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INSIDE

Geologic Records in Deep Sea Muds

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Sectioning a piston core aboard the R/V *Yaquina*.

Bringing core aboard the Glomar *Challenger*.

ABSTRACT

The geologic record of the muds and clays of the deep sea contains information regarding uplift within and climate of the continental source region for those sediments and, to a lesser extent, of changes in sea level. Detailing the terrigenous sedimentary record in a hemipelagic or pelagic core is the only way in which the climatic histories of the land and sea can be compared directly. The history of the mass accumulation rate of terrigenous sediments is the starting point for discussions of global mass balances and, together with other information, permits definition of when chemical and physical weathering processes were important during the Cenozoic. Significant chemical weathering began at the Eocene-Oligocene boundary and continued for at least 20 m.y. before physical weathering became dominant in the middle or late Miocene.

INTRODUCTION

Ninety-five percent of the terrigenous material entering the ocean is delivered by rivers, and most of it is deposited on or near the continental margin. A minor amount bypasses the continental margin and is deposited, by a variety of processes, in the deep ocean. In the past decade marine geologists have become proficient at reading the multifaceted record offered by the accumulation of terrigenous materials in hemipelagic and pelagic environments. They have found that this record can be applied widely to questions of broad geological importance. In this overview, examples of the kind of research now being carried out in this area illustrate the different geological topics that are amenable to investigation by studies of the record of terrigenous sediment in the deep sea.

The deposition of terrigenous sediment in the deep sea is controlled by a combination of mountain uplift, climate of the sedimentary source region, and sea level. Signals of these three may be fully integrated in the core-record we recover from the sea floor, but commonly one of them clearly predominates and provides insight into geologic process or history. Uplift of the source region can result in an order of magnitude or greater signal in the accumulation rate of the mineral component of deep-sea sediments. The distal view of uplift of a major mountain range thus obtained integrates over subcontinental-sized drainage basins and is capable of providing a holistic overview of important tectonic events. The climate of the continental source region is commonly the dominant control of marine sedimentation. Input of river-derived hemipelagic mud responds to the degree of physical erosion in, relative humidity of, and runoff from the drainage basin. The flux of eolian dust to the deep sea is a record of the relative aridity of the eolian source region. Ice-rafted debris (IRD) indicates the presence of glaciers at sea level. Further, characterization of the continental record of global climate change from proxy records in pelagic sediment usually provides an opportunity to link the land record to the oceanographic record determined from the same core. Linking the land and sea records of climate change has been an important goal of the paleoclimate community for years. There is no better way to discover the interactive behavior among all parts of Earth's climatic system. The past 15 years have provided a clear demonstration of how changes in sea level control the deposition of sedimentary units or packages on continental margins. In general, highstands are times of deposition on continental shelves, and during lowstands more material is transported directly to the continental slope and sea floor. The distal, deep-sea record of this process is not well defined as yet, but it should be present in the form of either bottom-process-related sediments, such as turbidites, or in the mass accumulation rate of hemipelagic sediment. Finally, the history of the mass flux of particulates from the continents to the oceans provides a constraint for conceptual and computational models of geochemists pondering global cycles of elements and the oceanic aspect of such cycles.

Below I present brief summaries of current research involving aspects of terrigenous deposition. New information is available regarding important topics such as linking marine and continental records of climate change, uplift history of the Himalayas, and the times of chemical vs. physical weathering of continents. Older results like the major change in atmospheric circulation at the Paleocene-Eocene boundary or the paleoclimatic record provided by ice-rafted debris have stimulated new avenues of research.

PROCESSES OF TERRIGENOUS SEDIMENTATION

The general process of downslope mass movement of sediment as gravity flows of one category or another has been the subject of considerable research in sedimentology during the past several decades (Pickering et al., 1989) and will not be considered further here. It has been about two decades since marine geologists have become aware of how active a place the deep sea floor is, and that much of the sediment reaching the lower part of the continental slope or rise is redistributed by abyssal currents. These processes are particularly important in the Atlantic where both the southward-flowing North Atlantic Deep Water and the northward-flowing Antarctic Bottom Water redistribute abyssal sediments (e.g., Poag and de Graciansky, 1992), forming a variety of current-mediated deposits. Only when the sediment supply overwhelms the capacity of oceanic circulation to redistribute material along the continental margin do deposits such as the Mississippi Delta or the Amazon Cone or the Bengal Fan form.

Hemipelagic deposits consist of fine-grained, silt and clay-sized muds deposited within hundreds of kilometres of the continental margin. These muds, derived from winnowing of continental shelf and upper slope sediments, move offshore within the water column at 2 or 3 km depth in a plume or cloud of limited vertical extent. Resulting deposits blanket continental slopes and regions of the sea floor adjacent to the continents. The horizontal advection of lithogenous material has been well documented by sediment trap studies which have shown that this process is the dominant one of terrigenous sedimentation up to hundreds of kilometres offshore (Honjo et al., 1982; Heggie et al., 1987; Saito et al., 1992). These deep-sea muds are the least well known of all abyssal sediments, partly because they have been difficult to date and partly because their paleoenvironmental interpretation has not always been obvious. Both fluvial supply and sea level should exert a control on the mass accumulation rate of fine-grained hemipelagic mud in the deep sea, and these two determinants may often work in concert.

Calved bergs from glaciers reaching the ocean carry poorly sorted sedimentary debris far out to sea. The most obvious of these materials are dropstones, which are present in all high-latitude sediments during glacial times. Finer grained materials are also ice rafted along with the pebbles and provide insight into the details of high-latitude climatic and oceanographic processes.

Seaward of the regions characterized by hemipelagic deposition, away from the influence of turbidites and redistributional processes, and equatorward of the influence of ice rafting, the mineral component of deep-sea pelagic clays is dominated by eolian dust (Win-

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Penrose Conference Report

Continental Tectonics and Magmatism of the Jurassic North American Cordillera

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Although continental-margin subduction was established in latest Paleozoic or early Mesozoic time along the North American Cordillera, it was not until the Jurassic that tectonism extended far inboard (east) of the magmatic arc, and voluminous magmatism took place in and behind the arc. Many aspects of this Jurassic tectonic event have been studied in different regions and by diverse approaches, and a Penrose Conference was convened February 27 to March 4, 1993, at Lake Havasu City, Arizona, to bring together new information in order to better understand the whole event. The 59 participants, including five graduate students, represented three countries and regions from Alaska to Sonora. Included were structural geologists, petrologists, stratigraphers, geochemists, paleontologists, isotope geochemists, tectonicists, and generalists. This diversity was key to the success of the conference, for it provided a rare opportunity to integrate methodologies as well as regional data sets and resulted in a better understanding of the continental magmatic-tectonic events.

The conference began with a full-day field trip through the magmatic arc in the cratonal setting of western Arizona and adjacent California. In this region, Middle Jurassic explosive volcanism and plutonism transected older deformation belts in the continental crust. Evidence for short-lived episodes of contractile deformation and high-angle (extensional?) faulting before, during, and immediately after arc magmatism was discussed. Cessation of magmatic activity was signaled by sedimentation and the establishment of basins and fluvial system(s) recorded by the Jurassic and Cretaceous McCoy Mountains Formation.

In the opening address, Bill Dickinson noted that Jurassic arcs and deformation belts existed around the proto–circum-Pacific margin and that we see only one small part of that system in North America. He argued for a rethinking of several generally accepted tenets such as the need for extension within, or behind, west-facing subduction zones; the need for formation of the ophiolites found along the present coast of the southern Cordillera in marginal oceanic basins developed above a subduction zone; and whether the paleomagnetic evidence requires major latitudinal displacements of terranes other than the Alexander terrane. In a provocative interpretation of the Jurassic plate motion record, Dave Engebretson argued that although fast absolute motion to the northwest and sinistral oblique subduction along the North America plate were hallmarks for much of the Jurassic, the changes in plate motion are commonly more important tectonically (and leave their mark in the rock record) than the absolute motions themselves. Major plate-motion changes at about 180 and 142 Ma were the most important in the Jurassic. Evidence from ophiolites in California's Coast Ranges suggested to Bonnie Murchey that the age of subducted oceanic crust varied during the Jurassic, with subduction of relatively old crust matching the time of voluminous magmatism about 165–155 Ma. Apparently complex oceanic ridge and subduction zone interactions, perhaps analogous to the modern San Andreas system, characterized the plate margin from about 155 Ma onward. Peter Ward proposed a general subduction cycle, based on a Cenozoic analog, comprising (1) rapid subduction and accompanying magmatic lull, (2) uplift and erosion as the oceanic spreading center nears the continent, (3) transtension accompanying batholith formation, and (4) strike-slip and rifting, at which time blueschists and ophiolites are disgorged. For the Jurassic, he suggested that this cycle began about 225 Ma and ended about 152 Ma.

The opening talks provided conceptual models for evaluating data from subsequent sessions. Sessions focused on magmatism and radiogenic isotopes; the cratonic paleogeographic record; and structure, stratigraphy, and tectonics of regions as they applied to understanding continent-scale tectonics, terrane movements, and lithospheric processes. The Cordillera was examined from north to south with regional focus to emphasize the integration of the multidisciplinary data. The complete Jurassic record of the northern Cordillera was presented in a series of short talks that accompanied posters. The architecture of the northern Cordilleran "collage" of terranes is a first-order problem in the paleogeographic reconstruction of Jurassic arc magmatism, sedimentation, and tectonism. The outboard terranes were not accreted to ancestral North America until at least 185 Ma; therefore, comparisons with the more truly continental arcs of the southern Cordillera must consider postaccretionary events. There is considerable debate about the structural styles of some ca. 185 Ma plutons that appear to be synacretionary or are along terrane boundaries. Evidence of at least six episodes of Jurassic plutonism and/or volcanism is emerging from precise U-Pb dating and biochronology. Although there is a common spatial and temporal association between plutonism and volcanism, the transition from plutonic to volcanic environments is best exposed in tilted crustal sections along the western edge of Wrangellia. The origin of dual, compositionally similar but apparently unrelated Early Jurassic arcs within Stikinia and Wrangellia must be reconciled with the Paleozoic to Jurassic oceans represented by oceanic assemblages lying between them. Extensive upper Lower to Upper Jurassic sedimentary basins commonly mark the end of magmatism. Characterizing these somewhat similar basins is critical because they provide linkages among terranes. Of particular interest in comparisons with the southern Cordillera is the long-lived Middle to Late Jurassic (post–170 Ma) magmatism and its interaction with coeval contraction in southeastern British Columbia. Reconstructing the contractile structures places the hanging-wall rocks at or west of the present Coast Mountains. However, radiogenic isotopic compositions of Jurassic plutons cutting these rocks suggest that the craton did not extend as far west as required by structural data and Lithoprobe seismic imaging.

