were reminded of the changing environment of science policy in recent years and that the output of the study should be a broad policy statement that can serve much the same role as the broad principles laid down in the Vannevar Bush 1945 report. An example of the type of issue that could be discussed is the recommendation of that report for a central agency to fund all federally supported civilian research and development. This 1945 recommendation was never acted upon. The question of why the federal government should be involved in funding science at all, which was used to lead off the first roundtable, was also raised as a possible discussion point.

Members of the public are invited to submit letters and papers to the Science Policy Study for consideration. Also on the future agenda for the study are field briefings and hearings that will be held in spring 1998. A final report to Congress is expected at the end of 1998. The address for the Science Policy Study Web page, accessible through the Science Committee's Website, is www.house.gov/science/science_policy_study.htm.

At a press conference held the day before the kickoff for the study, Senator Phil Gramm (R—Texas) and cosponsors Senators Joe Lieberman (D—Connecticut), Jeff Bingaman (D—New Mexico), and Pete Domenici (R—New Mexico) presented the National Research Investment Act of 1998, Senate Bill 1305, a bill calling for a doubling of federal support for science, in most civilian science agencies over the next ten years. The bill specifically includes NASA, NSF, NOAA, EPA, NIST, the Smithsonian Institution, the Departments of Agriculture, Education, Energy, and Veterans Affairs, the Centers for Disease Control and Prevention, and the National Institutes of Health. The bill does not include scientific research in the Department of the Interior (DOI) or defense-related research. The omission of DOI is a carry-over from Gramm's previous objections to the activities of the former National Biological Service, now the U.S. Geological Survey's Biological Resources Division.

When introducing this new legislation, Lieberman stated that the bill "is important legislation designed to reverse a downward trend in the Federal Government's allocation to science and engineering research.… In other words, money spent to increase scientific and engineering knowledge represents an investment which pays rich dividends for America's future.… In broad terms, our innovation system consists of industrial, academic and governmental institutions working together to generate new knowledge, new technologies and people with the skills to move them effectively into the marketplace. Publicly funded science has been shown to be surprisingly important to the innovation system. A new study prepared for the National Science Foundation found that 73 percent of the main science papers cited by American industrial patents in two recent years were based on domestic and foreign research financed by governments or nonprofit agencies."

At the same press conference that unveiled the National Research Investment Act, science community representatives released a "Unified Statement on Research," which calls for a much more aggressive increase in federal funding of science. This statement has received endorsement from 106 science organizations, including the Geological Society of America. Collectively, these organizations represent more than 3,000,000 scientists and engineers. According to American Physical Society President and former Presidential Science Advisor D. Allan Bromley, the unified statement is "a call for a renewed commitment to investment in science and technology." The statement is available at the American Chemical Society's Web site. A future Washington Report will examine the progress made by the House Science Committee's Science Policy Study and the fate of the National Research Investment Act of 1998. ■

Forests as Carbon Sinks

***David J. Verardo**, 1997–1998 GSA Congressional Science Fellow*

On October 22, 1997, while many GSA members were engaged in the annual meeting in Salt Lake City, President Clinton unveiled his Climate Change Program. As broadly outlined at the time, the proposal called for $5 billion in spending for research and development and tax incentives to reduce atmospheric greenhouse gases. While the proposal was the first step in a comprehensive strategy to reduce levels of greenhouse gases in the atmosphere, it was heavily dependent on technological fixes to achieve its goal. Other cost-effective biological approaches were overlooked. Specifically, the Administration overlooked the capacity of domestic forests to sequester carbon.

Recognizing this oversight and the potential contribution from Oregon on this issue, U.S. Senator Ron Wyden (D—OR) urged the Administration to explicitly incorporate forest management programs into any national strategy for climate change. In a November letter to President Clinton, Sen. Wyden noted: "Forests possess an enormous capacity to absorb atmospheric CO_2 and act as natural and long-term carbon sinks. Since their development some 360 million years ago, forests have helped regulate atmospheric CO_2 levels. The enclosed fossilized laurel leaf is 50 million years old and provides mute testimony to the success of the most basic biological form of CO_2 regulation on Earth. The basic structure of the leaf, the point of uptake for CO_2, has remained virtually unchanged for eons because it works and works well. The forest ecosystem is an effective sink for carbon because it uses CO_2 for growth of vegetation and then stores carbon in soils and biomass. The forests of the Pacific Northwest are some of the most productive forests on Earth and are often overlooked for their tremendous value as carbon sinks. Today, ongoing studies from industry, academia, and government show that reforestation and sensible forest management strategies are cost-effective means to help achieve your goal of reaching 1990 levels of atmospheric CO_2 by 2008–2012."

In considering a legislative initiative to address atmospheric CO_2 reductions, two concerns were raised. First, how did Oregon contribute to the problem, and what could it contribute toward a solution? Oregon already had laws controlling greenhouse gas emissions and was the first state to require mandatory reductions in atmospheric CO_2. Moreover, the scientific basis for carbon sequestration by forests was sound. Studies of domestic forests in the United States showed that on-the-ground forest management programs that included tree planting and careful harvesting could effectively reduce excess atmospheric CO_2 concentrations by 30% of the President's goal at a cost of $2 to $20 per ton of carbon. That was much less costly than emissions controls or carbon taxes which were estimated to cost up to $100 per ton of carbon. Even so, the remaining 70% of the Administration's goals must eventually come from reduced gas emissions and increased energy efficiency. When analyzed for their total benefit, forestry efforts were attractive because they provided for early action and ancillary environmental benefits such as watershed and habitat protection and reduced risk of landslides.

Next, how could the public be helped to understand, in a simple way, the importance of trees to carbon sequestration? Luckily, most people generally understand the role that vegetation plays in atmospheric chemistry. What they often do not realize, however, is that forests and atmospheric carbon have been linked for hundreds of millions of years. To illustrate this latter point, a fossil leaf was included in the letter sent to President Clinton to provide tangible evidence of the timelessness of this process. Such a strategy proved useful to the general public as well, judging by responses following Sen. Wyden's press conferences announcing the forest initiative. At this point, the objective of winning hearts and minds was achieved. The struggle for the pocketbook, however, remains.

The forest ecosystem is an effective sink for carbon because it uses CO_2 for growth of vegetation and then stores carbon in soils and biomass.

Using forests for CO_2 mitigation received strong support by timber and fossil fuel companies, environmental organizations, and community groups. Unlikely partners such as British Petroleum and the Environmental Defense Fund joined ranks with Mobil Oil and timber and utility companies in committing corporate funds to domestic reforestation efforts. Historically, many local civic groups across the nation consistently promoted the planting of trees for their energy reduction (through shading) and beautification value. So, Americans from the corporate to community level recognize the value of forests. The next step, to be pursued during the second session of the 105th Congress, is to develop a suitable technical strategy and provide funding to best use this renewable resource.

Are forest management strategies a panacea for greenhouse gas reductions? Certainly not, because the problem is larger and the solution more complicated than simply planting trees. For a national program to be effective, it must take into account the concerns of all stakeholders and provide financial incentives for action. In this manner, industries that are part of the problem are also part of the solution. Also, since there are no physical barriers to CO_2 migration in the atmosphere, other nations will ultimately need to act, as well. Tree planting and forest management, however, provide a time-proven inexpensive carbon mitigation technique.

In formulating public policy, it is not enough to get the science right; to get the right science is also necessary, by exploring many possibilities. In a 1978 paper in the journal *Science*, M. Morgan wrote: "Good policy analysis recognizes that physical truth may be poorly or incompletely known. Its objective is to evaluate, order, and structure incomplete knowledge so as to allow decisions to be made with as complete an understanding as possible of the current state of knowledge, its limitations, and its implications." A difficult task, no doubt, but on the issue of using trees to reduce greenhouse gases, early indications are that forests provide a win-win solution. ■

David J. Verardo, 1997–1998 GSA Congressional Science Fellow, serves on the staff of Senator Ron Wyden (D—OR). The one-year fellowship is supported by GSA and by the U.S. Geological Survey, Department of the Interior, under Assistance Award 1434-HQ-97-GR-03188. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government or GSA. You can contact the author by mail at 717 Hart Senate Building, Washington, D.C. 20510, by phone at (202) 224-3430, or by e-mail at david_verardo@wyden.senate.gov

Tectonics of Continental Interiors

Conveners:
Stephen Marshak, *Department of Geology, University of Illinois, 1301 W. Green St., Urbana, IL 61801, smarshak@uiuc.edu*
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Continental interiors include those parts of continents that do not border an oceanic basin, do not lie within a plate-margin orogenic belt, and/or do not contain a Cenozoic suture. These regions include cratons (platforms and shields), as well as intracontinental mountain belts, such as the Tien Shan of central Asia, and the "Laramide-style" deformation provinces of North and South America. Continental interiors contain a fascinating, but relatively little studied, record of tectonic activity. We convened a Penrose Conference September 23–28, 1997, with the purpose of bringing together an international and interdisciplinary group of geoscientists to assess the current state of knowledge about continental interiors and to outline future research directions concerning these regions. Attendees included 101 geoscientists from 17 countries, who converged for five days at the Brian Head Resort, along the edge of the Colorado Plateau near Cedar Breaks in southern Utah, to study poster displays, hear talks, share in the discussions, and participate in field trips focused on continental interior tectonics.

We divided the conference into four sessions, each including lectures by one or two keynote speakers. Session 1, "Formation, Character, and Fabric," included a keynote by Çelal Sengör on the processes by which continental crust assembles and becomes cratonized. Session 2, "Epeirogeny, Basins, and Paleostress," featured keynotes by Michael Gurnis on the effect of mantle processes and subduction on continental stratigraphy and epeirogeny, and by Sierd Cloetingh on intracontinental basins and intraplate stress. The keynote for Session 3, "Continental-Interior Deformation," by Leigh Royden, was on quantitative analysis of extension in continents. Session 4, "Seismicity and Neotectonics" included a keynote by Mary Lou Zoback on stress and seismicity in continental interiors. Two field trips, led by George Davis, provided participants with the opportunity to examine the transition between the Basin-and-Range province and the Colorado Plateau in the western United States and to see the style of deformation in the Colorado Plateau.

The conference successfully provided a unique opportunity for a mix of geologists and geophysicists to learn about a vast array of related topics, including the petrology and structure of Precambrian provinces, strength as a function of depth in the lithosphere, seismic anisotropy in the subcontinental mantle, the distribution of earthquakes and faults in platform regions, Cenozoic tectonism of central Asia, advances in understanding the Laramide province, fission-track–based uplift history and geomorphology of central Australia, advances in basin subsidence analysis, the nature of stress and strain in affecting Midcontinent U.S. strata, new insight into the nature of deep continental crust from the study of high-pressure lithologies in shield areas, strain rates in intracontinental seismogenic zones and recurrence intervals of continental-interior earthquakes, and initial results of ongoing GPS measurements of contemporary crustal movements—among many other topics!

In this report, we highlight key *questions* raised by the presentations. We emphasize the questions because most participants would agree that in the end, the conference indicated a need for further study, rather than producing a consensus that key issues have been resolved.

What Is a "Continental Interior"?

The diversity of contributions to the conference emphasized that while most geologists intuitively distinguish among continental margins and continental interiors, there is disagreement about where to draw the boundary between these provinces, and whether such a distinction serves a useful purpose. Clearly, the Phanerozoic tectonic character of the U.S. Midcontinent differs from the tectonic character of the Andean orogen, but does a region like the Tien Shan behave more like the latter or like the former? Most participants concluded that there is indeed value in distinguishing among different kinds of crust on the basis of vertical strength profiles, on response to stress, and on strain style.

How Did Continental Interiors Evolve During the Precambrian?

Participants saw an image of continental interiors as forming from accreted arc terranes, brought together either by subduction or by vast strike-slip duplexing. Participants also learned about similarities and differences between tectonic processes in the Precambrian and tectonic processes of the Phanerozoic, ultimately reflecting contrasts in heat flow between the Precambrian and contemporary Earth, progressive devolatilization of deeper crust through time, and a long-term decrease in oceanic crustal thickness. Construction processes, by their nature, yielded continents with pronounced fabrics that affect the geometry of later tectonism. Conference participants also saw evidence for the existence of Precambrian continental-

Tectonics *continued on p. 24*

Penrose Conference Participants

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Fernando F. Alkmim
Walter Alvarez
Bernd Andeweg
Dragan Andjelkovic
Irina Artemieva
Donald L. Baars
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Steve Boger
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Robert Casavant
Ibrahim Cemen
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Wang-Ping Chen
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Dickson Cunningham
Gregory A. Davis
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Tim de Freitas
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Charles M. Onasch
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Leigh H. Royden
Mary Sanborn-Barrie
Christopher Schmidt
David Schwartz
Deborah Scott
A. M. Çelal Sengör
Colin Shaw
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Basil Tikoff
Sarah Tindall
Roy Van Arsdale
George Viele
Lev Vinnik
Yu Wang
Phil Wannamaker
Tim Wawrzyniec
Shimon Wdowinski
John Weber
Russell Wheeler
Terry J. Wilson
Donald U. Wise
An Yin
Tanja Zegers
Mary Lou Zoback

Tectonics *continued from p. 23*

interior orogens in the Canadian Shield and in the interior of Australia.