On a mid-meeting field trip, conference participants saw Jurassic volcanic rocks, plutons, and associated structures in several mountain ranges in the Mojave Desert. Shallow-level felsic plutons in the Bristol Mountains area generally are silica-depleted and potassium-enriched, and commonly show albitization and Fe-skarn associations. Evidence of Middle Jurassic intra-arc extension manifested by interbedded volcanic rocks and eolianites and evidence for syndepositional normal faulting was examined in the Cowhole Mountains. As a counterpoint, evidence for contraction, also of Middle Jurassic age, in nearby ranges was discussed.

Describing the southern Cordillera focused on conceptual models for orogenic belts, with the accompanying posters presenting detailed topical studies. It appears that lower-crustal décollements are necessary to balance orogenic deformation, and that oblique motions must be acknowledged in reconstructions. Many land-based studies argued for sinistral oblique plate convergence in the Jurassic, in agreement with the oceanic record. Apparently, the degree of oblique convergence was smaller in the Middle and Late Jurassic than it was earlier, so along-strike, or even local, differences of dextral and sinistral convergence are possible, depending upon plate motions and geometry. For example, in the Klamath Mountains and western Sierra Nevada, extension, contraction, and dextral and sinistral strike slip took place in various combinations in the interval from about 165 to 148 Ma. Because of precise U-Pb geochronology, this study provides sensitive local evidence for plate-tectonic interactions. The tectonic setting of the Middle Jurassic ophiolites found along the coastal region was revisited, with good evidence presented for their formation in an open ocean as well as along the continental margin within suprasubduction-zone settings.

Regional differences between the northern and southern Cordillera for timing of extension provide strong evidence for differential development of rift basins during sinistral oblique subduction. Knowledge of Great Basin tectonics is still poorly constrained because few structures are closely dated, but Middle Jurassic magmatism in the form of scattered plutons extended across a province of at least minor shortening and extension to central Utah, farther inboard from any other analogous place in North America. Regional arguments for dextral slip on the Upper Jurassic Pine Nut fault persist, despite growing evidence for mainly sinistral oblique subduction during the Jurassic. Farther south, the Mojave and Sonoran Deserts lack the typical continent-margin crust of west-

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ern Nevada and northern California. The continental crust in this region was previously truncated, beginning in the late Paleozoic. The magmatism in the Mojave Desert occurred only in the Middle and Late Jurassic, whereas activity in the Sonoran Desert began in the Early Jurassic. Intra-arc deformation in both regions consisted of extension and contraction, both apparently of small magnitude, and consistent with sinistral oblique subduction.

The close temporal association of magmatism and deformation identifies most or all tectonic activity as subduction-related, and study of the magmas provides clues for deep-lithosphere processes. Middle and Late Jurassic granitoids in the Mojave and Sonoran Deserts are chemically and isotopically distinct from Triassic and Cretaceous magmas, forming an intermediate position in a general evolution from primitive to evolved. Typical features include elevated K_2O to make an alkali-calcic suite, and associated albitization and iron skarns. Time-transgressive changes through the Mesozoic in magma compositions argue that the differences are fundamental to the magma-genesis processes, and further indicate that lithospheric mantle was not eroded tectonically and replaced by primitive mantle in association with emplacement of the Pelona-Orocopia schist tectonic slab. Geographic-transgressive patterns in isotopic compositions demonstrate the location, and the subsequent modification, of thick continental lithosphere beneath the arc. A hydrous, enriched mantle source, with variable assimilation and fractional crystallization of the magmas, accounts for most characteristics of Middle and Late Jurassic magmas.

Depositional patterns recorded by Jurassic strata in the continental interior (Colorado Plateau) reveal the orogenic effects of the Jurassic subduction system. The stratigraphic packages, which are bounded by precisely dated regional unconformities, provide very sensitive indicators of regional tilting patterns. Early Jurassic deposits thicken westward toward the arc and contain a volcanic component. However, in the Middle Jurassic (169 to 161 Ma), drainages shifted to deposit abundant detritus on the northwest side of the plateau. The end of the Jurassic is marked by a major unconformity. The stratigraphic record corresponds closely to the magmatic and structural chronology for the magmatic arc in nearby Arizona and southern California. Comparing tectonic styles, magmatic characteristics, and timing of events along the Cordillera from Mexico to the Yukon provided much new information. Especially striking was the synchroneity of major tectonic and magmatic events. Unlike Cretaceous and later magmatism and tectonism, Jurassic events were virtually synchronous. For instance, a major pulse of magmatism occurred everywhere at about 172 to 160 Ma. A potential breakthrough in a long-standing Canadian Cordilleran problem of reconciling (1) dual Early Jurassic arcs, (2) a long-lived intervening oceanic basin, and (3) a later, eastward-sweeping Middle Jurassic arc was reached by proponents of disparate models. The new idea encompassed the implications of plate motion reconstructions in the Middle to Late Jurassic to arrive at a simpler model of a single Jurassic arc disrupted by later transcurrent faults. However, the evidence for a single arc is not even complete in the southern Cordillera, and more work is required to prove or disprove the single- or double-arc hypotheses. Although agreement was by no means complete, many participants left the meeting feeling more convinced that terrane movements since the beginning of the Jurassic were not a fundamental driving force in orogeny, but rather that orogenic float or magmatic arc tectonics probably account for most observations. Results from studies of magmas are far from complete, but consensus was reached on the utility of such studies, and the need to focus on three especially useful approaches. (1) Study mafic rocks carefully, because they give less ambiguous information on processes involved. (2) Use uniform descriptive systems to reduce ambiguities. (3) Studies that include source rocks and contaminant rocks are needed to quantify crustal influences. Better geochronological data are required in most places to properly distinguish spatial and compositional evolution trends in magmas, as well as to precisely date extensional and contractional episodes. Total shortening normal to the continental margin remains poorly determined, but it is vital to actualistic models for continental tectonism and accurate paleogeographic reconstructions. Constraining depth to décollement and the role of the magmatic arc as active or passive during lateral shortening of crust are also important. The Mojave-Sonora megashear continues to haunt the southern Cordillera; its existence, location, and timing are still not closely defined. The megashear remains as a possible southern analog to postulated major arc-parallel movements in Canada and Alaska.

The conveners thank the participants for sharing data and ideas in oral and poster presentations and generating the many group discussions. The intent of the conference, to examine the first major magmatic-tectonic events to affect extensively continental crust of the North American Cordillera, was achieved, and participants were amply rewarded with abundant information and new ideas for research directions. ■

Penrose Conference Participants

Lawford Anderson
Robert Anderson
Thomas Anderson
Andrew Barth
Ronald Blakey
Stefan Boettcher
Richard Brown
Cathy Busby
Thierry Calmus
Lisel Currie
Susan DeBari
Ed DeWitt
William Dickinson
George Dunne
David Engebretson
Gary Ernst
Carol Evenchick
Lydia Fox
Dipak Ghosh
Allen Glazner
Bradley Hacker
Craig Hart
David Harwood
Gordon Haxel
Ken Hon
Cliff Hopson
Keith Howard
Steve Johnston
William Jordan
Murray Journeay
Stan Keith
David Kimbrough
Jim Lang
Brian Mahoney
John Marzolf
Dave Miller
Jonathan Miller
Jim Monger
Thomas Moore
Bonnie Murchey
John Oldow
Fred Peterson
John Proffett
Stephen Reynolds
Nancy Riggs
José Luis Rodríguez-Castañeda
Charles Sabine
Jason Saleeby
Joseph Satterfield
Elizabeth Schermer
Lee Silver
Phil Simony
Arthur Snoke
Chuck Thorman
Dick Tosdal
Peter van der Heyden
Douglas Walker
Peter Ward
Joseph Wooden

GSA Executive Director Announces Retirement

F. Michael Wahl

At the meeting of Council on May 7, 1993, F. Michael Wahl, Executive Director of the Society since 1982, announced that he would be retiring from that position, effective June 1994. He stated that, as of that date, he will have served the Society in this position for 12 years, and it is time for someone else to lead GSA into its next decade of new programs and activities. Acknowledging Wahl's announcement, President Bob Hatcher stated that the organization has evolved tremendously during Wahl's tenure as Executive Director and credited Wahl for his contributions and outstanding leadership in bringing the Society to this high point in its distinguished 105-year history. Hatcher also announced that a search committee was being appointed to seek a new executive director, with a selection to be made in early 1994, in time for the new person to take office officially in June of that year. An announcement of the position appears in this issue of *GSA Today,* and will also be published in other earth science publications in the coming months. Society members are urged to submit the names of qualified persons for this important position.

(*For position announcement, see page 211*)

About People

GSA Member **Craig M. Ashbrook,** Southwest Virginia Community College, Richlands, was selected 1992 Professor of the Year for Virginia by the Council for Advancement and Support of Education.

Fellow **Kennard B. Bork,** Denison University, Granville, Ohio, has received Denison's 1993 Teaching Excellence Award.

Fellow **Philip Cohen,** U.S. Geological Survey, Reston, Virginia, is the 1993 recipient of the American Institute of Hydrology's C. V. Theis Award.

Fellow **Samuel Epstein,** California Institute of Technology, Pasadena, has been awarded the Geological Society of London Wollaston Medal.

The American Institute of Professional Geologists has honored Fellow **Robert H. Fakundiny,** state geologist and chief of the New York State Geological Survey, Albany, with the John T. Galey, Sr., Memorial Public Service Award.

Fellow **Peter T. Flawn,** University of Texas at Austin president emeritus, has received the Hall of Honor Award from the university's College of Natural Sciences and Natural Sciences Foundation Advisory Council.

Fellow **Donald C. Haney,** state geologist and director, Kentucky Geological Survey, has been appointed to a two-year term on the Earth Science and Resources board of the National Research Council.

Fellow **Susan W. Kieffer** has been named head of the Department of Geological Sciences at the University of British Columbia, Vancouver.

Fellow **George D. Klein** has been named president of New Jersey Marine Sciences Consortium, Fort Hancock.

Fellow **John McPhee,** Princeton, New Jersey, is the 1993 winner of the American Geophysical Union's Walter Sullivan Award for Excellence in Scientific Journalism.

Fellow **Frank Press** has been appointed Cecil and Ida Green Senior Fellow at the Carnegie Institution of Washington.

Newly elected SEPM officers are GSA Member **Sherwood W. Wise, Jr.,** Florida State University, Tallahassee—president; Member **Noel P. James,** Queen's University, Kingston, Ontario—president-elect; Fellow **Carlton E. Brett,** University of Rochester, New York—councilor for paleontology; Fellow **Robert E. Garrison,** University of California, Santa Cruz—councilor for sedimentology; Fellow **John B. Southard,** Massachusetts Institute of Technology—editor, *Journal of Sedimentary Petrology*; and Fellow **Peter A. Scholle,** Southern Methodist University—editor, SEPM Special Publications.

Deep Sea Muds *continued from p. 205*

dom, 1975). Dust is transported to the ocean by a few powerful spring storms that raise material from arid and semiarid regions. The coarse fraction settles out of the air quickly, and the fine material travels long distances in the upper troposphere and is eventually deposited by both dryfall and washout processes. Dust in the deep sea provides a record of the aridity of the continental source region in its accumulation rate (Prospero, 1981; Prospero et al., 1983; Rea et al., 1985) and a record of the intensity of the transporting winds in its grain size (Janecek and Rea, 1985; Rea et al., 1985). Eolian flux and grain-size records vary independently.

RATES OF SEDIMENT DEPOSITION

Every component of a deep-sea sediment, whether biogenic, terrigenous, or even authigenic, accumulates in response to a different combination of physical, biological, and chemical processes. No component accumulates at a constant rate. Consideration of abundance percentage, a standard mode of investigation, provides some useful information about the dominant sediment component, but all minor components fluctuate in abundance in response to, and antithetically from, the major component. To determine the input history of any sedimentary component, it is necessary to determine the mass accumulation rate (MAR), or flux, of that component. Sediment MAR is measured in units of mass per unit area and time, commonly $g \cdot cm^{-2} \cdot ka^{-1}$, and is the product of the linear sedimentation rate in cm/ka and the dry bulk density in g/cm^3. Incorporation of the bulk density term into the MAR accounts for the compaction and dewatering that occur with time and sediment loading; thus, MAR values are directly comparable for sediments of all ages and burial depths. Furthermore, because they are true mass-flux measurements, MAR values are the appropriate starting point for any mass-balance calculations. The MAR of any one sediment component is the product of the total MAR and the percent abundance of that component. Some typical MAR values for terrigenous sediments are tens of $g \cdot cm^{-2} \cdot ka^{-1}$ for turbidites, 0.5 to 2 or 3 $g \cdot cm^{-2} \cdot ka^{-1}$ for hemipelagic muds, and a few to hundreds of $mg \cdot cm^{-2} \cdot ka^{-1}$ for eolian dust. It is these flux values, along with compositional and grain size information, that provide the Earth history signal in the terrigenous sediments of the deep sea.

SOME EXAMPLES OF THE RECORD CONTAINED IN DEEP-SEA MUDS

Among the several objectives of the Ocean Drilling Program (ODP) nine-leg effort in the Indian Ocean (Duncan et al., 1992) was to determine the uplift history of the Himalayas by studying the clastic material shed from them. In accomplishing this task, different investigators studied the composition (Yokoyama et al., 1990; Brass and Raman, 1990; Amano and Taira, 1992) and the sediment mass accumulation rate history (Rea, 1992) of the terrigenous deposits of the northern Indian Ocean. I combined the sediment flux calculations from eleven suitable sites into one stacked, averaged, and normalized record (Rea 1992; Fig. 1), which provides a clear picture of the geologic history of this process. There are two main pulses of sedimentation, one in the late Miocene, between 9 and 6 Ma, and one in the Pliocene, between 4 and 2 Ma. Lesser flux maxima occur at 0 to 1 and 10.5 to 11.5 Ma. Studies of the mineralogy of the Bengal Fan turbidites show that the two main sediment pulses are uniquely characterized by minerals derived from erosion of the metamorphic core of the Higher Himalayas (Brass and Raman, 1990; Amano and Taira, 1992). These marine data are in agreement with similar information from a more proximal setting; the sedimentation rate and mineralogy of the Siwalik deposits of Pakistan show the same temporal correspondence of metamorphic minerals and high flux rates (Johnson et al., 1985). The results all point to significant uplift of the Himalayas occurring in two distinct phases beginning in the late Miocene (Rea, 1992; Fig. 1).

In the northwestern Atlantic, the major Cenozoic pulse of siliciclastic deposition occurred in the middle Miocene, and rates continued to be high through the remainder of the Cenozoic. The Miocene pulse is thought to represent uplift in the central Appalachian source region; the Pliocene-Pleistocene high rates are most likely related to the glaciation of eastern North America (Poag, 1992).

The study of terrigenous deposition in the northern Indian Ocean (Rea, 1992) provided two insights that will be useful in future efforts. First, three sites drilled within 10 km of each other on the Bengal Fan all show similar sediment flux patterns, indicating that the problem of local variability in such deposits is much less than previously thought (Cochran, 1990). Second, the temporal flux patterns of the six turbidite records are as a group no different than the flux patterns of the five hemipelagic cores, although the amounts differ by an order of magnitude or more (Rea, 1992). This last is a particularly important point because it means that hemipelagic sites can be reliable recorders of the sediment input history of entire ocean basins; it is a critical observation because complete recovery of a hemipelagic sedimentary section is far more likely than even adequate recovery of a turbidite section.

Source-region climate exerts a significant control on the deposition of various kinds of terrigenous sediments. The clearest indication of glaciation is the presence of IRD in pelagic sediments. After a century and a half of discussion and controversy regarding the nature and timing of Northern Hemisphere glaciation, the time of the onset of significant continental ice accumulation was finally resolved by examination of the record of IRD in the North Atlantic (Shackleton et al., 1984a) and North Pacific (Rea and Schrader, 1985). These studies showed simultaneous beginning of significant IRD input at the time of the Matuyama-Gauss magnetic reversal, now thought to be 2.6 Ma (Cande and Kent, 1992). Similar studies conducted more recently in the Southern Ocean confirm the timing of the onset of Antarctic glaciation in the latest Eocene and earliest Oligocene (Barron et al., 1991; Zachos et al., 1992). Higher resolution studies of ice rafting reveal details of glacial-interglacial processes (Ruddiman, 1977; Krissek et al., 1985).

In regions and on shorter glacial-interglacial (or orbital) time scales where differential uplift does not dominate sediment delivery, the MAR of hemipelagic muds is determined by some combination of sea-level change and continental runoff. To my knowledge, no one has tried to distinguish between these two signals in a single hemipelagic core. Only a few hemipelagic cores have good data on mass accumulation rate. Two lie just west of South America, V19-29 at lat 3.6°S, about 250 km offshore from the mouth of the Guayaquil River of Ecuador, and Y71-6-12 at 16.4°S, 300 km offshore from southern Peru. The paleoclimatology of the northern Andes is adequately known and is a history of full lakes and moist climates during glacial times and dry lakes and salars during interglacial times, like now (cf. Van der Hammen, 1985). The Pacific margin of northern South America is quite narrow and is the site of modest sediment deposition at most; thus, the effects of sea-level change on deep-sea sedimentation, especially seaward of the trench, may be less there than elsewhere. The mineral flux data from both of these cores (Fig. 2; Molina-Cruz, 1977) show maxima are associated with glacial stages 2 and 4, and minima associated with interglacial stages 1, 3, and 5, values that are consistent with Andean runoff determining the flux of hemipelagic sediments to the easternmost South Pacific.

Results of two studies in the North Pacific are clear examples of the sort of paleoclimate information that the eolian component of pelagic sediments may provide. The first project of this type we undertook was to define the whole-Cenozoic record of eolian input in order to discover the history of continental climate change and of the intensity of atmospheric circulation (Janecek and Rea, 1983; Rea et al., 1985). That study showed that the single large event in dust flux is an order of magnitude increase that occurred in Pliocene time and reflects the drying of the China-Gobi eolian source area (Fig. 3). The surprising result of that work is contained in the record of eolian grain size. The middle to late Cenozoic record of eolian grain size is suggestive of ever-increasing intensity of atmospheric circulation, the expected phenomenon associated with the history of high-latitude cooling. The new information here is the Paleocene and latest Cretaceous part of this record which indicates atmospheric circulation more vigorous than that of the late Cenozoic glacial ages. The sudden reduction in grain size (Fig. 3) has since been shown to have occurred exactly at the Paleocene-Eocene boundary in both hemispheres and was apparently a

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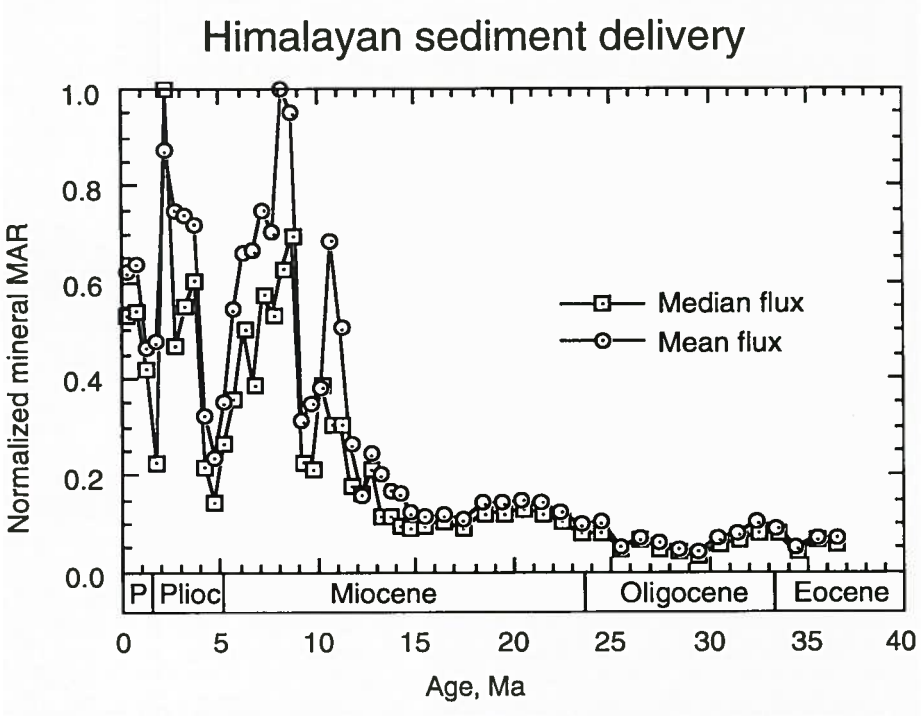

Figure 1. Normalized mass accumulation rate (MAR) of terrigenous sediment at 11 ODP and DSDP drill sites in the northern Indian Ocean. Data are from Rea (1992).