How Do Continental Interiors Become "Cratonized"?

Though the semantics of how to define a continental interior remained vague, there was no disagreement at the conference that some parts of continents—the cratons—are stronger than others, and have not undergone intense metamorphism and deformation since the Precambrian. In fact, such contrasts in continental crustal character were shown, quantitatively, to control the style of crustal rifting. Conference participants debated the issue of how continental crust becomes "cratonized." Does cratonization merely reflect the progressive slow cooling of continental lithosphere (thermal structure in continents changes with time), so that continental crust becomes stronger as it ages? Does it require the distillation, by igneous processes, of silicic components and volatiles out of the lower crust and migration of these components into the upper crust, thereby leaving a stronger, mafic, layer in the lower crust? Or does the strength derive from basalt depletion of the lithospheric mantle, or from a sublithosphere root composed of partially subducted Archean oceanic slabs? Participants also discussed the issue of whether cratonization could only happen in the Archean or Paleoproterozoic, or whether it could eventually happen to recently formed continental interiors such as central Asia.

What Do Continental Interiors Look Like at Depth?

Layered reflectors at depth continue to be enigmatic. In some, but not all, cases, cratons are a seismic "layer cake," but on closer examination, there seem to be distinct differences in the layering. Participants debated whether the asthenosphere beneath continental interiors is anisotropic, which may indicate the presence of a broad region of shear in the asthenosphere as continental plates move.

Why Do Epeirogenic Movements Occur in Continental Interiors?

Continental interiors have undergone broad, regional vertical displacements—i.e., "epeirogeny." Some of these movements yield discrete basins, domes, or arches; others appear to reflect tilting of whole continents or change in freeboard. Conference participants examined the record of epeirogenic movements, as recorded by stratigraphy and by fission-track dating studies. They debated the concept of dynamic topography, which relates epeirogeny to flow within the mantle (e.g., sinking of dense oceanic slabs), and the concept that pulses of epeirogeny reflect the movement of uncompensated loads that occurs when there is a decrease in lithosphere strength caused by thermal changes or by changes in stress state. A broad region of epeirogenic uplift encompasses the southern Urals, and freeboard of continents has not varied substantially through time (thus, there may be a feedback mechanism controlling freeboard).

What Is the Nature of Continental Interior Deformation?

The deformation of continental interiors yields at least four kinds of structures: epeirogenic depressions and uplifts, discrete fault-and-fold zones, penetrative strains in cover strata, and fracture arrays. In some cases, such structures are relatively subtle and lead to the false conclusion that interiors are completely stable, whereas in other cases, such structures are dramatic and yield major topography. Evidence presented at the conference supports the hypothesis that preexisting fabrics and faults to a large extent localize strain in continental interiors. But there were differing opinions concerning the proportion of strain due to stresses transmitted to the interior from interactions at continental margins relative to the proportion of strain resulting from lithosphere-asthenosphere interaction.

Intracontinental deformation in diverse geographic settings, including Central Asia (e.g., Tien Shan, Pamirs, Mongolia), southern South America (Pampean Ranges), western United States (Colorado Plateau and Rocky Mountains), and the U.S. Midcontinent shows pronounced similarities—for example, structures of the U.S. Midcontinent resemble structures of the Laramide-style provinces of the western United States and southern South America. In many, but not all, cases, the deformation appears to have involved reactivation of preexisting fault zones, some of which were associated with older rifting events. Some continental interior orogens are dominated by basement-involved thrusting or transpression, while others contain dominantly strike-slip faults with local uplifts related to restraining bends. Continental-interior deformation is most pronounced during marginal collisional or convergent tectonism, but it can occur at other times as well (as illustrated by contemporary seismicity in the New Madrid area). Presenters restated a key point throughout the meeting—significant strain occurs in localized areas in continental interiors.

What Is the Nature of Continental Interior Seismicity and Stress?

Participants debated whether or not seismicity can be associated with distinct preexisting fault zones, whether seismicity is affected by fluid pressure variations in the crust, and whether characteristics of contemporary seismic zones, such as the New Madrid zone of the central United States, serve as a model of continental interior seismicity in general or are simply an anomaly. Could seismicity suddenly migrate to other regions? Is it linked to the intersections of fault zones? Ongoing studies aim to characterize seismic recurrence intervals and strain rates in continental interior seismic zones of Asia and North America. The question of why significant uplift does not necessarily occur around contemporary seismic zones remains unanswered, as do questions regarding the source of stress driving seismicity. Recent stress measurement studies suggest that the continental crust is just about at a state of failure, so that very slight increases in differential stress can trigger earthquakes. Clearly, a better understanding of strength as a function of depth in the continents will provide important constraints on models of continental dynamics.

SUMMARY

This Penrose Conference highlighted current accomplishments of research on interiors of continents and suggested many problem areas that require additional work. The conference demonstrated that there has been significant progress toward development of a comprehensive model explaining the origin and behavior of continental interiors, but that such a model is not yet complete. Its ultimate formulation will require input from many geoscience disciplines.

ACKNOWLEDGMENTS

We thank the Geological Society of America for sponsoring this conference and for providing funds to help support student participation. We are very grateful to the Tectonics Program (Tom Wright) of the National Science Foundation and the Office of External Research (John Sims) of the U.S. Geological Survey for providing grants that helped support students, overseas participants, keynote speakers, and the field trip. We also greatly appreciated the participation of George Davis, who organized two superb field trips; Bill Lund of the Utah Geological Survey, who set up the poster-display facility and helped with numerous logistical issues; Leonard Johnson, who described NSF funding opportunities to the participants; and the keynote speakers (Çelal Sengör, Sierd Cloetingh, Mike Gurnis, Mary Lou Zoback, Leigh Royden, and Larry Brown), who provided a solid framework for the meeting. We thank Lois Elms for expertly handling the conference logistics; the staff of the Brian Head Lodge, who helped make the meeting run smoothly despite El Niño and Hurricane Nora; and Wang-Ping Chen for reviewing a draft of this report. ■

Faults and Subsurface Fluid Flow: Fundamentals and Applications to Hydrogeology and Petroleum Geology

Conveners:
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Representatives from academia, industry, and government agencies participated in the Penrose Conference "Faults and Subsurface Fluid Flow: Fundamentals and Applications to Hydrogeology and Petroleum Geology" held September 10–15, 1997, in Albuquerque and Taos, New Mexico. The mixture of structural geologists, geochemists, hydrogeologists, engineers, and petroleum geologists encouraged fruitful interdisciplinary exchanges, and the conference benefited from the active participation of 11 students, who received significant financial support from a variety of sources (see acknowledgments).

The conference began with a short field trip in the Albuquerque area, followed by a trip to Taos for three days of talks, posters, and discussions. We initially focused on primarily geologic studies of individual faults and fault zones, progressed to laboratory and field studies involving the quantification of permeability changes related to faulting, geochemical and geophysical techniques for investigating fault-fluid interactions, and finally addressed basin-scale studies and applications to petroleum geology.

Discussions, Opinions, and Implications

Six key points deserve special mention.

1. Fault zones, whether developed in sediments, sedimentary rock, or crystalline rock, are structurally and hydrologically heterogeneous. One of the more provocative statements, offered by an environmental consultant, was that much of the fault characterization work conducted in the academic community was too arcane and at scales too detailed to be of immediate use to practitioners. The group agreed that including modelers in a given project at an early stage would ensure collection of geologic and hydrologic data necessary and appropriate for mathematical models. Modelers, however, are still asking how these data should be generalized for use in flow and transport models. All agreed that scales of observation and methods for upscaling measurements of properties such as permeability are critical issues.

2. One participant noted that most data on the relation between faults and fluid flow have been collected in areas populated by normal faults. Thrust faults have been studied to a lesser extent and strike-slip faults have, with few exceptions, been ignored. The group agreed that the degree to which data collected from one tectonic setting could be applied to another is undetermined.

3. The field trip and subsequent talks and posters emphasized differences between fault-zone structures and deformation processes in rock and those in poorly consolidated sediments. These differences have implications for the hydrogeologic characterization of individual faults. For example, the Sand Hill fault, subject of the field trip, cuts poorly consolidated sediments and is characterized by an absence of open fractures and by extensive grain-scale tectonic mixing of sediments such as sands and clays. On the other hand, faults in rocks may exhibit extensive fracture networks and flow channels.

4. The wide variety of geochemical techniques currently available allows characterization of fluid sources resulting in fault-zone diagenesis. These techniques offer a window into paleo–fault-zone plumbing. Integration of diagenetic studies with other fault-zone research can promote an understanding of the relative timing of cementation versus deformation, and allow us to better characterize faults as dynamic systems. Geochemists in the group also emphasized the importance of thermodynamic testing of models of rock-fluid interaction, models that are often proposed by geologists and geophysicists with limited geochemical background. The latter can be unaware of advances in understanding of geochemical processes, such as the importance of fluid mixing and biogenic activity in the precipitation of cements.

5. Advances in interpreting seismic reflection profiles, especially those of saturated faults in accretionary prisms, suggest the possibility of better subsurface characterization of fault-zone features. Part of the lesson to be learned may be that researchers working in different tectonic environments should spend more time talking to each other.

6. Participants considered how discussions started at the meeting might be translated into long-term collaborative relationships and continued interaction among representatives of different disciplines. Further discussion centered around industry funding of academic research. Petroleum industry representatives emphasized that academic researchers could indeed successfully work in concert with industrial sponsors, but that the research has to provide solutions to practical problems in an economical and timely manner. Industry will generally not fund vague or overly generalized projects that do not appear to hold promise of future economic benefit. Others raised the point that the kinds of studies that would be of most practical use are the most expensive and generally beyond the resources of funding sources such as the NSF hydrologic sciences or tectonics programs (e.g., large-scale drilling and fault characterization projects). Academic-industrial consortia were suggested as one possible solution, using the ongoing collaborative work in Dixie Valley as an example, and the Ventura anticline was suggested as a possible target for collaborative effort because of the wealth of petroleum industry data.

Field Trip

The Sand Hill fault is one of the major normal faults bounding the Rio Grande rift. Where exposed, it juxtaposes synrift sediments of the uppermost Oligocene to middle Miocene lower Santa Fe Group against those of the Pliocene to lower Pleistocene upper Santa Fe Group. Field relationships indicate that the Sand Hill fault, like other faults associated with the Rio Grande rift, is a growth fault. As a consequence, sediments of different ages that have been cut by the fault have undergone different amounts of slip. Subsurface data indicate that the base of the lower Santa Fe Group is offset about 600 m by the fault. In contrast, recent mapping by Michiel Heynekamp shows that the uppermost unit of the upper Santa Fe

Fluid Flow *continued on p. 26*

Fluid Flow *continued from p. 25*

Group, the youngest unit cut by the fault, is offset only about 10 m.

Heynekamp's work further indicates that deformation and cementation are largely controlled by the grain size of the faulted sediments. Where juxtaposed sediments are fine grained, the zone of deformation is narrow and structurally simple, and the fault is only lightly cemented with micritic calcite. Where juxtaposed sediments are coarse grained, the zone of deformation is wide and structurally complicated, and the fault is cemented with sparry calcite cement. Like faults in rock, the Sand Hill fault includes a damage zone (with minor slip surfaces, deformation bands, and folded beds) and a core zone (clay-rich along most of the fault). In contrast to faults in rock, it also contains mixed zones that flank the fault core. The mixed zones contain everything from little deformed pods of sediment to tectonically well mixed sediments, in which material from different beds is mixed almost to the point of homogenization.

Where the hanging-wall mixed zone is coarse grained, it is typically heavily cemented with calcite, in some places forming elongate concretions believed to be paleoflow direction indicators. Neither the genesis of the cement nor the spatial variability of elongate concretion orientations in and directly adjacent to the fault are well understood. Discussions focused on the unresolved problems and on development of fault-zone foliations and lineations, reasons for the absence of open fractures in uncemented sediments and cemented zones, development of the mixed zones, and mechanisms for the formation of oriented concretions.

Fault Zone Architecture

The Taos part of the conference began with a session devoted to fault-zone architecture and characterization, including the opening talks, "Models of fault zone architecture and permeability structure" (Forster), "Self-generation of fracture permeability by migrating fluids" (Sibson), and "Structural characteristics of flow channel geometry along faults" (Bruhn).

Poster presentations included "Correlation of clay mineralogy, sediment physical properties and the development of structural discontinuities in the northern Barbados Accretionary Complex" (Brückmann), "Architecture, permeability structure, and evidence for fluid flow in Fault 6, Traill Ø, east Greenland" (Caine, Forster, and Bruhn), "A method for sampling faults in unconsolidated sediments" (Dimeo), "Grain size controls on fault-zone architecture of the Sand Hill fault zone" (Heynekamp, Mozley, and Goodwin), "A collaborative study of the Sand Hill fault in New Mexico" (Holl, Shea, Vrolijk, and Fairchild), "Fluid flow properties and sealing mechanisms of a cored fault zone in the Hickory Sandstone aquifer, Texas Hill Country" (Ibáñez, Shea, and Johnson), "Three-dimensional structure of small faults and hydrogeologic implications" (Martel and Boger), "GIS fault database of the middle Rio Grande basin: Georeferenced fault-characterization data input for hydrogeologic models" (Minor), and "Characterization of fault-related ground-water compartmentalization in a porous sandstone aquifer in the Texas Hill Country" (Johnson).

Modification of Permeability Through Deformation

The second session of the conference provided a bridge from primarily geometric studies of fault zones to the question of the influence of faulting on the permeability of sediments and rocks. Introductory talks were: "Laboratory studies of sandstone deformation" (Wong), "Permeability of fault zones within siliciclastic and carbonate rocks" (Antonellini), and "Fault-zone deformation of poorly consolidated sediments" (Goodwin, Heynekamp and Haneberg).

Posters presented at the session were: "Seismogenic faulting and fluid flow at 550–700 m depth: Products of Hyogoken-Nanbu (Kobe) earthquake" (Agar et al.), "Fluid pathways provided by contemporaneous activity of thrust and normal faults during the Marche thrust belt development, central Apennines, Italy" (Ghisetti and Vezzani), "Vertical discharge of extremely overpressured fluids along growth faults in the Rio Grande Embayment, Gulf of Mexico Basin, USA" (McKenna), "Analysis of brittle deformation and permeability structure of cataclastic faults in porous sandstone" (Myers), "Fault and fracture network controls on hydrocarbon migration and fault sealing in deep-water sandstone reservoirs" (Nelson), "Changes in petrophysical and hydraulic characteristics of faulted poorly consolidated sand, Santa Fe Group, central NM" (Sigda and Wilson), "Structural features as fast pathways at Yucca Mountain, Nevada" (Sweetkind), and "The brittle-ductile transition and permeability evolution: Experimental measurement, microstructural observations, and network modeling" (Zhu and Wong).

Geophysical Studies and New Techniques

The third session, concerned with geophysical methods and new techniques, opened with the talks "Faults and fluid flow in accretionary prisms: Contrasts to hard rock examples and applicability of geophysical tools" (Casey Moore), "Dynamic elastic properties of fault zones in fine-grained marine sediments: Implications for seismic imaging of pore pressure and fluid content" (Tobin), and "Geophysical investigations of faults and fluid flow in Dixie Valley" (Barton).

Posters presented were "Deep hydraulic fracture tiltmeter imaging" and "San Andreas near-field stress state" (Castillo), "The use of seismic methods to locate deep water wells within fault and fracture zones: An example from Flagstaff, Arizona" (Catchings), "Initiation and evolution of fault zones in accretionary prisms: Comparing cores, logs, seismic amplitude, and seismic coherency" (C. DiLeonardo and J. C. Moore), "Investigation of the hydraulic response of faults identified by geophysical studies at Owens Lake, California" (Jacobson), "Use of tritium data to define and model the hydraulics and contaminant transport of a faulted clay at a DNAPL site" (Losonsky), and "GIS-based analysis of subsurface fluid migration in sedimentary basins (Paulus)

Fluid-Rock Interaction and Hydrothermal Systems

Opening talks were: "Geochemistry of fluids and their role on the dynamics of the San Andreas fault, California" (Kharaka, Kennedy, Evans, and Thordsen),

Fluid Flow *continued on p. 27*

Penrose Conference Participants

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Marco Antonellini
Colleen Barton
Craig Bethke
Venugopal Bhat
Claudia Borchert
Warner Bruckmann
Ronald L. Bruhn
Michael P. Bunds
Michael C. Carpenter
David A. Castillo
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Dana Coffield
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Mike Whitworth
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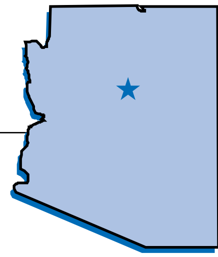
John Wilson
Teng-fong Wong
Wenlu Zhu

Final Announcement

ROCKY MOUNTAIN SECTION, GSA 50th Annual Meeting

Flagstaff, Arizona May 25–26, 1998



The Rocky Mountain Section of the Geological Society of America and the Department of Geology at Northern Arizona University in Flagstaff will host the 1998 section meeting on the campus of Northern Arizona University.

SETTING

The 50th annual meeting of the GSA Rocky Mountain Section will be held at the DuBois Center on the campus of Northern Arizona University. Flagstaff is at the base of San Francisco Mountain, a composite cone over 12,600 feet in elevation—the highest point in Arizona. The San Francisco volcanic field covers about 2,000 square miles along the southern margin of the Colorado Plateau. There are more than 550 vents in the area, the latest eruption occurring in A.D. 1065 and leaving Sunset Crater, 15 miles north of Flagstaff and but one of many easily accessible volcanic features in the area. Flagstaff is situated on the southern margin of the Colorado Plateau province near the transition into the Basin and Range to the south. Excellent exposures of mid- to late Paleozoic strata occur south of Flagstaff in the Red Rock country near Sedona, Arizona. To the north fluvial and eolian strata of Triassic and Jurassic age crop out throughout the Navajo and Hopi reservations and in the Lake Powell–Glen Canyon region. Grand Canyon National Park is 80 miles north of Flagstaff and Petrified Forest National Park is 120 miles to the east.

During late May, the days are typically clear, with temperatures averaging 75–80 °F, and the nights are cool and pleasant; there is little precipitation this time of year. The weather should be ideal for field excursions and trips to nearby scenic areas and parks, as well as visits to Lowell Observatory, the Museum of Northern Arizona, and Meteor Crater.

Flagstaff lies at the junction of Interstates 40 and 17 and thus is easily reached by car. Rail service is available from the east and west. Flagstaff airport is approximately 3 miles south of the city.

Rocky Mountain *continued on p. 28*

Fluid Flow *continued from p. 26*

and "Ion microprobe (SIMS) work on carbonate veins from the Cascadia drilling leg 146—Mathematical modeling of fluid flow, heat transport, and deformation" (Sample).

The posters presented in this session were: "Fluid flow and mixing across gouge-filled fault cores" (Bunds), "Scale and rates of fault-related fluid flow in the Miocene Monterey Formation, coastal California" (Eichhubl and J. R. Boles), "Fault influence on fluid flow and reservoir diagenesis" (Lee), "Mineralogic associations of fault and fracture flowpaths in tuff, Yucca Mountain, Nevada" (Levy), "Evolution of Rio Grande Rift barite-fluorite-galena deposits, New Mexico" (McLemore), "Evolution of fracture permeability under hydrothermal conditions" (Moore), "Formation mechanism of fracture-vein system in geothermal reservoirs" (Tamanyu), and "The close interrelationships between jointing, pressure solution and mass transfer that together play a crucial role in the nucleation of faults in limestones exposed along the Bristol Channel, UK" (Willemse).

Mathematical Modeling of Fluid Flow, Heat Transport, and Deformation

Opening talks were: "Coupled models of ground-water flow and heat transport" (Smith), "Numerical simulations of granular shear zones using the distinct element method" (Morgan), and "Hydrostructural facies—A bridge between the field and models" (Haneberg).

The posters were: "Importance of alteration reactions for the brittle Death Valley fault zone" (Cladouhos, P. J. Vrolijk, D. S. Cowan, Morgan), "Modeling potential fault-related fast-pathways in the vicinity of Yucca Mountain, Nevada" (Czarnecki), "Modeling fault propagation in compressive stress regime" (Germanovich), "Integration of tectonic heterogeneities into advanced reservoir simulations: Methodology and applications" (A. G. Koestler), "Modeling fluid flow and heat transfer at Basin and Range faults" (Lopez, Smith, M. Sorey), "Micromechanics of localization in granular shear zones revealed by DEM simulations: The role of particle size distribution and interparticle friction" (Morgan), "Fluid flow pathways in fractured porous media at the outcrop scale: Integration of field observations and numerical modeling" (Taylor), "The influence of the San Andreas fault on ground-water flow in the upper Coachella Valley, California: A mathematical modeling investigation" (Mayer), and "Results of current investigations into fluid flow along growth faults in the Gulf of Mexico" (Roberts).

Basin-Scale Studies and Petroleum Geology

The two opening talks of this session were: "Modeling basin scale fluid flow" (Person), and "Trapping mechanisms and producing characteristics of faulted sandstone reservoirs" (Shea).

Posters were: "Timor Sea fault-seal integrity" (Castillo), "Fault geometry and fault conductivity studies, Prudhoe Bay Field, North Slope, Alaska" (Coffield et al.), "Structural and tectonic constraints on fracture zone aquifers of Northern Oman" (Fielding), "Evaluating fault-controlled fluid flow in an exhumed petroleum reservoir" (Forster), "Fault-controlled basin-scale fluid migration of mineralizing fluids in the northeastern Rhenish Massif, Germany" (Grobe), "The significance of fracture-redirected recharge on the water budget of an arid alluvial aquifer, Indian Wells Valley, California" (Thyne and J. Gillespie), "The influence of structural features on regional ground-water flow in the Salt Basin and Toyah Basin of West Texas" (Uliana), and "Tectonic controls on the hydrothermal evolution of the Rio Grande rift near Socorro" (Person).

ACKNOWLEDGMENTS

Financial support for the conference was provided by the Geological Society of America, the National Science Foundation, Exxon Production Research, Daniel B. Stephens & Associates, the New Mexico Geological Society, the New Mexico Bureau of Mines & Mineral Resources, and the New Mexico Tech Office of Research & Economic Development. We also thank Rita Case for her secretarial support, Lois Elms for her logistical expertise, and the staff of the Sagebrush Inn for their attentive service. This report is also available at http://www.nmt.edu/~haneberg/PenroseAnnouncement.html. ■

Rocky Mountain *continued from p. 27*

REGISTRATION

Preregistration Deadline: *April 24, 1998*

Preregistration fees are lower than on-site fees, so preregister as soon as possible. Name badges will be mailed to the preregistrants at least three weeks before the meeting. Badges must be worn for access to all activities from 6 p.m. Sunday, May 24, through 5 p.m. Tuesday, May 26.

Members of GSA and its associated Societies pay discounted fees. Please indicate your affiliation(s) to register using the member rates.

Full payment MUST accompany registration. Unpaid purchase orders are NOT accepted as valid registration. Charge cards are accepted as indicated on the preregistration form. Please recheck the card numbers, because errors will delay your registration. The confirmation card will be your receipt for all payments. No other receipts will be sent.

Register one professional or student per form. Copy the form for your records.

Guest registration is required for those attending guest activities, technical sessions, or the exhibit hall. Guest registrants MUST be accompanied by a professional or student registrant. A guest is defined as a nongeologist spouse or friend of a professional or student registrant.

Students and K–12 teachers must show a *current* ID in order to obtain these rates. Students or teachers not having a current ID when registering will be required to pay the professional fee.

It is important that the preregistration deadline be met because the badges and other meeting information will be mailed to the registrants. All registrations received after this date will be held for on-site processing and charged on-site rates. Packets containing restaurant and local information will be mailed following receipt of preregistration forms.

On-site registration will be on Sunday, May 24, from 4 to 8 p.m., Monday, May 25, from 7 a.m. to 4:30 p.m., and Tuesday, May 26, from 7 a.m. to 12 noon, in the ballroom of the DuBois Center on the Northern Arizona University campus. For additional information, contact Michael Ort (Michael.Ort@nau.edu), Registration Chairperson, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011.

GSA is committed to making every event at the 1998 Rocky Mountain Section meeting accessible to all people. If you have any special needs, such as an interpreter or wheelchair, contact Larry Middleton (Larry.Middleton@nau.edu) or (520) 523-2429 by *March 15, 1998*.

REGISTRATION FEES

	Advance *(by April 24)*		On Site	
	Full meeting	One day	Full meeting	One day
Professional				
Member	$60	$40	$75	$50
Nonmember	$70	$50	$85	$60
Student				
Member	$20	$15	$30	$25
Nonmember	$25	$20	$40	$30
K–12 Professional	$20	$5	$25	$5
Guest or Spouse	$10	N/A	$15	N/A

Cancellations, Changes, and Refunds

All requests for registration additions and changes must be made in writing and received by *May 1, 1998*. NO REFUNDS OR CREDITS WILL BE MADE ON CANCELLATION NOTICES RECEIVED AFTER MAY 1. Refunds will be mailed from GSA after the meeting. Fees paid by credit card will be credited according to the card number on the registration form. There will be NO refunds for on-site registration and ticket sales.

FIELD TRIPS

Premeeting

1. **Miocene Volcanism and Geomorphology in Verde Valley, and Petrology of Alkaline and Mildly Alkaline Rocks at House Mountain Shield Volcano, Sedona, Arizona.** May 24. Richard Holm (Richard.Holm@nau.edu), Dept. of Geology, Northern Arizona University, P.O. Box 4099, Flagstaff, AZ 86011; Wayne Ranney, Zia Enterprises, Flagstaff; James Wittke and Katherine Lee, Northern Arizona University. We will examine the basalt-covered southern margin of the Colorado Plateau and enter the Verde Valley on a lava ramp down the Mogollon Rim, focusing on the stratigraphic, geomorphic, and tectonic relations of basalt lava flows and their underlying erosion surfaces, the lacustrine Verde Formation, and volcanic centers in the region. The trip concludes with a visit to House Mountain, where we will examine the stratigraphy, petrology, and geochemistry of the shield volcano. A large basanitic nephelinite dike was intruded into mildly alkaline and subalkaline flows of the shield volcano. The dike hosts phaneritic rocks including nepheline monzosyenite and feldspar ijolite. Cost: $45 (includes transportation, lunch, refreshments, reprints, field guide). Limit: 19.