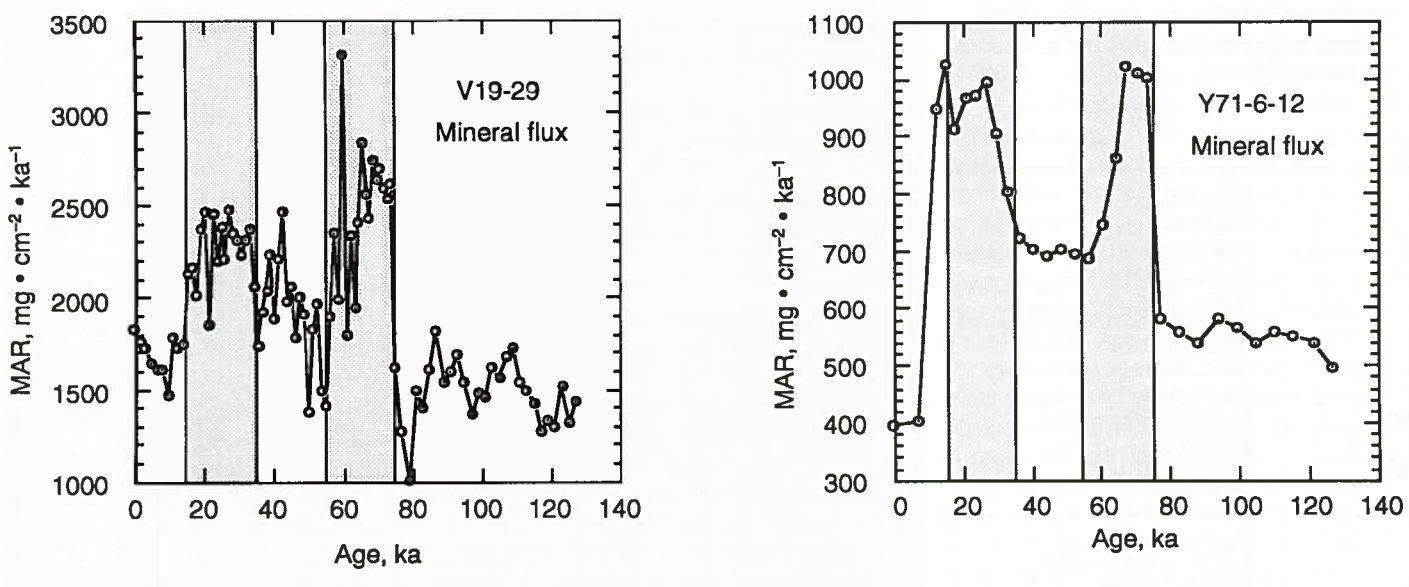

Figure 2. Mass accumulation rate (MAR) of the hemipelagic component of deep-sea sediments in two cores west of South America. See text for locations. Flux maxima at about 15 to 35 ka and 55 to 75 ka (shaded) correspond approximately in time to glacial stages 2 and 4, respectively. Data are from Molina-Cruz (1977).

global event (Rea et al., 1985, 1990; Hovan and Rea, 1992). We now interpret this sudden reduction in the intensity of atmospheric circulation as reflecting an abrupt increase in the ability of the ocean to transport heat. The several world-wide changes that occurred at the Paleocene-Eocene boundary, such as the extinction of benthic foraminifers, evolutionary radiation of mammals, large excursions in oceanic $\delta^{18}O$ and $\delta^{13}C$, and important changes in both atmospheric and oceanic circulation, are not fully understood and are the subject of continuing research (Miller et al., 1987; Rea et al., 1990; Kennett and Stott, 1991; Hovan and Rea, 1992; Sloan et al., 1992).

A second example of the paleoclimatic information contained in records of eolian deposition is also a good example of the next important aspect of these studies of terrigenous deposition in the deep sea: such records also provide the only linkage between proxy indicators of continental changes (the mineral component) and indicators of oceanic change commonly found in pelagic cores. Details of dust deposition during the past 500 ka in the Northwest Pacific provide an oceanic record of the vast loess deposits of China, one of the classic Quaternary terrestrial sequences (Fig. 4; Hovan et al., 1989, 1991). There, dust flux maxima correspond to the known loess horizons, and minima correspond to the soil interlayers. Determination of this record in a pelagic carbonate-bearing core enables us to tie the China loess record directly to the marine oxygen-isotopic record of global change (Fig. 4). Hovan et al. (1989, 1991) were able to use the results from this core with good terrestrial and marine records to refine the dating of the loess horizons and to show that the loess deposition is in phase with orbitally induced changes in ice volume.

Other examples of linkage between land and sea records of global change include the South American runoff records in East Pacific hemipelagic, carbonate-bearing cores (Fig. 2). For the northern Indian Ocean Prell et al. (1992) defined the history of the monsoons on the basis of proxy indicators of upwelling and atmospheric circulation in deep-sea sediments. One can compare the records of Prell et al. (1992) to the uplift history of the Himalayas depicted in the sediment fluxes shown in Figure 1 and see that monsoons became important in the late Miocene. Because without the mountains the monsoons would be

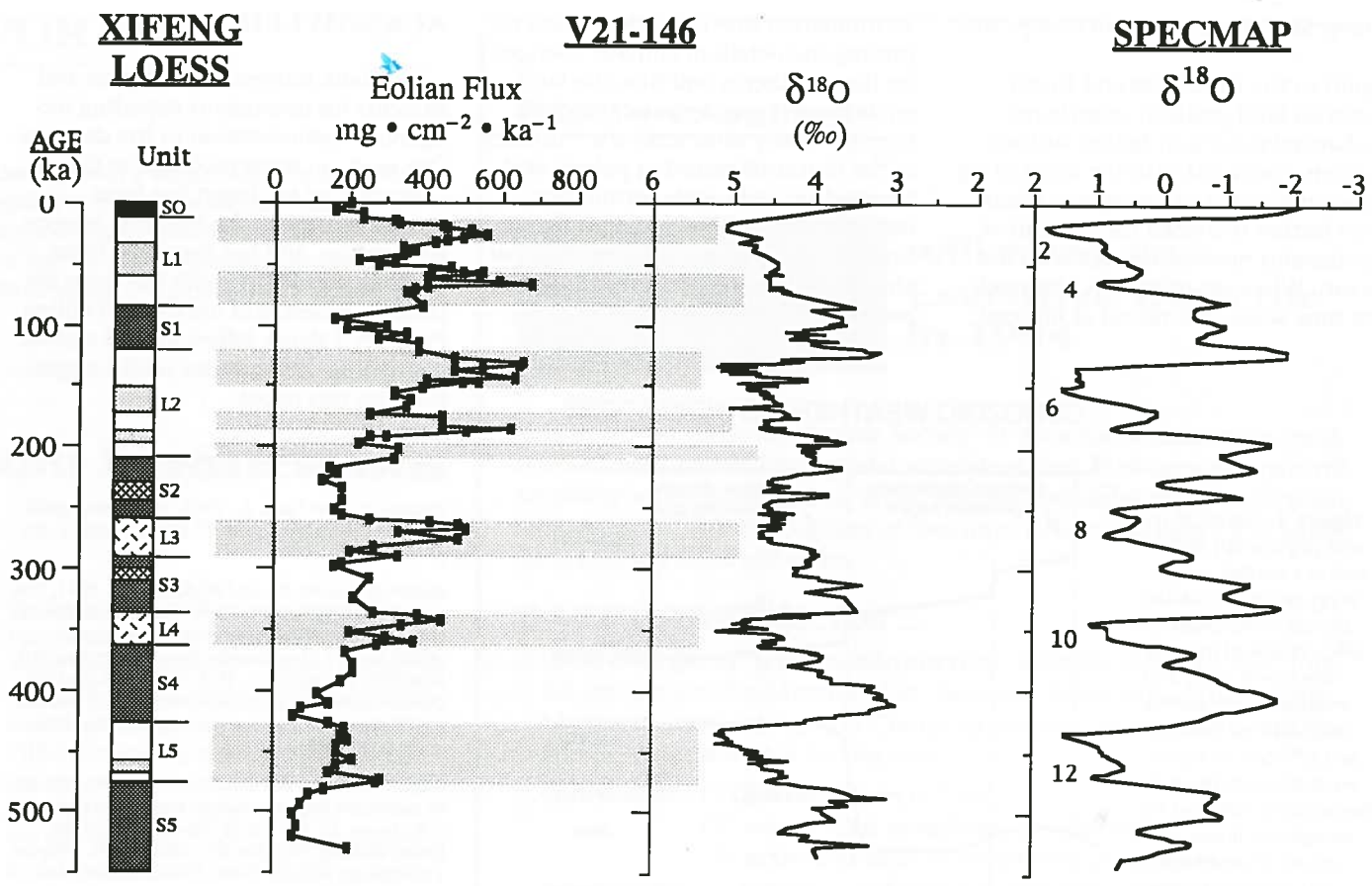

Figure 4. Eolian mineral flux and oxygen isotopic record from the northwest Pacific Ocean, core V21-146. Left column shows the China loess stratigraphy; dust flux maxima correspond to loess horizons, flux minima to the soil interlayers. Right column shows the SPECMAP stack oxygen isotope record of Quaternary global change; glacial stages are numbered (relative $\delta^{18}O$ values: Imbrie et al., 1984); more positive $\delta^{18}O$ values indicate greater ice volume. These data are the first to link these two classic continental and marine Quaternary sequences (from Hovan et al., 1989, 1991).

minimal, the temporal correlation of these events is taken to reflect cause and effect (Prell et al., 1992; Rea, 1992).

Despite the clear suggestion that times of lowered sea level should be times of enhanced sediment deposition in the deep sea, the few records we have of Cenozoic siliciclastic accumulation seem to be dominated by either tectonic or climatic events. Records from the northern Indian Ocean (Rea, 1992), the western North Atlantic (Poag, 1992), and an older record from the South Atlantic (Shackleton et al., 1984b) do not show a depositional pattern reminiscent of the Cenozoic sea-level curve (Haq et al., 1987). Particularly, the mid-Oligocene severe drop in sea level does not appear in any of these records. Admittedly, three records provide only a very preliminary view of this history, but from them it seems that sea-level change causes only a second-order effect on terrigenous deposition rates in the deep ocean.