2. **Exploration for and Ecological Importance of Shallow and Deep Ground Water Around the San Francisco Mountains.** May 24. Abe Springer (abe.springer@nau.edu), Dept. of Geology, Northern Arizona University, Box 4099, Flagstaff, AZ 86011; Don Bills, U.S. Geological Survey, Flagstaff. Around San Francisco Mountain near Flagstaff, ground water occurs in three different types of aquifers: (1) shallow perched water-bearing zones, (2) a deep aquifer in consolidated sediments, and (3) an even deeper aquifer in Permian to Devonian limestones. We also will visit areas where shallow water occurs in seeps and springs, discuss critical riparian ecosystems dependent on them, and examine efforts to restore the ecosystems where they have been damaged intentionally or unintentionally by human activity. We also will visit sites of recent comprehensive studies to explore for new well fields in the deeper regional aquifer; remote sensing, geologic mapping, and surface geophysical techniques are being used to locate and define fractures and faults. Although little is known about the deeper aquifer in the Flagstaff area, its relation to overlying water-bearing zones and its importance as a regional ground-water resource will be discussed briefly. Cost: $40 (includes transportation, lunch, field guide). Limit: 20.

3. **Volcanism and Sedimentation in the Miocene-Pliocene Hopi Buttes and Hopi Lake.** May 23, 8 a.m. to May 24, 6 p.m. Michael Ort (mho@nauvax.ucc.nau.edu), Jorge Vazquez, Todd Dallegge, Dept. of Geology, Northern Arizona University, Box 4099, Flagstaff, AZ 86011; James White, Dept. of Geology, University of Otago, P.O. Box 56, Dunedin, New Zealand, phone 64-3-479-9009. The Hopi Buttes volcanic field is a late Miocene to Pliocene nephelinitic volcanic field that erupted through mid–late Miocene Hopi Lake sediments. The trip will concentrate on the volcanic structures and facies associated with the maar volcanoes. We will look at excellent exposures into the eroded roots of maars, into the maars structures themselves, and the maar lake sediments, with spectacular continuous outcrops showing the lateral and vertical variations in the deposits. We will also focus on the Hopi Lake sediments, paying particular attention to the timing of the lake's presence in the area, and its relation to the maar volcanism. Cost: $130 (includes van transportation, 1 night double-occupancy in motel in Holbrook, field guide, field lunches, and refreshments). Limit: 20.

4. **Tertiary Volcanism, Sedimentation, and Tectonics of the Central Arizona Transition Zone.** May 24. Robert S. Leighty (leighty@asu.edu), Ari-

zona Geological Survey, 416 W. Congress St., Suite 100, Tucson, AZ 85701. This trip will provide an overview of Tertiary geology across the Basin and Range–Colorado Plateau transition zone from Flagstaff to the Phoenix area. Morning activities will focus on volcanic and sedimentary stratigraphy, paleogeography, and petrogenesis of the Hickey Formation, Chalk Canyon Formation, and Middle Tertiary latites in the Verde Valley, Cordes, Black Canyon City, and New River areas. Structural features and regional tectonism will be discussed during afternoon activities in the Cave Creek, Humboldt Mountain, and Bloody Basin areas. Hiking will be minimal; weather conditions will vary widely. Cost: $45 (includes transportation, lunch, snack, field guide). Limit: 24.

Postmeeting

5. **Permian Rocks in North-Central Arizona: A Comparison of the Sections at Grand Canyon and Sedona.** May 27–28. Ronald Blakey (rcb@vishnu.glg.nau.edu) and Larry Middleton, Dept. of Geology, Northern Arizona University, Box 4099, Flagstaff, AZ 86011. The classic Permian sections of Sedona and Grand Canyon will be compared and contrasted. Depositional systems and paleotectonics will be emphasized. We will discuss reasons for the contrasts between the two sections while taking several short to intermediate hikes each day. The beautiful scenery and excellent exposures of the two areas offer abundant photographic opportunities. Cost: $100 (includes transportation, lunch, snack, field guide). Does not include May 27 lodging in Flagstaff. Limit: 35.

6. **Proterozoic Rocks Within the Mojave-Yavapai Boundary Zone, Northwestern Arizona: Comparison of Metamorphic and Structural Evolution Across a Major Lithospheric(?) Structure.** May 26, 5 p.m. to May 28, 8 p.m. Ernie Duebendorfer (ernie.d@nau.edu), Dept. of Geology, Northern Arizona University, Box 4099, Flagstaff, AZ 86011; Matt Nyman, University of Michigan. On the first day, we will focus on three phases of Proterozoic ductile deformation, two phases of granulite-facies metamorphism, and syndeformational magmatism in the Cerbat Mountains, astride the 75-km-wide boundary zone between the Mojave and Yavapai Proterozoic crustal provinces. On day two we will examine polyphase deformation and metamorphism in the Hualapai Mountains, which are within the Proterozoic boundary zone. We will discuss constraints on the timing and nature of juxtaposition of the two provinces and the local effects and regional implications of Paleoproterozoic and Mesoproterozoic plutonism, metamorphism, and deformation. Cost: $160 (includes 4-wheel-drive transportation, 2 nights double-occupancy in motel in Kingman, field guide, field lunches, and refreshments). Limit: 17.

7. **A Tale of Two Rivers: Mid-Tertiary Structural Inversion and Drainage Reversal Across the Southern Boundary of the Colorado Plateau.** May 26, 5 p.m. to May 28, 10 p.m. Andre R. Potochnik (arp4@infomagic.com), Dept. of Geology, Arizona State University, Tempe, AZ 85287; James E. Faulds, Nevada Bureau of Mines and Geology. On this trip, we conduct a paleogeographic transect across the Basin and Range–Colorado Plateau transition zone to examine evidence for a Laramide fluvial depositional system that was later defeated by mid-Tertiary extension and volcanism. We follow an early Tertiary paleovalley (of Grand Canyon scale), that contains a remarkably complete record of the structural and sedimentologic history that led to regional drainage reversal across the Colorado Plateau boundary. Choice of return to Flagstaff or Phoenix. Cost: $120 (includes transportation, field guide, meals from breakfast May 27 through lunch May 28). Camping only (no lodging). Dinners on the road May 26 and 28 not included. Limit: 19.

8. **Meteor Crater, Arizona: Geology and Cultural History.** May 27. Jeff Kargel (jkargel@flagmail.wr.usgs.gov), U.S. Geological Survey, Flagstaff, AZ 86001. This 5-hour trip to Meteor Crater, just 40 miles (65 km) east of Flagstaff, will take participants on a walking tour (total distance <5 km) around the crater rim and over the ejecta blanket. We will examine evidence for the composition of the impactor; the dynamics of the explosive impact, including impact melting and the effective depth of the explosion; and geologic disturbances represented by the crater, including such effects as inverted stratigraphy and faulting. Participants will also inspect rusted remains of the world's first-ever attempt, by Daniel Barringer early in this century, to mine an asteroid. Cost: $21 (includes lunch). Limit: 30.

SYMPOSIA

General sessions will include tectonics and structural geology of the Rocky Mountains, Colorado Plateau, and Basin and Range–Colorado Plateau transition zone, igneous, metamorphic, and sedimentary petrology, stratigraphy and sedimentology, paleontology, geochemistry, hydrogeology, and environmental geology. General questions concerning symposia should be addressed to Wendell Duffield, Technical Program Coordinator, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, (520) 556-7205, wdufffield@flagmail.wr.usgs.gov. For the symposia listed below, prospective authors should contact individual chairs.

1. **Tertiary Evolution of the Transition Zone.** Nancy Riggs, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011, Nancy.Riggs@nau.edu.

2. **Paleontologic and Stratigraphic Studies in the Grand Canyon Area: A Symposium in Honor of Stanley S. Beus.** David Elliott, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011, David.Elliott@nau.edu.

3. **Synthesis of Recent Geomorphic Research Along the Colorado River.** Richard Hereford, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, rhereford@flagmail.wr.usgs.gov.

4. **Evolution of Mid- to Late Proterozoic Basins in the Southwest—Tectonic and Depositional Settings.** Larry Middleton, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011, Larry.Middleton@nau.edu.

5. **Late Cenozoic Evolution of the Colorado Plateau.** Jon Spencer, Arizona Geological Survey, 416 Congress St., Suite100, Tucson, AZ 85701, jspencer@geo.arizona.edu.

6. **Geological Framework of the Grand Staircase–Escalante Monument Area.** Wendell Duffield, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, wduffield@flagmail.wr.usgs.gov.

7. **Tectonics of the Southern Rio Grande Rift and Adjacent Basin and Range—Their Connection.** Greg Mack, Dept. of Geological Sciences, New Mexico State University, Las Cruces, NM 88003. gmack@nmsu.edu.

8. **Geoscience and Environmental Science Education Using Computer Multimedia: What Works and Why.** Michael Kelly, Center for Environmental Sciences and Education, Northern Arizona University, Flagstaff, AZ 86011, Michael.Kelly@nau.edu.

9. **Middle and Late Mesozoic Tectonics of the Borderland: From Bisbee Extension to Laramide Shortening.** Timothy Lawton, Dept. of Geological Sciences, New Mexico State University, Las Cruces, NM 88003, tlawton@nmsu.edu.

10. **Active Tectonics of the Central and Northern Rocky Mountains.** David Lageson, Dept. of Earth Sciences, Montana State University, Bozeman, MT 59717-0348, uesam@msu.ocs.montana.edu.

11. **Water Quantity and Quality: Issues Related to Perched Aquifers.** Abe Springer, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011, Abe.Springer@nau.edu.

POSTER SESSIONS

Each poster will be exibited for one half day in the main ballroom of the DuBois Center. Please indicate your preference for poster presentation on the abstract form.

Rocky Mountain *continued on p. 31*

Preregistration Form

GSA Rocky Mountain Section **Flagstaff, Arizona, May 25–26, 1998**

Please print clearly • THIS AREA IS FOR YOUR BADGE

Name as it should appear on your badge (last name first)

Employer/University Affiliation

City State or Country

Mailing Address (use two lines if necessary)

City State

ZIP Code Country (if other than USA)

Circle member affiliation (to qualify for registration member discount):

(A) GSA (B) NAGT (C) PS (D) SEPM

GUEST INFORMATION • Please print clearly • This area is for badge

Name as it should appear on your guest's badge

City State or Country

Please inform us by March 15 of any special considerations that you or your guest require.

☐ I will need special considerations.

( ) - **Business Phone**

( ) - **fax**

( ) - Home Phone

Preregistration Deadline: April 24, 1998.
Cancellation Deadline: May 1, 1998.

MAIL TO:
GSA ROCKY MOUNTAIN SECTION MEETING, P.O. BOX 9140, BOULDER, CO 80301

Remit in U.S. funds payable to: 1998 GSA Rocky Mountain Section Meeting
(All preregistrations must be prepaid. Purchase Orders not accepted.)

Payment by (check one):
☐ Check ☐ American Express ☐ VISA ☐ MasterCard

Card Number

Signature Expires

REGISTRATION FEES

	Full Meeting	One Day	Qty.	Amount
Professional Member*	(10) $60 ☐	(11) $40 ☐	__	$ ______
Professional Nonmember	(14) $70 ☐	(15) $50 ☐	__	$ ______
Student Member*	(30) $20 ☐	(31) $15 ☐	__	$ ______
Student Nonmember	(32) $25 ☐	(33) $20 ☐	__	$ ______
K–12 Professional	(60) $20 ☐	(61) $ 5 ☐	__	$ ______
Guest or spouse	(90) $10 ☐	NA	__	$ ______

*Member fee applies to any current Professional OR Student Member of GSA or Associated Societies listed at left. Discount does not apply to guest registrants.

SPECIAL EVENT

	Date	Code	Fee	Qty.	Amount
1. Verde Canyon Railroad Trip	May 24	(301)	$ 32	__	$ ______

FIELD TRIPS

	Date	Code	Fee	Qty.	Amount
1. Miocene Volcanism, Verde Valley	May 24	(401)	$ 45	1	$ ______
2. Shallow and Deep Groundwater, San Francisco Mtns.	May 24	(402)	$ 40	1	$ ______
3. Miocene-Pliocene Hopi Buttes and Hopi Lake	May 23–24	(403)	$130	1	$ ______
4. Tertiary Volcanism, Central AZ Transition Zone	May 24	(404)	$ 45	1	$ ______
5. Permian Rocks in North-Central Arizona	May 27–28	(405)	$100	1	$ ______
6. Proterozoic Rocks, Mojave-Yavapai Boundary Zone	May 26–28	(406)	$160	1	$ ______
7. A Tale of Two Rivers, Colorado Plateau	May 26–28	(407)	$120	1	$ ______
8. Meteor Crater, Arizona	May 27	(408)	$ 21	1	$ ______

TOTAL FEES $ ______

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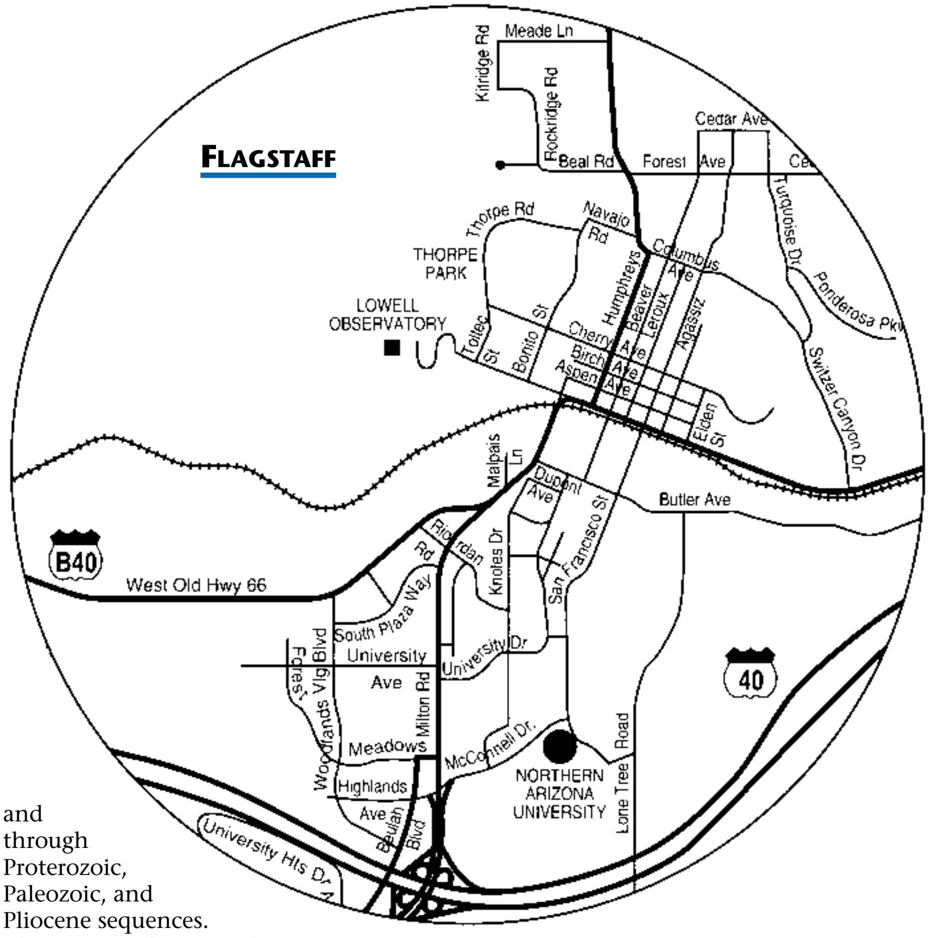
Rocky Mountain *continued from p. 29*



PROJECTION EQUIPMENT

Projection equipment will be provided for standard 35 mm slides. Two projectors and two screens will be available. Authors must provide their own carousel; only a limited number will be available on site. Other special equipment—e.g., a computer—must be requested in advance. A speaker-ready room will be available for previewing and loading carousels.

EXHIBITS

The exhibit area will be in the DuBois Center and will be open during the welcoming reception Sunday, May 24, and from 8 a.m. to 5 p.m. Monday and Tuesday. Exhibit space will cost $50 for an area about 12 ft. × 12 ft. For further information, contact Paul Umhoefer, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011, (520) 523-6464, Paul.Umhoefer@nau.edu.

STUDENT PRESENTATIONS

Awards will be given for the best paper and second-best papers by students. The GSA Rocky Mountain Section encourages students to present their research at this meeting. We want both undergraduate and graduate contributions.

STUDENT TRAVEL SUPPORT

The GSA Rocky Mountain Section has funds to support travel to the meeting for students. Submit requests to Ken Kolm, Dept. of Environmental Science and Engineering, Colorado School of Mines, Golden, CO 80401, kkolm@mines.colorado.edu. Applications must be received by March 15, 1998.

SPECIAL EVENTS and SPOUSE or GUEST PROGRAM

The welcoming reception will be Sunday, May 24, from 6 to 9 p.m. at the DuBois Center on the Northern Arizona campus. Hors d'oeuvres will be available, and there will be a cash bar. The Rocky Mountain Section business meeting will be held at 12 noon Tuesday, May 26.

Flagstaff features the Museum of Northern Arizona and Lowell Observatory, and Meteor Crater is nearby. The Red Rock country of Sedona is 30 miles to the south. Other attractions include a round trip by rail from Williams to Grand Canyon through the San Francisco Volcanic Field. Reservations can be made by calling (520) 773-1976 or faxing 520-773-1610. The cost is $49 per person and includes the park entrance fee.

GSA has arranged to have a group excursion on the Verde Canyon Railroad, Sunday, May 24 from 1 to 5 p.m. The trek follows the Verde River south of Flagstaff and through Proterozoic, Paleozoic, and Pliocene sequences. The renovated New York Metro Line coach cars travel through two national forests and give visual access to abundant protected wildlife. The group rate is $32 each for a group of 20 or more. If the minimum is not reached, participants will be notified well in advance.

Address inquiries to Ronald Blakey, Special Events Chairperson, Dept. of Geology, Northern Arizona University, Flagstaff, AZ 86011, Ronald.Blakey@nau.edu. Specifics of each trip will be provided upon request.

ACCOMMODATIONS

Blocks of rooms have been reserved on the campus of Northern Arizona University, only a few minutes walk from the DuBois Center, the site of the meetings. The rate for these rooms is $45 per person per night based on double occupancy. This includes breakfast, lunch, and dinner in the dining hall on campus. Contact Louise Brown, (520) 523-1246, to make reservations at NAU. ALL motels listed below, except for Fairfield Inn, are within one-quarter mile of the meeting site. Meeting participants must contact these motels directly for reservations. Remember, this is Memorial Day weekend so book early. Below prices are subject to change. Prices shown are for single and double occupancy. ZIP code for these Flagstaff motels is 86001.

Amerisuites Flagstaff, 2455 S. Beulah Blvd., (520) 774-8042. $75/$85
Days Inn I-40 Flagstaff, 2735 S. Woodlands Village Blvd., (520) 779-1575. $65/$65
Econolodge West, 2355 Beulah Blvd., (520) 774-2225. $70/$70
Embassy Suites, 706 S. Milton Rd., (520) 774-4333. $125/$135
Fairfield Inn by Marriott, 2005 S. Milton Rd., (520) 773-1300. $90/$90
La Quinta, 2355 S. Beulah Blvd., (520) 556-8666. $69/$79
Motel 6, 2745 S. Woodlands Village Blvd., (520) 779-3757. $33/$39
Ramada Inn, 2755 Woodlands Village Blvd., (520) 773-1111. $60/$60
Quality Inn Flagstaff, 2000 S. Milton Rd., (520) 774-8771. $80/$80

A limited shuttle will be provided. The schedule will be in the program.

DETAILED INFORMATION

Address questions concerning registration to Michael Ort, Dept. of Geology Northern Arizona University, Flagstaff, AZ 86011, Michael.Ort@nau.edu. Direct questions regarding lodging and activities to Larry Middleton, Dept., of Geology, Northern Arizona University, Flagstaff, AZ 86011, Larry.Middleton@nau.edu, fax 520-523-9220. ■

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Southeastern	3/30–3/31	$15		$
Cordilleran	4/7–4/9	$15		$
Rocky Mountain	5/25–5/26	$15		$
Annual Meeting (Toronto)	10/26–10/29	$38.75		**$**
		Total		**$**

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ON-SITE PURCHASES may be made in the registration area. Supplies are limited.

CALENDAR

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

1998 Penrose Conferences

May

May 14–18, **Linking Spatial and Temporal Scales in Paleoecology and Ecology,** Solomons, Maryland. Information: Andrew S. Cohen, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721, (520) 621-4691, fax 520-621-2672, acohen@geo.arizona.edu.

June

June 4–12, **Evolution of Ocean Island Volcanoes,** Galápagos Islands, Ecuador. Information: Dennis Geist, Dept. of Geology, University of Idaho, Moscow, ID 83844, (208) 885-6491, fax 208-885-5724, dgeist@uidaho.edu.

July

July 4–11, **Processes of Crustal Differentiation: Crust-Mantle Interactions, Melting, and Granite Migration Through the Crust,** Verbania, Italy. Information: Tracy Rushmer, Dept. of Geology, University of Vermont, Burlington, VT 05405, (802) 656-8136, fax 802-656-0045, trushmer@zoo.uvm.edu.

September

September 13–17, **Ophiolites and Oceanic Crust: New Insights from Field Studies and Ocean Drilling Program,** Marshall, California. Information: Yildirim Dilek, Dept. of Geology, Miami University, Oxford, OH 45056, (513) 529-2212, fax 513-529-1542, dileky@muohio.edu.

1998 Meetings

March

March 3–5, **Australian Gold Conference,** Kalgoorlie-Boulder, Australia. Information: 1998 Australian Gold Conference, 132 Edward St., Perth, WA 6000, Australia, phone 61-8-9328-2910, fax 61-8-9328-1240, 98gold@rhk.com.au, http://www.rhk.com.au/98gold/.

April

April 14–17, **Geoscience 98,** Keele, Staffordshire, UK. Information: Conference Office, Geological Society, Burlington House, Piccadilly, London W1V 0JU, UK, lakinj@geolsoc.org.uk.

April 17–19, **National Association of Geoscience Teachers—Far Western Section Spring Field Conference:** Geology of Southeastern Sierra Nevada—Revisited, Bishop, California. Information and registration: Mario V. Caputo, Mt. San Antonio College, Dept. Earth Sciences, 1100 North Grand Avenue, Walnut, CA 91789; mvcaputo@msn.com.

July

July 4–13, **FORAMS'98: International Symposium on Foraminifera,** Monterrey, Mexico. Information: Martha A. Gamper, Florida International University, gamperma@fiu.edu, http://www.fiu.edu/~longoria/forams98.

August

August 20–28, **Metallogeny and Geodynamics of the North Asian Craton and Framing Orogenic Belts,** with Field Excursion to Southern Lake Baikal and Zun-Kholba Lode Gold Deposit, Irkutsk, Russia. Information: Tatiana Bounaeva, Institute of Geochemistry, Russian Academy of Sciences, P.B. 4019, Irkutsk 664033, Russia; phone: 7-3952-46-59-64, fax 7-3952-46-40-50; tabun@igc.irkutsk.su.

Calendar *continued on p. 33*

GSA ANNUAL MEETINGS

1998

October 26–29
Metro Toronto Convention Centre
Sheraton Centre Toronto Hotel
www.geosociety.org/meetings/98

GENERAL CHAIRS

Jeffrey J. Fawcett, *University of Toronto,*
Peter von Bitter, *Royal Ontario Museum*

TECHNICAL PROGRAM CHAIRS

Denis M. Shaw, *McMaster University*
Andrew Miall, *University of Toronto*
Proposal deadline was January 2.

FIELD TRIP CHAIRS

Pierre Robin, Henry Halls,
University of Toronto
No more field trips will be accepted.

ASSEMBLY OF A CONTINENT

1999

Denver, Colorado
October 25–28
Colorado Convention Center

FUTURE MEETINGS

2000	Reno, Nevada	November 13–16
2001	Boston, Massachusetts	November 5–8
2002	Denver, Colorado	October 28–31

GSA SECTION MEETINGS—1998

NORTHEASTERN SECTION, March 19–21, Holiday Inn by the Bay, Portland, Maine. Information: Stephen G. Pollock, Dept. of Geosciences, University of Southern Maine, Gorham, ME 04038, (207) 780-5350, fax 207-780-5167, pollock@usm.maine.edu. *Preregistration deadline: February 13, 1998.*

NORTH-CENTRAL SECTION, March 19–20, Ohio State University, Columbus, Ohio. Information: William I. Ausich, Geological Sciences, Ohio State University, 275 Mendenhall, 125 S. Oval Mall, Columbus, OH 43210, (614) 292-0069, fax 614-292-7688, ausich.1@osu.edu. *Preregistration Deadline: February 13, 1998.*

SOUTH-CENTRAL SECTION, March 23–24, OU Continuing Education Center, Norman, Oklahoma. Information: M. Charles Gilbert, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd St., Suite 810, Norman, OK 73019-0628, (405) 325-4424, fax 405-325-3140, mcgilbert@ou.edu. *Preregistration Deadline: February 6, 1998.*

SOUTHEASTERN SECTION, March 30–31, Embassy Suites, Charleston, West Virginia. Information: Larry D. Woodfork, West Virginia Geological and Economic Survey, P.O. Box 879, Morgantown, WV 26507-0879, (304) 594-2331, fax 304-594-2575, woodfork@geosrv.wvnet.edu. *Preregistration Deadline: February 27, 1998.*

CORDILLERAN SECTION, April 7–9, California State University, Long Beach, California. Information: Stan Finney, Dept. of Geological Sciences, California State University, Long Beach, CA 90840, (562) 985-8637, scfinney@csulb.edu. *Preregistration Deadline: March 6, 1998.*

ROCKY MOUNTAIN SECTION, May 25–26, Northern Arizona University, Flagstaff, Arizona. Information: Larry Middleton, Dept of Geology, Box 4099, Northern Arizona University, Flagstaff, AZ 86011, (520) 523-2429, Larry.Middleton@nau.edu. *Preregistration Deadline: April 24, 1998.*

Calendar *continued from p. 32*

August 23–27, **American Chemical Society National Meeting,** Boston, Massachusetts. Information: Sally Pecor, ACS News Service, 1155 16th St., N.W., Washington, DC 20036, (202) 872-4451, fax 202-872-4370, s_pecor@acs.org.