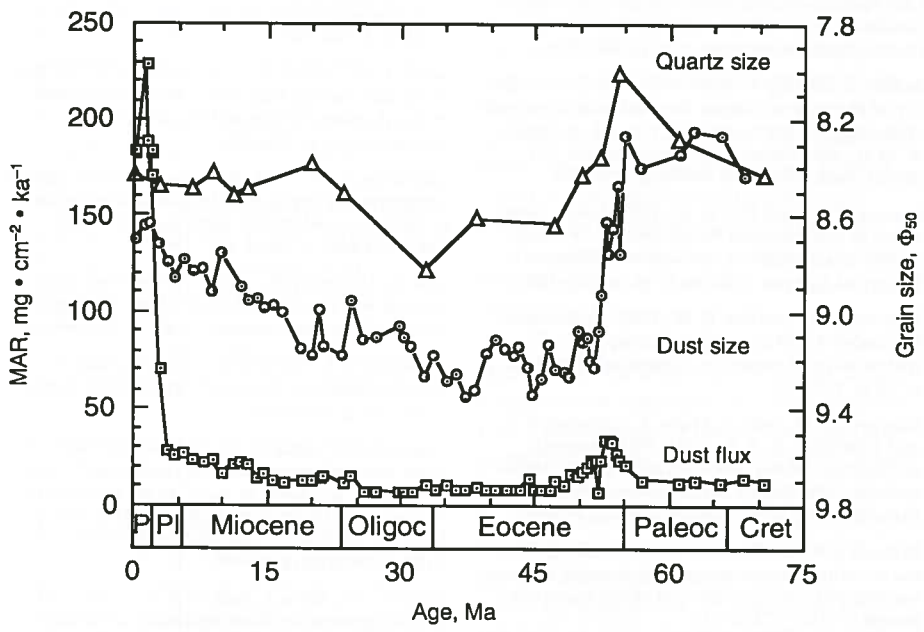

Figure 3. Cenozoic eolian record from the central North Pacific, core LL44-GPC3, showing flux and grain size of the eolian mineral component and size of the isolated quartz grains. Notice the large flux increase at ca. 3 Ma and the large reduction in grain size at ca. 55 Ma. Data are from Janecek and Rea (1983).

Finally, the history of terrigenous sedimentation in the deep sea provides useful constraints to our hypotheses of global geochemical cycles (Fig. 5). Two important aspects of Cenozoic ocean paleochemistry make good examples here. First is the level of the calcite compensation depth (CCD), which denotes that depth where the dissolution rate of $CaCO_3$ matches the sea-surface production rate and below which no calcite is deposited. The deeper the CCD, the more $CaCO_3$ is deposited in the ocean. The largest Cenozoic change in the CCD is a rapid deepening at the Eocene-Oligocene boundary (van Andel, 1975). The isotopic composition of seawater strontium has become increasingly radiogenic since the Paleogene; the steepest part of this curve, indicating the most rapid input of radiogenic strontium (derived from granitic rock) to the ocean, begins at the Eocene-Oligocene boundary and ends in middle Miocene deposits (Hess et al., 1986). These paleochemical changes, the deepening of the CCD, and the onset of radiogenic Sr input have been interpreted as reflecting greatly enhanced input of Ca and of radiogenic Sr to the ocean starting at the Eocene-Oligocene boundary. Climatic deterioration corresponding to the formation of ice on Antarctica has been thought to be the general cause for enhanced weathering and erosion necessary to change the Ca and Sr budgets so dramatically.

Comparison of these records to that of terrigenous input shows that the rapid mid-Cenozoic changes in ocean chemistry were not accompanied by significant siliciclastic deposition. Together, these data suggest four stages of weathering-erosion and concomitant input to the oceans (Fig. 5): (1) Paleocene and Eocene, characterized by low particulate and dissolved fluxes to the ocean; (2) Oligocene to middle Miocene, characterized by important dissolved fluxes but low particulate fluxes, denoting the predominance of chemical weathering of relatively low-lying continents; (3) middle Miocene to late Pliocene, when particulate fluxes predominated over dissolved in a time of broad uplifts; and (4) late Pliocene to present, characterized by significant dissolved and particulate fluxes, mostly as a result of the climatic influence of Northern Hemisphere glaciation on already uplifted continents.

The clear indication of a decoupling of siliciclastic and chemical input to the ocean indicated by Figure 5 is an exciting and unexpected result of this compilation. Conventional wisdom indicates that physical weathering results in a large increase in grain surface area, which in turn allows more rapid chemical weathering. In fact, the Cenozoic record shows that a large increase in the rate of chemical weathering occurred 20 m.y. before any significant physical weathering. Furthermore, chemical weathering rates may have declined in the middle Miocene when rates of physical weathering, as recorded by the terrigenous input to oceans, increased markedly. A conclusion based on this information would indicate that chemical weathering is determined largely by hemispherical to global climate change and that physical weathering is controlled mostly by tectonism and uplift. The two effects combined in the Pliocene-Pleistocene to result in the increased chemical and particulate fluxes observed for that time (Fig. 5).

SUMMARY

On long time scales, the deposition of fine-grained muds in the deep sea appears to be controlled more by uplift in the sedimentary source region than by changing climate or sea level. Analysis of the sedimentary record shows that during the Cenozoic, siliciclastic deposition became important in middle to late Miocene time because of

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Deep Sea Muds *continued from p. 209*

uplift in the Himalayas and North America (and probably elsewhere). Enhanced erosion in higher latitude regions associated with the onset of significant Northern Hemisphere glaciation further increased the amount of terrigenous material deposited in the ocean. When examined on intermediate time scales, the record of mineral accumulation provides information regarding the details of climatic changes on the continents and how the land environment may respond to orbital forcing. At any time scale, the existence of the terrestrial record in pelagic and hemipelagic sediments permits the only possible direct correlation of continental and oceanic histories of global change, a critically important aspect of paleoclimate research.

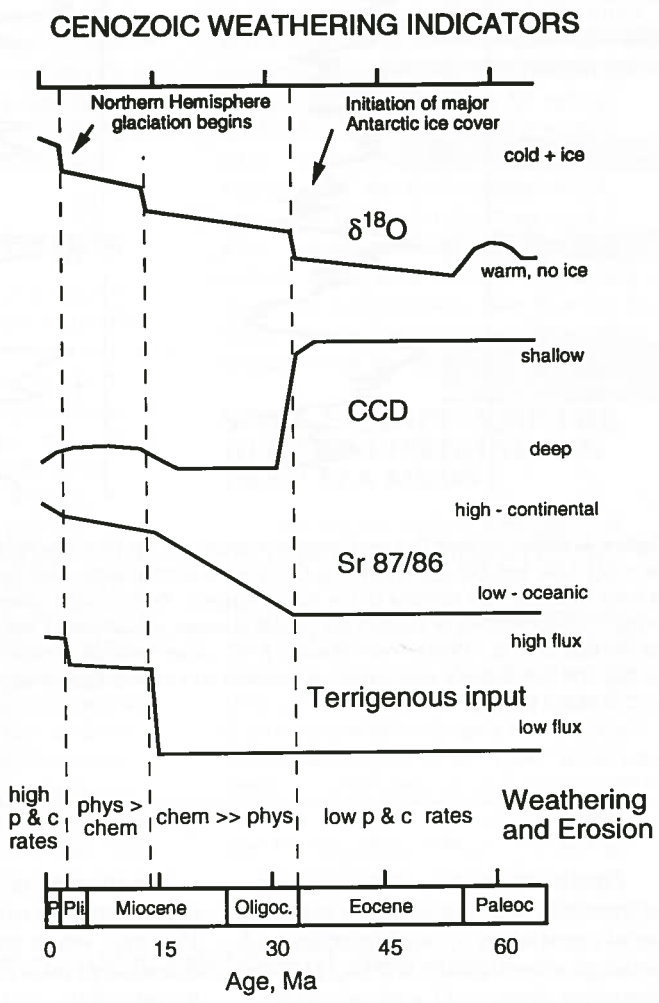

Figure 5. Chemical (c) and physical (p) indicators of Cenozoic weathering processes. Global climate is indicated by $\delta^{18}O$, chemical input to the ocean of Ca and radiogenic Sr^{87}/Sr^{86} is indicated by the CCD and Sr^{87}/Sr^{86} of seawater, particulate input to the ocean is indicated by terrigenous fluxes, and nature of weathering and erosion of continents: low rates in the Paleocene and Eocene, high chemical weathering rates in the Oligocene and early Miocene, high physical weathering and relatively reduced chemical weathering rates in the later Miocene and Pliocene, high physical and chemical weathering rates in the late Pliocene and Quaternary.

ACKNOWLEDGMENTS

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REFERENCES CITED

Amano, K., and Taira, A., 1992, Two-phase uplift of Higher Himalayas since 17 Ma: Geology, v. 20, p. 391–394.

Barron, J., Larsen, B., and Baldauf, J. G., 1991, Evidence for late Eocene to early Oligocene Antarctic glaciation and observations on late Neogene glacial history of Antarctica: Results from Leg 119, *in* Barron, J., Larsen, G., et al., Proceedings of the Ocean Drilling Program, scientific results, Volume 119: College Station, Texas, Ocean Drilling Program, p. 869–891.

Brass, G. W., and Raman, C. V., 1990, Mineralogy of sediments from the Bengal Fan, *in* Cochran, J. R., Stowe, D. A. V., et al., Proceedings of the Ocean Drilling Program, scientific results, Volume 116: College Station, Texas, Ocean Drilling Program, p. 35–41.

Cande, S. C., and Kent, D. V., 1992, A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, v. 97, p. 13,917–13,951.

Cochran, J. R., 1990, Himalayan uplift, sea level and the record of Bengal Fan sedimentation at the ODP Leg 116 sites, *in* Cochran, J. R., Stowe, D. A. V., et al., Proceedings of the Ocean Drilling Program, scientific results, Volume 116: College Station, Texas, Ocean Drilling Program, p. 397–414.

Duncan, R. A., Rea, D. K., Kidd, R. B., von Rad, U., and Weissel, J. K., editors, 1992, Synthesis of results from scientific drilling in the Indian Ocean: American Geophysical Union Monograph 70, 475 p.

Haq, B. U., Hardenbol, J., and Vail, P. R., 1987, Chronology of fluctuating sea levels since the Triassic: Science, v. 235, p. 1143–1167.

Heggie, D. C., Maris, A., Hudson, J., Dymond, J., Beach, R., and Cullen, J., 1987, Organic carbon oxidation and preservation in NW Atlantic continental margin sediments, *in* Weaver, P. P. E., and Thompson, J., eds., Geology and geochemistry of abyssal plains: Geological Society of London Special Publication 31, p. 215–236.