September

September 22-25, **Gold Exploration and Mining in NW Spain,** Oviedo, Spain. Information: Daniel Arias Prieto, Facultad de Geología, Universidad de Oviedo, c/ Arias de Velasco s/n, 33005 Oviedo, Spain, fax 34-8-5103087, darias@asturias.geol.uniovi.es.

October

October 5–7, **Fifth International Conference on Remote Sensing for Marine and Coastal Environments,** San Diego, California. Information: Robert H. Rogers, ERIM International, P.O. Box 134008, Ann Arbor, MI 48113-4008, (313) 994-1200, ext. 3234, fax 313-994-5123, http://www.erim-int.com/CONF/conf.html. *(Deadline for submitting summaries of papers: February 27, 1998.)*

October 12–16, **Third International Conference on Arctic Margins,** Celle, Germany. Information: F. Tessensohn, ICAM III, c/o BGR, Postfach 51 01 53, D-30631 Hannover, Germany, phone 49-511-643-3137, fax 49 511 643 2304 (subject: ICAM III), geopolar@bgr.de, http://www.mms.gov/omm/alaska/icam/1998/98ann.html or http://www.bgr.de/b3.icam3.html. *(Abstract deadline: March 31, 1998.)*

November

November 9–12, **4th International Conference on the Geology of the Middle East,** Beirut, Lebanon. Information: Mustapha Mroueh, Lebanese National Geological Committee, P.O. Box 11-8281, Beirut, Lebanon, phone 961-1-862665-840262, fax 961-1-822639, ngc@cnrs.edu.lb

Send notices of meetings of general interest, in format above, to Editor, *GSA Today,* P.O. Box 9140, Boulder, CO 80301, E-mail: editing@geosociety.org.

February *BULLETIN* and *GEOLOGY* Contents

The Geological Society of America
BULLETIN
Volume 110, Number 2, February 1998

CONTENTS

GEOLOGY
VOLUME 26
NO. 2
P. 97–192
FEBRUARY 1998

Nominations Sought for 1998 AWGF Outstanding Educator

The Association for Women Geosciences Foundation requests nominations for the 1998 AWG Outstanding Educator Award. The award honors well-established college or university teachers who have played a significant role in the education and support of women geoscientists both within and outside the classroom.

Nominations must include the nominator's supporting letter, a summary of the nominee's academic and professional accomplishments, and at least six letters of recommendation from professional colleagues, former students, and current students. Send nominations to Janet Bauder Thornburg, 810 West Forest Dr., Houston, TX 77079-3324. **Deadline for nominations is March 15, 1998.**

The AWG Foundation presents the award at the annual meeting of the Geological Society of America. Previous recipients are Lisa Pratt, Linda Abriola, Mary Savina, B. Charlotte Schreiber, Margaret Delaney, Marie Morisawa, Laurie Brown, Sharon Mosher, and Maria Luisa Crawford.

CLASSIFIED ADVERTISING

Published on the 1st of the month of issue. Ads (or cancellations) must reach the GSA Advertising office one month prior. Contact Advertising Department (303) 447-2020, 1-800-472-1988, fax 303-447-1133, or E-mail:acrawfor@geosociety.org. Please include complete address, phone number, and E-mail address with all correspondence.

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Positions Open

ASSISTANT PROFESSOR — DARTMOUTH COLLEGE

The Department of Earth Sciences at Dartmouth College invites applications for a tenure-track position in neotectonics/active tectonics/surficial processes and/or physical hydrogeology at the assistant professor level. The successful candidate will be expected to demonstrate excellence in both teaching and research, develop a vigorous externally funded research program, and advise student research at the B.A., M.S., and Ph.D. levels. A strong field component of research is essential to this position.

Send curriculum vitae, list of publications, description of proposed teaching and research interests and objectives, and the names, addresses, and fax/phone numbers of at least three references to: Search Committee, Department of Earth Sciences, Dartmouth College, 6105 Fairchild Hall, Hanover, NH 03755; e-mail: earth.sciences@dartmouth.edu; web pages: http://www.dartmouth.edu/artsci/rox.

Evaluation of applications will begin January 15 and will continue until the position is filled. The appointment will be effective July 1, 1998.

Dartmouth College is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

**THE UNIVERSITY OF TEXAS AT DALLAS
CLASTIC SEDIMENTOLOGIST**

The Geosciences Department at The University of Texas at Dallas invites applications for a tenure-track faculty appointment in clastic sedimentology to begin Fall 1998. This position is at the Assistant Professor level, although outstanding candidates will be considered for a higher rank. We are particularly interested in applicants whose qualifications commplement one or more of our existing efforts in geophysics, global change, geohydrology, and environmental geology, and can teach courses in sequence stratigraphy and basin analysis. Applicants should have a Ph.D. in the Geosciences. We seek a creative and dynamic individual who will develop an externally-funded research program and who is keenly interested in teaching at both the undergraduate and graduate levels and supervising M.S. and Ph.D. students. Applications, including a statement of research interests, and teaching objectives, curriculum vitae, and the names, addresses, phone numbers, and e-mail addresses of three references should be sent to: Academic Search #2032, The University of Texas at Dallas, P.O. Box 830688—M/S AD23, Richardson, TX 75083-0688. Indication of sex and ethnicity for affirmative action statistical purposes is requested as part of the application but not required. Inquiries can be made directly to: Robert J. Stern (rjstern@utdallas.edu). For more information, see the UTD World Wide Web site: http://www.utdallas.edu/ dept/geoscience/. The University of Texas at Dallas is an Affirmative Action/Equal Opportunity Employer that is committed to fostering diversity in its student body, faculty, and staff.

SEDIMENTOLOGIST/STRATIGRAPHER

Austin Peay State University Department of Geology/Geography invites applicants for an Assistant Professor, tenure-track position in Sedimentology/ Stratigraphy to begin August 1, 1998. Completed Ph.D. required. Teaching load will include Physical Geology, Historical Geology and Stratigraphy/Sedimentation on a rotational basis.

The Department offers a B.S. degree with a faculty of nine and four adjunct instructors. Although the Department's primary emphasis is undergraduate teaching, the appointee will be expected to pursue an active research program.

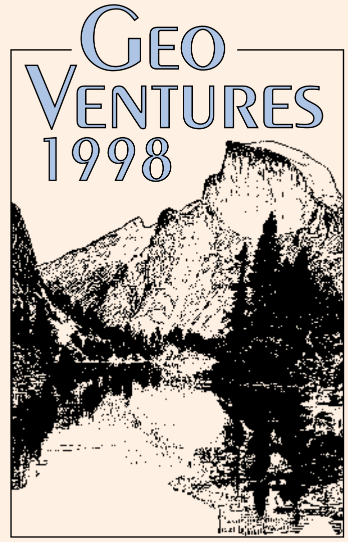
Applicants should send a letter of interest, curriculum vitae and three letters of reference to Phillip Kemmerly, Chair, Department of Geology and Geography, Austin Peay State University, Clarksville, TN 37044. Review of applications will begin March 1, 1998 until filled.

Austin Peay State University is an equal opportunity/ affirmative action employer. Applications from women and minority groups are strongly encouraged.

**FULL PROFESSORSHIP
OF SEDIMENTARY GEOLOGY**

The University Henri Poincaré (Nancy, France, 20,000 students, 2500 employees) invites applications for a full professor position beginning September 1998. Candidates must have demonstrated potential in the development of significant multidisciplinary research programs in the field of sedimentary basins and should have experience in setting up of interactions with industry (petroleum and environmental management). The appointee will be co-responsible for a research group (30 permanent researchers plus Ph.D. students) and will have a major role in the organization of lecture courses. Research areas considered especially important to this offer are: 1) innovative reconstruction of paleoenvironments based on modern sedimentological approaches including organic and mineral geochemistry, 2) integrated study of sedimentary basins. Fluent French is not necessary but will be strongly appreciated. Submit curriculum vitae, publication record and summary of research prospects to: Dr. P. Landais, Director, CREGU, BP 23, 54501 Vandoeuvre Cedex. France. e-mail: landais@cregu.cnrs-nancy.fr. fax: +33-383440029. tel: +33-383441900. Use the same address to get further information. Deadline: February 29, 1998.

Classifieds *continued on p. 38*



Field Trips with a Difference … for GSA Members and Friends

GeoVentures are a special benefit created for members, but are open also to guests and friends. GeoVentures is the overall name for adult educational and adventure experiences of two kinds: GeoTrips or GeoHostels. Both are known for expert scientific leadership. Fees for both are low to moderate, relative to the length of time and destination, and include lodging and meals as designated. Detailed itineraries for each GeoVenture and helpful travel information are available from GSA. Contact Edna Collis, ecollis@geosociety.org, GSA Meetings Department, 1-800-472-1988, ext. 134, or (303) 447-2020, or fax 303-447-0648.

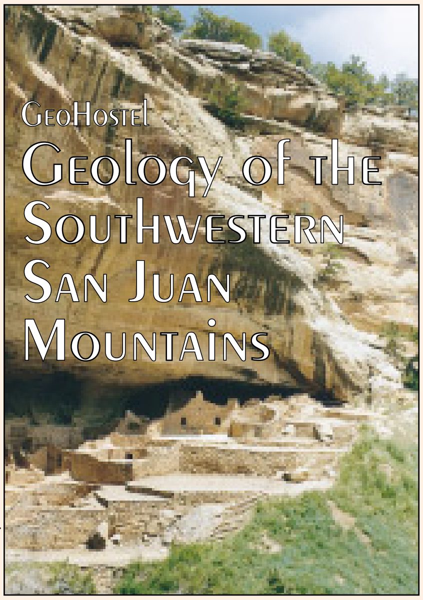


Photo by Ken Kolm.

Fort Lewis College, Durango, Colorado
June 27–July 2, 1998
6 days, 6 nights

Scientific Leaders:
Gregory Holden and Kenneth Kolm, Colorado School of Mines, Golden, Colorado

Greg Holden and Ken Kolm are experienced GeoHostel leaders and ran a Durango GeoHostel in 1992. Both are associate professors at the Colorado School of Mines and know the Durango area well. You will find them informed, informing, and enthusiastic.

Description

Durango, Colorado, was founded more than a century ago as the supply center for the mining camps of the San Juan Mountains. Located at the boundary of the Colorado Plateau and the Colorado Rockies, the town today is the recreational center for some of the most scenic, historic, and geologically diverse country in the west. The Durango townsite was the terminus to the Ice Age Animas River glacier, largest to drain the San Juan icefield. Fort Lewis College is 300 feet above the town, on the remnant of an outwash terrace. Erosion during Neogene uplift has exposed Precambrian basement rocks, a complete Paleozoic and Mesozoic sedimentary section, and Tertiary caldera-related pyroclastic rocks and associated mineralization. The area is home to the historic Durango & Silverton Narrow Gauge Railroad, Anasazi Indian ruins, ghost towns, and spectacular mountain wildflowers and scenery.

Lodging, Meals, and Ground Transportation

The group will be lodged at Fort Lewis College, West Hall. All lodging is based on single occupancy, or doubles for couples. Meals will include plentiful hors d'oeuvres at the Welcoming Reception–Orientation on Saturday evening, daily breakfasts and sack lunches, and a hearty farewell dinner on Thursday evening. Field trip transportation will be provided in air-conditioned, 15-passenger vans.

Fee and Payment

$660 for GSA Members *$710 for Nonmembers*
$100 deposit is due with your reservation and is refundable through April 30, less $20 processing fee. Total balance due: April 30.

Included: Classroom programs and materials; field trip transportation; lodging for 6 nights (single-occupancy, or double for couples); breakfast and lunch daily, train ride on the Durango & Silverton Narrow Gauge Railroad, welcoming and farewell events.

Not included: Transportation to and from Durango, Colorado; transportation during hours outside field trips; and other expenses not specifically included.

GeoHostel: Geology of the Grand Teton–Yellowstone Country

SOLD OUT

Teton Village, Jackson, Wyoming, 6 days, 6 nights • July 18–23, 1998 • Rob Thomas and Sheila Roberts

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Register Today!

Send a deposit to hold your reservation; please pay by check or credit card. You will receive further information and a confirmation of your registration within two weeks after your reservation is received.

	Deposit Per Person	No. of Persons	Total Paid Deposit
GH982—Durango	$100	____	$________
	TOTAL DEPOSIT		$________

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☐ VISA ☐ MasterCard ☐ American Express

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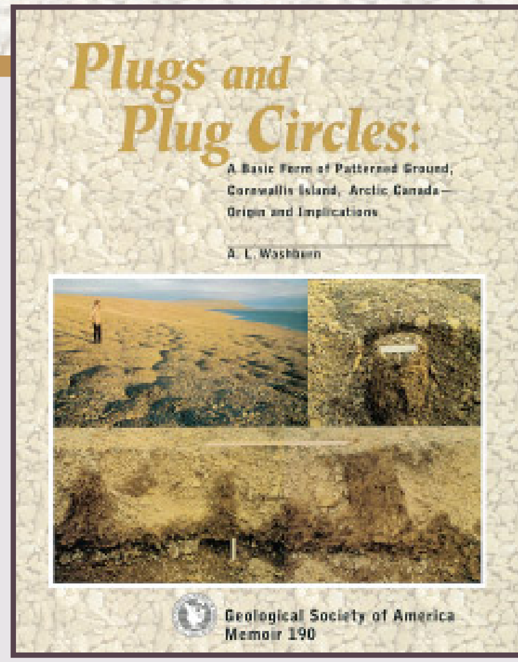
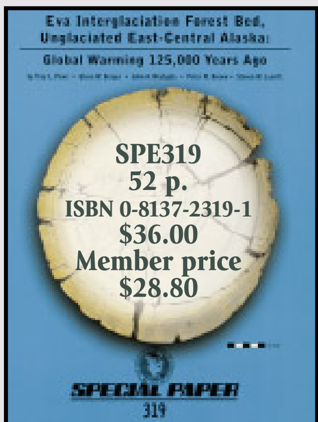


A. L. Washburn, 1997

Patterned ground, encompassing circles, nets, polygons, and stripes, indicate soil, temperature, hydrologic, and other environmental conditions, past and present. Plug circles and plugs, a variety of patterned ground, occur in both nonsorted and sorted forms in permafrost environments. Study in the Canadian High Arctic and a review of hypotheses of origin support the conclusion that plug circles and plugs are diapiric forms resulting from frost heaving, and that surfaceward seepage accounts for many occurrences. Plug circles and plugs are perhaps transitional to larger forms with prominent stoney ringlike borders of the classic Spitsbergen variety of sorted circle, whose origin is commonly linked to circulatory soil processes; details of that origin are still somewhat problematical.

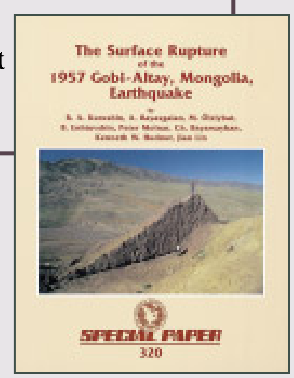
MWR190, 102 p., indexed, ISBN 0-8137-1190-8, $45.00, Member price $36.00



Eva Interglaciation Forest Bed, Unglaciated East-Central Alaska: Global Warming 125,000 Years Ago

edited by T. L. Péwé and others, 1997

The ancient, boreal Eva forest, buried in frozen loess of the subarctic, forms the centerpiece in this evaluation of the time and nature of the environment during an interglaciation warmer than that of the present. This book brings together results of examination of hundreds of loess exposures over the past 50 years, when loess faces were still frozen in gold-mining excavations, and new data on the character and age of the deposits from fission-track dating of tephra, paleomagnetism of the loess, thermoluminescence dating of loess, and new radiocarbon dating by liquid scintillation. Dendrochronology studies of trees and $^{13}C/^{12}C$ isotopic ratios of wood from the Eva forest bed are compared to those from trees of the modern boreal forest. This last interglaciation of 125,000 years ago is demonstrated for the first time to be a period of major erosion of loess and deep and rapid thawing of permafrost, followed by emplacement of the Eva forest bed. During the past 100,000 years, the treeless steppe environment returned and the deposits were refrozen.



The Surface Rupture of the 1957 Gobi-Altay, Mongolia, Earthquake
by R. A. Kurushin and others, 1997

The 1957 Gobi-Altay earthquake is the last major earthquake (M ~ 8) to occur in a continental region. The full complement of processes that distinguishes continental tectonics from plate tectonics—internal deformation of blocks, conjugate faulting, variations in amounts of slip along faults, block rotations about vertical axes, basement folding, and even the formation of new faults (through fault-bend folding at the earth's surface)—occurred in 1957 and remain clearly exposed in the arid environment of the Gobi-Altay. Because of the variety of styles and the extent of deformation, the subparallel surface ruptures, ~25 km apart, provide a microcosm of intracontinental mountain building at a large scale.

SPE320, 160 p., ISBN 0-8137-2320-5, $69.00, Member price $55.20

Volumes are 8-1/2" x 11". Prices include ordinary shipping and handling.

The Geological Society of America

1-800-472-1988
www.geosociety.org

Publication Sales, P.O. Box 9140, Boulder, CO 80301, 303-447-2020, fax 303-447-1133

 continued from p. 35

HYDROGEOLOGY / SEDIMENTARY GEOLOGY
TOWSON UNIVERSITY

Towson University in Towson, Maryland, seeks to fill an entry-level tenure-track position at the Assistant Professor level in Hydrogeology/Sedimentary Geology to begin Fall 1998. The successful candidate will demonstrate a strong commitment to undergraduate teaching in a metropolitan area. Towson's geology program is a concentration in the Geosciences major and is housed within the Physics Department.

In addition to upper-level undergraduate courses in Sedimentology & Stratigraphy, Hydrogeology, and Sedimentary Petrology, this faculty member should be able to develop and teach new courses to help expand Towson's Geosciences program and support the Environmental Sciences major. Responsibilities will inlcude teaching introductory Physical and Historical Geology on a rotational basis and supervising undergraduate research. A viable research program and teaching experience are desirable.

Interested persons should send curriculum vitae, statement of teaching philosophy, and names of three references to: Dr. Rachel Burks, Chair of Geology Search Committee, Physics Department, Towson University, Towson, MD 21252. Applications must be received by March 2, 1998. A Ph.D. is required at time of appointment.

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.

SCHOOL OF EARTH AND OCEAN SCIENCES
UNIVERSITY OF VICTORIA

Applications are invited for two tenure-track faculty positions in the School of Earth and Ocean Sciences. Rank is open, but strong preference will be given to appointments at the Assistant or Associate Professor level in the following fields: a) tectonics-structural geology; b) chemical oceanography or low temperature geochemistry (new laser-ICP-MS facility available); c) global climate, atmospheric or related biogeochemical science. Close interactions are fostered with nearby government laboratories of the Geological Survey of Canada Pacific; B.C. Geological Survey; Canadian Climate Centre; and Institute of Ocean Sciences. Applicants should have an interest in research and teaching aspects of earth system science.

Qualifications include the completion of a Ph.D. and demonstrated strong research and teaching potential. Duties will include teaching at undergraduate and graduate levels. Letters of application, clearly outlining the candidate's expertise, teaching experience and research interests, along with curriculum vitae and names, addresses, fax and e-mails of three referees should be sent by February 27, 1998 to: Dr. C. R. Barnes, Director, School of Earth and Ocean Sciences, University of Victoria, P.O. Box 3055, Victoria, B.C. V8W 3P6 Canada.

In accordance with Canadian immigration regulations, this advertisement is directed to Canadian citizens and permanent residents. The University of Victoria is committed to employment equity and encourages applications from women, members of visible minorities, aboriginal peoples, and persons with disabilities.

TENURE-POSITION — VOLCANOLOGIST
UNIVERSITY OF ALASKA, FAIRBANKS

The Geophysical Institute and the Department of Geology & Geophysics at the University of Alaska, Fairbanks, invite applications for a 12-month (3/4 time research, 1/4 time teaching), tenure-track faculty position. The level of appointment will depend upon experience. The successful applicant will develop a program of externally funded research in volcanology. We seek someone with a focus on the physics of magmatic processes and an interest in field observations at active systems. This research program should complement existing strengths in volcanic petrology, seismology, geology, and geochemistry. The appointee will also 1) supervise graduate and undergraduate student research projects, 2) contribute to the teaching of topics such as geology, physical volcanology, and geodynamics at both the graduate and undergraduate levels, and 3) assist with monitoring of volcanoes and response to eruption crises. A Ph.D in an appropriate field is required. The appointee will be a member of the Volcanology Group at the Geophysical Institute, and will be expected to take an interdisciplinary approach to research through collaboration with researchers in other disciplines, institutions, and countries. The appointee will also serve on the staff of the Alaska Volcano Observatory (AVO), a cooperative program of the U.S. Geological Survey, UAF, and Alaska Division of Geological and Geophysical Surveys. AVO operates dense seismic networks on 16 active Aleutian arc volcanoes, conducts daily satellite surveillance of the entire arc, investigates magmatic processs relevant to volcanic hazards within the arc, and maintains close ties with volcanologists in Kamchatka and Japan. The appointee will, through participation in the AVO team and through independent research efforts, seek to develop a more rigorous quantitative understanding of the coupled physical, chemical, and thermal processes that comprise volcanism. Research facilities at UAF include theSeismology Laboratory, electron microprobe facility, the remote sensing data archives and computer resources of the Alaska Synthetic Aperture Radar Facility, the Alaska Data Visualization and Analysis Laboratory, and the Arctic Region Supercomputing Center. New scientific opportunities will develop as the International Arctic Research Center, currently under construction adjacent to the Geophysical Institute, begins operations in 1998. Please send a letter of application, resume, statement of research and teaching interests and experience, and names, addresses and phone numbers of three references by March 1, 1998 to: Dr. John C. Eichelberger, Chair, Volcanology Search Committee, Geophysical Institute, University of Alaska, Fairbanks, P.O. Box 757320, Fairbanks, AK 99775-7320. Phone: 907-474-5530; fax: 907-474-7290; e-mail eich@gi.alaska.edu.

The University of Alaska is an equal opportunity/affirmative action employer and educational institution. Women and minorities are encouraged to apply. Your application for employment with the University of Alaska is subject to public disclosure under the Alaska Public Records Act.

STRUCTURAL GEOLOGY
DEPARTMENT OF GEOSCIENCES
UNIVERSITY OF MASSACHUSETTS, AMHERST

The Department of Geosciences at the University of Massachusetts in Amherst invites applications for a tenure-track position at the Assistant Professor level in the broad areas of structural geology, tectonics, and geodynamics. This person will augment the exisitng structural geology program. Areas of particular interest include neotectonics, fracture analysis, seismology and planetary structural geology, but all related fields will be considered. The ability to intereact with other programs in the Department such as hydrogeology, geophysics, Quaternary geology, or petrology is essential. Appointee will be expected to establish a funded research program. Teaching duties will include undergraduate and graduate courses within structural geology - field geology - tectonics program, occasional courses in general geology, and courses in the candidate's area of interest. Applications should include a statement of research and teaching interests, and the names, addresses, fax numbers and e-mail addresses of three or more referees. Copies of published papers or preprints should be included. All materials should be sent to: Structural Geology Search Committee, Department of Geosciences, University of Massachusetts, Amherst, MA 01003-5820. Review of applications began in early January 1998 and will continue until the position is filled. Further information about the Department can be found at our Web site: http://www.geo.umass.edu. The University of Massachusetts Web site is http://www.umass.edu. The University of Massachusetts is an Affirmative Action/Equal Opportunity Employer; women and minorities are encouraged to apply.

DIRECTOR -- ANALYTICAL LABORATORY
DEPARTMENT OF GEOLOGICAL SCIENCES
INDIANA UNIVERSITY

The Department of Geological Sciences invites applications for a position as Director of Analytical Services. Duties include the supervision of the operation and maintenance of analytical instrumentation, including an atomic absorption spectrophotometer with graphite furnace, an ICP spectrophotometer, an ion analyzer, and sulfur/carbon analyzer. Additional duties will include routine and novel methods for analyses of solids and waters. A minimum of an M.S. degree in chemistry, geochemistry, or a related area is required. Preference will be given to Ph.D.s with research orientations. Submit a resume and a statement of analytical interests to: Dr. Edward M. Ripley, Chair of Search Committee, Department of Geological Sciences, Indiana University, Bloomington, IN 47405. Indiana University is an Affirmative Action Equal Opportunity Employer.

SEDIMENTARY GEOLOGY AT DUKE UNIVERSITY

The Division of Earth & Ocean Sciences (EOS) of the Nicholas School of the Environment at Duke University invites applications for an anticipated tenure-track position in the general area of sedimentary geology to be filled at the assistant professor level. The starting date will be open, but we hope to fill the position by Fall 1998.

EOS at Duke includes 14 full-time faculty, 3 faculty with secondary appointments from other units, and 3 research scientists. Research and educational programs of EOS cover a broad spectrum of subdisciplines in geology, marine geology, hydrology, and oceanography. Supporting facilities at Duke include a wide range of computer hardware and software, analytical equipment, laboratories, and research vessels. We look forward to receiving applications from qualified applicants who will enhance the existing strengths of EOS and NSOE in these areas. Please see our web site at http://www.geo.duke.edu for additional information.