Hess, J., Bender, M. L., and Schilling, J.-G., 1986, Evolution of the ratio of strontium-87 to strontium-86 in seawater from Cretaceous to present: Science, v. 231, p. 979–984.

Honjo, S., Spencer, D. W., and Farrington, J. W., 1982, Deep advective transport of lithogenic particles in the Panama Basin: Science, v. 216, p. 516–518.

Hovan, S. A., and Rea, D. K., 1992, Paleocene/Eocene boundary changes in atmospheric and oceanic circulation: A Southern Hemisphere record: Geology, v. 20, p. 15–18.

Hovan, S. A., Rea, D. K., Pisias, N. G., and Shackleton, N. J., 1989, A direct link between the China loess and marine $\delta^{18}O$ records: Aeolian flux to the north Pacific: Nature, v. 340, p. 296–298.

Hovan, S. A., Rea, D. K., and Pisias, N. G., 1991, Late Pleistocene continental climate and oceanic variability recorded in northwest Pacific sediments: Paleoceanography, v. 6, p. 349–370.

Imbrie, J., and eight others, 1984, The orbital theory of Pleistocene climate: Support from a revised chronology of the marine $\delta^{18}O$ record, *in* Berger, A., et al., eds., Milankovitch and climate: Dordrecht, Netherlands, D. Reidel, p. 269–305.

Janecek, T. R., and Rea, D. K., 1983, Eolian deposition in the northeast Pacific Ocean: Cenozoic history of atmospheric circulation: Geological Society of America Bulletin, v. 94, p. 730–738.

Janecek, T. R., and Rea, D. K., 1985, Quaternary fluctuations in the northern hemisphere tradewinds and westerlies: Quaternary Research, v. 24, p. 150–163.

Johnson, N. M., Stix, J., Tauxe, L., Cerveny, P. F., and Tahirkheli, R. A. K., 1985, Paleomagnetic chronology, fluvial processes and tectonic implications of the Siwalik deposits near Chinji Village, Pakistan: Journal of Geology, v. 93, p. 27–40.

Kennett, J. P., and Stott, L. D., 1991, Abrupt deep-sea warming, paleoceanographic changes and benthic extinctions at the end of the Paleocene: Nature, v. 353, p. 225–229.

Krissek, L. A., Morley, J. J., and Lofland, D. K., 1985, The occurrence, abundance and composition of ice-rafted debris in sediments from Deep Sea Drilling Project Sites 579 and 580, northwest Pacific, *in* Heath, G. R., Burckle, L. H., et al., Initial reports of the Deep Sea Drilling Project, Volume 86: Washington, D.C., U.S. Government Printing Office, p. 647–655.

Miller, K. G., Janecek, T. R., Katz, M., and Keil, D. J., 1987, Abyssal circulation and benthic foraminiferal changes near the Paleocene/Eocene boundary: Paleoceanography, v. 2, p. 741–761.

Molina-Cruz, A., 1977, The relation of the southern trade winds to upwelling processes during the last 75,000 years: Quaternary Research, v. 8, p. 324–338.

Pickering, K. T., Hiscott, R. N., and Hein, F. J., 1989, Deep marine environments clastic sedimentation and tectonics: London, Unwin Hyman, 416 p.

Poag, C. W., 1992, U.S. Middle Atlantic continental rise: Provenance dispersal and deposition of Jurassic to Quaternary sediments, *in* Poag, C. W., and de Graciansky, P. C., eds., Geologic evolution of Atlantic continental rises: New York, Van Nostrand Reinhold, p. 100–156.

Poag, C. W., and de Graciansky, P. C., editors, 1992, Geologic evolution of Atlantic continental rises: New York, Van Nostrand Reinhold, 378 p.

Prell, W. L., Murray, D. W., Clemens, S. C., and Anderson, D. M., 1992, Evolution and variability of the Indian Ocean summer monsoon: Evidence from the western Arabian Sea drilling program, *in* Duncan, R. A., et al., eds., Synthesis of results from scientific drilling in the Indian Ocean: American Geophysical Union Monograph 70, p. 447–469.

Prospero, J. M., 1981, Eolian transport to the world ocean, *in* Emiliani, C. ed., The sea, Volume 7, The oceanic lithosphere: New York, John Wiley & Sons, p. 801–874.

Prospero, J. M., Charlson, R. J., Monhnen, V., Jaenicke, R., Delany, A. C., Moyers, J., Zoller, W., and Rahn, K., 1983, The atmospheric aerosol system: An overview: Reviews of Geophysics and Space Physics, v. 21, p. 1607–1629.

Rea, D. K., 1992, Delivery of Himalayan sediment to the northern Indian Ocean and its relation to global climate, sea level, uplift, and seawater strontium, *in* Duncan, R. A., et al., eds., Synthesis of results from scientific drilling in the Indian Ocean: American Geophysical Union Monograph 70, p. 387–402.

Rea, D. K., and Schrader, H., 1985, Late Pliocene onset of glaciation: Ice rafting and diatom stratigraphy of North Pacific DSDP cores: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 49, p. 313–325.

Rea, D. K., Leinen, M., and Janecek, T. R., 1985, Geologic approach to the long-term history of atmospheric circulation: Science, v. 227, p. 721–725.

Rea, D. K., Zachos, J. C., Owen, R. M., and Gingerich, P. D., 1990, Global change at the Paleocene-Eocene boundary: Climatic and evolutionary consequences of tectonic events: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 79, p. 117–128.

Ruddiman, W.F., 1977, Late Quaternary deposition of ice-rafted sand in the subpolar North Atlantic (lat 40° to 65°N): Geological Society of America Bulletin, v. 88, p. 1813–1827.

Shackleton, N. J., and 16 others, 1984a, Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region: Nature, v. 307, p. 620–623.

Shackleton, N. J., and Members of the Shipboard Scientific Party, 1984b, Accumulation rates in Leg 74 sediments, *in* Moore, T. C., Jr., Rabinowitz, P. D., et al., Initial reports of the Deep Sea Drilling Project, Volume 74: Washington, D.C., U.S. Government Printing Office, p. 621–644.

Saito, C., Noriki, S., and Tsunogai, S., 1992, Particulate flux of Al, a component of land origin, in the western North Pacific: Deep-Sea Research, v. 39, p. 1315–1327.

Sloan, L. C., Walker, J. C. G., Moore, T. C., Jr., Rea, D. K., and Zachos, J. C., 1992, Possible methane-induced polar warming in the early Eocene: Nature, v. 357, p. 320–322.

van Andel, T. H., 1975, Mesozoic/Cenozoic calcite compensation depth and the global distribution of calcareous sediments: Earth and Planetary Science Letters, v. 26, p. 187–194.

Van der Hammen, T., 1985, The Plio-Pleistocene climatic record of the tropical Andes: Geological Society of London Journal, v. 142, p. 483–489.

Windom, H. L., 1975, Eolian contributions to marine sediments: Journal of Sedimentary Petrology, v. 45, p. 520–529.

Yokoyama, K., Amano, K., Taira, A., and Saito, Y., 1990, Mineralogy of silts from the Bengal Fan, *in* Cochran, J. R., Stowe, D. A. V., et al., Proceedings of the Ocean Drilling Program, scientific results, Volume 116: College Station, Texas, Ocean Drilling Program, p. 59–73.

Zachos, J. C., Breza, J., and Wise, S. W., Jr., 1992, Early Oligocene ice-sheet expansion on Antarctica: Sedimentological and isotopic evidence from Kerguelen Plateau: Geology, v. 20, p. 569–573.

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WASHINGTON REPORT

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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. In future issues, Washington Report will present summaries of agency and interagency programs, track legislation, and present insights into Washington, D.C., geopolitics as they pertain to the geosciences.

Federal Scientists and Engineers—Next Steps?

A newly released National Research Council report concludes that Uncle Sam should be doing more to attract top scientists. The report, *Improving the Recruitment, Retention, and Utilization of Federal Scientists and Engineers* (National Academy Press, 1993, 120 pages, $24 plus shipping), recommends a series of steps that the Federal Government must take to improve its ability to recruit and retain top-flight researchers, including implementing of federal pay reform. The premier recommendation focuses on implementing "as fully as possible by the President and the departments and agencies, in order to redress pay inequities and reward superior performance among all federal employees, including scientists and engineers," the Federal Employees Pay Comparability Act of 1990 (FEPCA). FEPCA would permit Federal Government agencies much greater flexibility in compensating employees.

Recent actions by the Clinton administration suggest that they have not as yet received their copy of the report, or that they have not had an opportunity to closely examine the report or to study the 15 recommendations it contains. Coincident with the release of the report, the Clinton administration has rejected many of FEPCA's provisions. Specifically, the administration has proposed to delay and reduce the size of future federal employee pay raises and to also delay and restructure "area pay," a system designed to tie compensation for federal jobs to comparable private-sector salaries in the same geographic region.

Prepared for the Carnegie Commission on Science, Technology, and Government by the Committee on Scientists and Engineers in the Federal Government, the report notes that over the next seven years, retirements will leave the government with vacancies, but improvements in the economy of the private sector will create jobs at salaries well above what the government is able to pay. The result will be government competing unsucessfully with academia and industry to recruit high-level scientific and engineering talent.

The report recommends (1) implementation of FEPCA; (2) decentralizing Office of Personnel Management (OPM) management of FEPCA by giving control of pay issues to "appropriate" levels within individual departments and agencies; (3) establishing within OPM an "organizational focus for science and engineering personnel policy"; (4) development within every science and technology agency of an action plan for identifying goals, staffing plans, and maximizing recruitment, retention, and utilization of scientists and engineers; (5) development of an interagency committee on federal scientific and engineering personnel, within the Executive Office of the President; (6) Congress taking an active role to change the civil service system to improve nonsalary issues; (7) development of a coordinated review system to evaluate the effectiveness of the science and engineering personnel system; (8) OPM developing a data base to evaluate the effectiveness of the science and engineering personnel system; (9) establishment of a Senior Research and Development Service with a separate pay system; (10) peer review of scientific and technical accomplishments by government scientists and engineers; (11) more flexible position classification; (12) quadrennial review of the recommended science and engineering personnel system; (13) providing adequate equipment and staffing for federal laboratories; (14) formulation and implementation of professional development policies; and (15) preparation of ethics rules that do not restrict the involvement of federal professionals in professional associations.

FEPCA establishes new procedures for setting civil service pay levels to make them comparable to salaries within the private sector; provides a mechanism to increase federal salaries in high wage areas and to provide interim locality adjustments; and provides flexibility in recruitment by establishing recruitment bonuses, retention allowances, authority to pay new hires above the minimum specified wage, performance awards, and flexibility to pay critical positions above existing pay scales. As part of the FY94 budget approval process, the Clinton administration has successfully fought or delayed implementation of many of these provisions.

Profile of Federal Scientists and Engineers

In addition to its efforts to improve the existence of scientists and engineers in the Federal government, the report provides an interesting snapshot of the demographics, education, and characteristics of scientists and engineers working in science and engineering job classifications in the Federal government. (The report does not consider another approximately 139,000 science- and engineering-educated individuals who work in nonscience and nonengingeering Federal job classifications, and it does not include about 70,000 health professionals.)

The report documents that the Federal government is the single largest employer of scientists and engineers in the United States. On the basis of data provided by the National Science Foundation (NSF), the report describes that in 1989 (the latest year for which detailed statistics existed), the Federal government employed a total of 223,343 scientists (111,988) and engineers (111,355). Of this total, 32,803 (14.7%) were women. These 223,343 individuals represent more than 13% of the total Federal work force.

In the Federal government, there are 80 scientific and engineering job classifications, out of a total of 441 "white collar" classifications. With respect to highest level of education, a total of 22,012 scientists and engineers had earned doctorate degrees, 50,010 had earned masters degrees, and 145,667 had earned bachelors degrees. Of the 5654 remaining, 1615 had "professional degrees," and information was not available for the other 4039. More than one-third of all of the Ph.D.s were physical scientists (7720).

Types of scientists were: life scientists (33,839); physical scientists (26,556); computer scientists (24,262); social scientists (14,271); mathematicians and statisticians (9668); and psychologists (3392). In 1989, there were 2503 geologists, 592 geophysicists, 2236 hydrologists, 710 oceanographers, and 290 geodesists working under the physical science job classification. The largest group of physical scientists was chemists (7331). Although the data are not from the same year, it is interesting to note that in 1992, the Geologic Division of the U.S. Geological Survey employed 934 geologists, 278 geophysicists, and 96 chemists. Types of engineers were: electrical and electronics engineers (34,774); mechanical and related engineers (27,561); other engineers (24,574); civil engineers (18,404); industrial engineers (3080); chemical and related engineers (1709); and materials engineers (1253). More than one-fourth (25.14%) of all Federal government engineers were electronics engineers (27,991).

Scientists and engineers can be found in every Federal department and agency. Yet the distribution of where these individuals are employed is quite surprising. The Department of Defense (DOD) alone employed 111,176 (49.85%), nearly one-half of all Federal government scientists and engineers. The Navy is the largest DOD employer of scientists and engineers: a total of 47,882 (21.44% of all Federal scientists and engineers). The dozen largest employers of scientists and engineers are 1—DOD; 2—Agriculture: 28,584 (12.80%); 3—Interior: 14,950 (6.69%); 4—National Aeronautics and Space Administration: 12,840 (5.75%); 5—Health and Human Services: 8560 (3.83%); 6—Commerce: 8172 (3.66%); 7—Environmental Protection Agency: 5448 (2.43%); 8—Transportation: 5400 (2.41%); 9—Veterans Affairs: 5156 (2.31%); 10—Energy: 4453 (1.99%); 11—Tennessee Valley Authority: 3394 (1.52%); and 12—National Science Foundation: 402 (0.18%). ■

The GSA Institute for Environmental Education—A Brief Overview

Fred A. Donath
Executive Director—Institute for Environmental Education

IEE. Its logo is prominently displayed in Annual Meeting materials, and it sponsored the highly successful Annual Environmental Forum on Ground-water Cleanup vs. Ground-water Protection, as well as several theme sessions, at last fall's meeting in Cincinnati. But what is IEE and its role in the Society? And what is IEE planning for the future?

Some history might help to place these questions in perspective. The idea of a program that would focus on geology, environment, and education was first suggested by the GSA Foundation's Trustees at the 1988 Centennial meeting in Denver. However, it took another year to formulate general concepts and select someone who would develop IEE's mission, objectives, and a general plan of action. The position of Executive Director of the Institute for Environmental Education was accepted on a part-time basis by Fred A. Donath, a GSA Foundation Trustee. Drafts of a mission statement, objectives, and proposed programs were distributed for comment among GSA Division and Section officers, and approved by the GSA Council during 1991. To paraphrase then-President Doris Curtis, the IEE is a logical evolutionary development in GSA programs, in that a clear emphasis on environmental geology exists within the membership, and the Society must be responsive to and provide support for its members in their areas of specialization.

Recognizing that initial programs would be highly dependent upon volunteered efforts, IEE worked closely with the GSA Divisions and the Committee on Geology and Public Policy during 1992. This effort culminated in the theme sessions and the environmental forum referred to above. Another stimulating Annual Environmental Forum—on Boston Harbor and Massachusetts Bay—and several theme sessions are planned for the Boston meeting this fall. With the success of the forum and theme sessions at the annual meetings as incentive, IEE is now exploring expansion of these activities to Section meetings, in an effort to involve a larger number of GSA members and, ultimately, to develop a new public outreach program.

A major objective of the IEE mission is to increase the awareness of geoscientists and the public of the role of geoscience in addressing environmental concerns. In expanding its activities geographically, IEE would embark on the development of a public outreach program to incorporate relevant geoscience in environmental decision making from the community to national level. The program will aim to enhance public dialogue by involving GSA and its membership in activities that heighten public understanding of geoscience as it relates to important environmental issues. Because geoscience is relevant to such a broad array of environmental issues, IEE would select a subset on which to focus in initiating the program. For 1994 the subject being considered is "Toward Responsible Energy Decisions: Improving Communication with Geoscience."

Everyone is affected by issues related to energy and the environment. Whether the concern is national security, economic stability, or the quality of the environment, citizen action groups in many parts of the country today are attempting to reshape national energy policy through efforts initiated at the grass roots level. Offshore drilling on the U.S. West Coast, resource exploration in the Arctic National Wildlife Refuge, the proposed Yucca Mountain nuclear waste repository, hydroelectric dams on the Columbia River, and geothermal development in roadless areas are just a few examples of high–profile issues capable of generating substantial conflict. The outcome can often be an intractable stalemate that results from differences in perceptions of risk, disagreements about appropriate resource use, or disputes over resource potential.

An increasingly evident lack of public understanding of geologic factors related to such energy issues demonstrates that there is an urgent need for geoscientists to participate in public outreach efforts. The existing communications gap affects the quality of decision making on policies from the community to national level. GSA and its members are in a unique position to facilitate understanding of these often complex issues and to become leaders in efforts to strengthen communication among the scientific and lay communities and decision makers. The program's objectives are to increase public awareness of the importance of geoscience in environmental issues and to increase the efficiency and effectiveness of disseminating geoscience information for use by the public and decision makers. The benefits to society include the promotion of informed action following an open exchange of information and ideas on environmental issues, and movement of the public agenda toward more responsible decision making.

IEE's approach in developing the public outreach program will involve several key steps: (1) to identify individuals and organizations who can contribute to meeting program objectives; (2) to identify local or regional environmental issues and potential audiences and individuals who can benefit from the program; and (3) to develop theme sessions, forums, and/or workshops in association with the GSA Section meetings that promote program objectives at the local or regional level.

During the next several months IEE will be contacting various GSA groups, state geological surveys, and other geoscientists in industry, government agencies, and academia—as well as others in government, industry, and public interest groups—to determine interests and identify issues. That will be followed with the identification of advocate organizers and topics appropriate for the sections, in cooperation with the respective meeting chairpersons and program committees. Persons interested in participating, nominating individuals or topics, or simply commenting on this new IEE public outreach program on geology and the environment are encouraged to write to IEE, Geological Society of America, P.O. Box 9140, Boulder, CO 80301. ■

Memorial Preprints

The following memorial preprints are now available, free of charge, by writing to GSA, P.O. Box 9140, Boulder, CO 80301.

Claude C. Albritton, Jr.
James E. Brooks

Oliver Duncan Blake
Siegfried Muessig, Bette Ellis-Blake

E. Gail Carpenter
Robert F. Walters, Elbie G. McNeil

John Thomas Dillon
John C. Crowell

John Walter Handin
Mel Friedman

Mason Lowell Hill
Rollin Eckis, Marie Hill, Dorothy Stout

Noye Munroe Johnson
Robert C. Reynolds, Jr.

John C. Ludwick, Jr.
George F. Oertel II

Harry M. Mikami
Douglas J. Calkin

Chalmer J. Roy
David C. Roy, Robert L. Heller, John Lemish

John Sinclair Stevenson
John A. Elson

Jerry Eli Upp
Frederick N. Murray

Robert Thomas Daubigny Wickenden
C. R. Stelck

GSAF UPDATE

Robert L. Fuchs, GSA Foundation President

Rip Rapp Establishes Award Fund

George R. "Rip" Rapp of the University of Minnesota has established the Rip Rapp Archaeological Geology Award Fund at the GSA Foundation. The initial gift of $2000 was received by the Foundation in December 1992. Additional gifts will be made over a period of years under the terms of an agreement between Rapp and the Foundation, in order that the fund will ultimately grow to at least $50,000. Income from this fund will be used to make annual awards of the Archaeological Geology Division, at GSA annual meetings and other appropriate occasions.

In commenting on his gift, Rip Rapp said, "I have not lost my missionary zeal to expand the recognition of archaeological geology as an important subdiscipline of the science. I hope that the endowment of this Division award will serve as a continuing stimulus to those who are specializing or wish to specialize in the ever-increasing relationship between the history of mankind and geology."

In his usual dynamic fashion, Rip Rapp managed to establish this award between extended "digs" in China, Greece, and Turkey. He did lament the fact that sooner or later he was going to have to "dig" out his office in Duluth.

The Foundation's Special Funds—II

BIGGS FUND—$8000

The Biggs Fund began in 1990 as a memorial to Donald L. Biggs. Family and friends, led by Don's widow, Carolyn, and Larry Wu, provided the initial funds. This group felt that an educational fund, the income from which will be used to bring young people closer to geology, would be a fitting memorial to a GSA member who spent his life teaching the science, from instructor to full professor. In 1991 Carolyn Biggs died, and the Biggs Fund also became a memorial to her. The fund was subsequently renamed the Donald L. and Carolyn N. Biggs Excellence in Earth Education Fund.