The successful candidate will hold a Ph.D. degree and will be expected to develop a vigorous research program in his or her specialty as well as being committed to both undergraduate and graduate teaching, including B.S., M.S., and Ph.D. level geology degree candidates. The position is broadly defined in terms of specialty and could include outstanding individuals with innovative approaches to stratigraphy, sedimentation, sedimentary petrography, basin analysis, etc. We especially encourage applications from candidates who use the sedimentary record in investigations of global change and tectonics.

Send vitae and names of 3 references to: Chair of the Search Committee, Division of Earth & Ocean Sciences, Box 90230, Duke University, Durham, NC 27708-0230. All applications received by March 1, 1998, will be guaranteed consideration. Duke University is an Equal Opportunity/ Affirmative Action Employer.

DIVISION OF EARTH SCIENCES
NATIONAL SCIENCE FOUNCATION (NSF)

NSF's Division of Earth Sciences is seeking qualified candidates for an Associate Program Director or Program Director in our Tectonic Program. This position is excepted from the competitive Civil Service and may be filled either on a 1- to 2- year Visiting Scientist/Temporary basis or under the provisions assignment of the Intergovernmental Personnel Act (IPA). IPA applicants must be permanent, career employees of eligible organizations for at least 90 days prior to entering into a mobility assignment agreement with NSF. Reimbursement of salary and other related costs are negotiated between NSF and the individual's institution.

Current annual salary for the position ranges from: Associate Program Director— $54,629 to $86,059; Program Director— $64,555 to $100,611.

Applicants must have a Ph.D. or equivalent experience in some field of earth sciences. In addition, for the Associate Program Director, 4 years of successful research, research administration and/or management experience beyond the Ph.D. and for the Program Director, 6 years of successful research, research administration and/or management experience beyond the Ph.D. in an area supported by the Program is required. A broad general knowledge of earth sciences research and familiarity with the U.S. scientific community are desirable.

The Tectonics Program supports field, laboratory, theoretical, and computational studies of processes and kinematics accompanying deformation at plate boundaries and in plate interiors. Areas of research include structural geology, tectonics, geochronology, petrology, paleomagnetics, and other fields releated to understanding the tectonic history of the lithosphere through time.

Interested scientists should send a resume and a letter indicating areas of interest and time frame of availability to: National Science Foundation, Division of Earth Sciences, Room 785, 4201 Wilson Boulevard, Arlington, VA 22230.

For further information, contact Alan Gaines at (703) 306-1553; emai: againes@nsf.gov. Hearing-impaired individuals should call TDD at (703) 306-0189. NSF is an equal opportunity employer committed to employing a highly qualified staff that reflects the diversity of our nation.

BIOGEOCHEMISTRY
PORTLAND STATE UNIVERSITY

The Geology Department of Portland State University seeks to fill a tenure-track Assistant Professor position in the area of Biogeochemistry to begin Fall 1998. The successful candidate is expected to teach undergraduate and graduate courses and conduct a vigorous externally funded research program, including supervision of master's students in geology and master's and Ph.D. students in environmental sciences and resources. Primary interest is in low-temperature microbialgeochemical processes in geological systems. Candidates should also be interested in applying their knowledge and skills to the general education of all undergraduate students. We are interested in secondary areas of interest, which could include paleontology, historical geology, geographical information systems, hydrogeology or secondary education. The new faculty should interface with ongoing studies in soils, weathering, hydrogeology, contaminant modeling, lacustrine and estuarine processes. The Ph.D. is required by the date of hire. A detailed resume including two letters of professional references and a statement of research and teaching interests must be received by March 1, 1998. Address the Biogeochemistry Search Committee; Geology Department; Portland State University; Portland, Oregon 97207-0751. Fax (503) 725-3025. E-mail marvin@ch1.ch.pdx.edu. The Geology Department home page is http://www.geol.pdx.edu. Portland State University is an equal opportunity/ affirmative action employer and the Geology Department is committed to diversifying its faculty.

SOIL / ENVIRONMENTAL GEOSCIENTIST
STANFORD UNIVERSITY

The Department of Geological and Environmental Sciences at Stanford University invites applications for a tenure-track assistant professorship in soil/environmental geosciences. This new position is intended to complement our growing research and teaching programs, at both the graduate and undergraduate levels, in environmental geoscience. Research specialities may include but are not limited to geochemical and biogeochemical studies of soils, both modern and ancient, aqueous/groundwater geochemistry, mineral/soil-water interactions, and geochemical cycling and modeling.

Priority will be given to those applications received by March 16, 1998. Applicants must have a Ph.D. degree at the time of appointment. This appointment must be made at the assistant professor level. Please send a letter of interest, a statement of teaching and research objectives and accomplishments, a curriculum vitae, a publication list, and the names and addresses of three potential recommenders to: Professor Gordon E. Brown, Jr., Department of Geological and Environmental Sciences, Stanford University, Stanford, CA 94305-2115.

Stanford University has a strong institutional commitment to the principle of diversity. In that spirit, we particularly encourage applications from women, members of ethnic minorities, and individuals with disabilities.

Services & Supplies

LEATHER FIELD CASES. Free brochure, SHERER CUSTOM SADDLES, INC., P.O. Box 385, Dept. GN, Franktown, CO 80116.

Research, Award, and Internship Opportunities

National Research Council Associateship Programs

The National Research Council announces the 1998 Postdoctoral and Senior Research Associateship Programs to be conducted on behalf of over 120 research laboratories throughout the United States representing nearly all U.S. government agencies with research facilities. The programs provide opportunities for Ph.D. scientists and engineers of unusual promise and ability to perform research on problems largely of their own choosing yet compatible with the research interests of the sponsoring laboratory.

Approximately 350 new full-time Associateships will be awarded on a competitive basis in 1998 for research in: chemistry; earth and atmospheric sciences; engineering, applied sciences and computer science; life, medical, and behavioral sciences; mathematics; space and planetary sciences; and physics. Most of the programs are open to both U.S. and non-U.S. nationals, and to both recent doctoral recipients and senior investigators.

Awards are made for one or two years, renewable for a maximum of three years; senior applicants who have held the doctorate at least five years may request shorter periods. Annual stipends for recent Ph.D.'s for the 1998 program year range from $30,000 to $47,000 depending upon the sponsoring laboratory, and will be appropriately higher for senior award recipients.

Applications submitted directly to the National Research Council are accepted on a continuous basis throughout the year. Those postmarked no later than April 15 will be reviewed in June, and by August 15 in October.

Information on specific research opportunities and participating federal laboratories, as well as application materials, may be obtained from the National Research Council, Associateship Programs (TJ 2114/D3), 2101 Constitution Ave., NW, Washington, DC 20418, fax 202-334-2759, rap@nas.edu, http://www.nas.edu/rap/welcome.html.

Opportunities for Students

Teaching Assistantships. Geology Department at California State University has teaching assistantships available for students wishing to pursue an M.S. in geology. Appointment carries tuition waiver and $10,000 salary for academic year. Department strengths are in the areas of sedimentary geology, structural geology, and environmental geology. Bakersfield is located in the heart of California's petroleum and agricultural areas, and abundant opportunities exist for industry-supported thesis projects. For additional information and application materials contact: Robert Horton, Graduate Coordinator, Department of Geology, California State University, Bakersfield, CA 93311-1099. (805) 664-3059 or visit the department's web site at http://www.geol.csubak.edu/Geology/.

Traveling Fellowship: Interdisciplinary Research Training Group (RTG) in ecology, geology, archeology, geography, and soils. Graduate students are invited to Minnesota for up to 3 months to enhance training in "Paleorecords of Global Change." Stipend (provided for citizens, nationals or permanent residents of the U.S.), travel and living allowance, and tuition. Application deadline April 1 (for travel July 1 — December 31) and October 1 (for travel January 1 — June 30). For application contact 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 Grants Available. The Colorado Scientific Society invites graduate students to apply for research grants, to be awarded in early May 1998. Applicants must be enrolled in a Master's or Ph.D. program at an accredited college or university. Approximately eight grants ranging from $500 to $1200 will be awarded for field-oriented research on the geology, geochemistry, and geophysics of the Rocky Mountain region. In addition, grants as large as $1000 are awarded for engineering geology research (with no restriction on the geographic area of interest), and one grant as large as $1000 is offered for studies of the Heart Mountain Fault in northwest Wyoming. Interested students can obtain applications forms and grant information directly from the Society website at http://rainbow.rmi.net/~css/ or by mail from the Chair of the Memorial Fund Funds Committee, Colorado Scientific Society, P.O. Box 150495, Lakewood, CO 80215. Deadline for applications is April 3, 1998.

Graduate Research Assistantships in Exploration Geophysics. Department of Geosciences, University of Houston, seeks graduate research assistants (M.S. and Ph.D.) starting August 1998. Qualified students will be involved in geophysical projects that are closely related to hydrocarbon exploration in the Gulf of Mexico. More specifically, they will be involved in one or all of the following research areas: (1) salt tectonics, (2) numerical modeling/inversion of gravity and heat flow, and (3) processing and interpretation of seismic-reflection data. Students with strong background in geophysics, geology, petroleum engineering, physics, and mathematics are encouraged to apply. It is desirable that applicants have some familiarity with the UNIX computation environment. A variety of analytical software such as MATLAB, GeoQuest (IESX and CPS-3), GeoDept, ARC/INFO, ArcView, and GMT runs on Sun workstations of the department.

Application deadline is March 1, 1998. Individuals wishing more information about the research projects should write to Dr. Seiichi Nagihara, Department of Geosciences, University of Houston, Houston, TX 77204-5503; e-mail: nagihara@uh.edu.

JOI/USSAC Ocean Drilling Fellowships. JOI/U.S. Science Advisory Committee is seeking Ph.D. and M.S. degree candidates of unusual promise and ability who are enrolled at U.S. institutions to conduct research compatible with that of the Ocean Drilling Program. April 15, 1998, is the next fellowship application deadline for both shipboard and shorebased research proposals. Shipboard research is related to future ODP legs on which students wish to sail as scientists. Shorebased research may be directed towards broad themes or the objectives of a specific DSDP or ODP leg — past, present, or future.

Shipboard proposals submitted for the upcoming April 15 deadline should be based on the following ODP legs: Leg 182 Great Australian Bight, Leg 183 Kerguelen Plateau, Leg 184 East Asia Monsoon, Leg 185 Izu-Mariana, and Leg 186, W. Pacific Seismic Net/Japan Trench, and Leg 187 Australia-Antarctic Discordance. Fellow candidates wishing to participate as shipboard scientists must also apply to the ODP Manager of Science Operations in College Station, TX. A shipboard scientist application form and leg descriptions are included in the JOI/USSAC Ocean Drilling Fellowship application packet.

Both one-year and two-year fellowships are available. The award is $22,000 per year to be used for stipend, tuition, benefits, research costs and incidental travel, if any. Research may be directed towards objectives of a specific leg or to broader themes. For more information and to receive an application packet contact: JOI/USSAC Ocean Drilling Fellowship Program, Joint Oceanographic Institutions, Inc. 1755 Massachusetts Ave., NW, Suite 800, Washington, DC 20036-2102 (Andrea Johnson; Tel: 202-232-3900, ext. 213; email: ajohnson@brook.edu).

NASA Planetary Biology Internships. The Marine Biological Laboratory, Woods Hole, Massachusetts, invites applications from graduate students and seniors accepted to graduate programs for awards of $2200 plus travel to participate in research at NASA centers and collaborating institutions for approximately 8 weeks. Typical intern programs include: global ecology, remote sensing, microbial ecology, biomineralization, and origin and early evolution of life. Application deadline: 2 March 1998. For information/applications, contact: Michael Dolan, Planetary Biology Internship, Department of Biology, Box 3-5810, University of Massachusetts, Amherst, MA 01003-5810. Email: pbi@bio.umass.edu. Tel (413) 545-3223. An Equal Opportunity/Affirmative Action Employer.

The Southwest Earth Studies Program. A NSF-sponsored Research Program in Philosophy and the Earth Sciences. June 15 to August 8, 1998, Durango, Colorado. Southwest Earth Studies is a research program into the nature of knowledge. The program consists of two professors and ten students, five each from the earth sciences and philosophy. Students explore the philosophic implications of scientific issues, and investigate the role that scientific information can play in philosophic and public policy debates. These themes are developed through an examination of the issues surrounding acid mine drainage in the San Juan Mountains of southwest Colorado. Qualified applicants receive: tuition and fees, room and board; 3 hours credit in environmental studies; $1000 stipend. Prerequisites: Junior or Senior standing w/GPA of 3.3 or higher; background in the earth sciences and in philosophy. Send college transcripts, resume, two letters of recommendation from professors, a 500-word statement explaining your interest in this program, and a telephone number, to: Robert Frodeman, Director, Southwest Earth Studies Program, University of Tennessee, 615 McCallie, Chattanooga, TN 37403.

For additional information: http://www.utc.edu/~ses.
Application deadline is March 16, 1998.