In 1992 GSA Education Coordinator Ed Geary proposed establishing the Biggs Earth Science Teaching Award, appropriately shortened to the BEST Award. The first BEST recipient of a $500 check was Heather MacDonald of the College of William and Mary in Williamsburg, Virginia, who was particularly praised for her ability to develop her students' writing skills.

The BEST Award will be made annually and can be given to more than one recipient, depending upon the amount of endowment income available from the fund.

DWORNIK PLANETARY GEOSCIENCE FUND—$9000

Stephen E. Dwornik established the Dwornik Planetary Geoscience Fund in 1991; the income from it will be used for the Planetary Geoscience Student Paper Award. Currently that award is made annually in the amount of $500 each to two recipients. In recognizing Dwornik for this gift, GSA's Planetary Geology Division noted that this award acknowledges students' work, stimulates research, encourages excellence, publicizes planetary science, and supports solar system exploration. Steve Dwornik was presented with a certificate of appreciation for his philanthropy at the 1992 GSA meeting in Cincinnati.

Stephen Dwornik received geology degrees from the University of Buffalo, and he joined NASA in 1963. When the gift to the Foundation was announced, Dwornik said, "My work in planetary geoscience at NASA was an exciting, fulfilling career, one of which I am very proud.... I believe that it is the responsibility of people like myself, who have been fortunate enough to enjoy such a rewarding career, to give something back to the young planetary geoscientists who follow." Under the terms of an agreement with the Foundation, the Dwornik Fund will grow to an endowment of at least $12,000 this year.

JOHN C. FRYE ENVIRONMENTAL AWARD—$18,000

John C. Frye died in 1982, shortly after his retirement from GSA, where he served as executive director for eight years. Most of John Frye's career was spent with state surveys, in Kansas and Illinois.

The term "environmental geology" had its origin at the Illinois Survey during John Frye's tenure there. He was clearly one of the early proponents of this sector of geology, and the award that is supported by the income from this fund is appropriately entitled the John C. Frye Environmental Award. An awardee is selected annually by the Association of American State Geologists and GSA for a paper on environmental geology published by a state survey or in a GSA publication. Currently the award is a $1000 cash gift. Recent additions to this fund have increased the principal, which has generated additional income and allowed a larger award. ■

Donors to the Foundation—March, April, and May 1993

Birdsall Award
Ed Kiessling

CADY Award Fund
M. William Pullen

History of Geology Award Fund
Michele L. Aldrich*
Charles F. Berkstresser, Jr.
George R. Harlow
Donald M. Hoskins
Royal H. Mapes
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Thomas Pickett
Brian J. Skinner
Roger D. K. Thomas
David Archer White
Hatten S. Yoder, Jr.

Hydrogeology Division Award
L. Darlene Batatian
Steve J. Germiat
T. N. Narasimhan
Edwin P. Weeks
Norman F. Williams
Joe C. Yelderman, Jr.

GEOSTAR Funds

Claude C. Albritton, Jr. Memorial
Jane Albritton

Biggs Excellence in Earth Education Fund
Lawrence Wu*

Allan V. Cox Student Scholarship
L. W. Funkhouser*
Gordon A. Thrupp

Doris M. Curtis Memorial
Elwood R. Brooks
DeWitt C. Van Siclen

John T. Dillon Alaska Scholarship Award
ARCO Foundation
John Decker*
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Dwornik Planetary Geoscience Fund
Gerald G. Schaber

John C. Frye Environmental Award
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Wayne R. Harris
Laraine Heese
Ross L. Kinnaman
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J. M. Schoeck
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Janet Bauder Thornburg
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3300 Penrose Place
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Boulder, CO 80301
(303) 447-2020

☐ Enclosed is my contribution in the amount of $_____.
☐ Please add my name to the Century Plus Roster (gifts of $150 or more).
☐ Please credit my gift to the _____ Fund.

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In Memoriam

Clayton G. Ball
Evanston, Illinois

Raymond C. Becker
Boulder, Colorado
June 26, 1993

Francis D. Bode
Sequim, Washington
May 23, 1993

H. Rudy Katz
Lower Hutt, New Zealand
June 23, 1991

Watson H. Monroe
Leesburg, Virginia
October 23, 1992

James A. Noble
Jackson, Wyoming
March 23, 1993

Humberto Padilla
Santiago, Chile

John C. Reed
Columbus, Indiana
May 23, 1993

Mark L. Rosenberg
Chicago, Illinois
November 1991

Benjamin M. Shaub
Northampton, Massachusetts
March 24, 1993

Robert R. Shrock
Lexington, Massachusetts
June 22, 1993

Stanley A. Skapinsky
San Jose, California
October 31, 1992

Joseph M. Trefethen
Friendship, Maine

Blakemore E. Thomas
Merced, California

J. Tuzo Wilson
Ontario, Canada
April 14, 1993

SAGE REMARKS

SAGE Suggestion #1:
Take an Earth Science Teacher to Boston

H.B. Stonehouse,
Executive Advisor Emeritus, National Earth Science Teachers Association

Find a teacher of earth science from your local school district and invite him or her to go to the special series of events that have been designed for K–12 Earth Science teachers at the GSA Annual Meeting in Boston, October 25–28. The program will include *Workshops:* Hands-On Earth Science for K–12 Teachers, Teaching Topics in Earth Science and Geology with Video as a Partner—for Secondary School Teachers, Preparing Successful Grant Proposals to Fund Curriculum Innovation in the Geosciences, and Introducing ... Contaminant Hydrogeology; *Field Trips:* Urban Geology: Foundation for Inner City Health, Boston Harbor Explorations, Coastal Geology of North Boston, Geology of Boston Basin, Geosecrets of Downtown Boston: City Geology with a City Geologist, and Evolution of Cape Cod Landscapes: Marine and Glacial Field Techniques Applied to Cape Cod; *Symposia:* Alternative Pedagogies in Geological Sciences, Beyond Student Literacy—Creating an Earth-Literate Public, Successfully Funded Laboratory and Field Technique Programs in the Geosciences, Teaching Mineralogy, and New Developments in Quaternary Geology: Implications for Geoscience Education and Research; *Exhibits* including the Science Classroom of the Future; and *Social Events:* Earth Science Information Share-A-Thon and Earth Science Educators Social Hour. Please see the June 1993 issue of *GSA Today* for detailed information on the above events.

Remember that in addition to airfare and hotel costs, teachers will probably have to pay their school district for a substitute; but GSA has given them a bargain preregistration cost of only $15. If, between you, they cannot find a way to attend the entire meeting, contract with them to go to one (or more) of the short courses, field trips, or technical sessions arranged for them daily between Saturday, October 23 and Wednesday, October 27. When you return home you can complete your contract by meeting with them to discuss how you can work together to improve their students' understanding of earth materials and processes. It is true that geology is only a part of an earth science curriculum, but the Saturday workshop will also feature astronomy, meteorology, and the global environment. Remember that many teachers of earth science have little background, and that at least some K–12 earth science offerings should have as their outcome earth literacy rather than professional geoscience. This effort will provide you and your teacher contact(s) an introduction to the benefits of the Partners for Excellence Program, a joint GSA–NESTA program. For further information about the current status of K–12 Earth Science education, see A Summary of the First GSA Presidential Conference of Earth Science Education by Ed Geary and E-an Zen in the April 1993 issue of *GSA Today.*

SAGE Suggestion #2:
Volunteer to Be a GSA Teacher-Host

Ed Geary, Coordinator for Educational Programs, GSA

Do you remember how you felt at your first GSA meeting? Were you nervous? Overwhelmed? You probably didn't know anyone except your advisor and a fellow student or two. Well imagine that you are a K–12 teacher at your first GSA meeting. You are excited about the incredible scientific and educational opportunities, but you may be a bit intimidated or confused by the session titles and the poster sessions. You are probably also hesitant to walk up to people you've never met and ask them to explain a *P-T-T* diagram or the significance of fluid-volcano interactions.

To make teachers feel more welcome at our meetings, we are asking all willing GSA members to wear special apple stickers during the meeting. These stickers will identify you as being a meeting Teacher-Host. With your apple sticker prominently displayed on your badge, teachers will be able to know at a glance that you are willing and eager to talk with them about science or education and answer their questions about technical sessions or posters they are interested in. Perhaps you could even invite them to have coffee or join your group of colleagues for lunch.

There will be a brief welcoming session for K–12 teachers and Teacher-Hosts on Monday, October 25 at 7:15 a.m., Hynes Convention Center, Boylston St. Lobby by Room 300. Teacher-Host apple stickers will also be available at the K–12 Teacher Information Desk in the registration area. ■

Notice of Council Meeting

Meetings of the GSA Council are open to Fellows, Members, and Associates of the Society, who may attend as observers, except during executive sessions. Only councilors, officers, and section representatives may speak to agenda items, except by invitation of the chair. Because of space and seating limitations, notification of attendance must be received by the Executive Director prior to the meeting. The next meeting of the Council will be Wednesday morning, October 27, 1993, at the Annual Meeting in Boston.

GSA ANNUAL MEETINGS

■ 1993

Boston, Massachusetts
Hynes Convention Center
October 25–28

Chairman: James W. Skehan, S. J., Boston College

Preregistration Deadline: September 24
Technical Program Schedule: September *GSA Today*

For information call the GSA Meetings Department, (303) 447-2020.

New for '93 **Registration Materials are in JUNE *GSA Today*—REGISTER EARLY**

1993 Poster Session Awards

GSA will be sponsoring a best poster award daily after each morning and afternoon session. Entries will be judged on the basis of scientific content, clarity, coherence, and graphics. Specific guidelines will be mailed to poster authors in their speaker kits in late August. Winners' names will be posted daily and will appear in a future issue of GSA Today. If you would like to be a Poster Award judge, please volunteer by contacting J. Allan Cain, Dept. of Geology, University of Rhode Island, Kingston, RI 02881, (401) 792-2184 or (401) 792-2265.

Bravo Boston GSA Chorale

Tuesday, October 26, 8:00 p.m.
Jordan Hall at New England Conservatory of Music
Cost: Concert only $18; Concert with Reception $28.

This year one of the special events for the GSA Annual Meeting is indeed very special. Many of you may recall the performance by the 1988 GSA Centennial Orchestra of geologists in Denver, heard on National Public Radio. Once again musical geologists will have the opportunity to come together, this time in a dazzling choral performance in Boston, where the musical arts are a thriving part of the city's culture.

The performance will take place in the intimate and cherished Jordan Hall, treasured for its turn-of-the-century architecture, renowned for its excellent acoustics, and widely used by recording companies and famous artists. The hall is on the campus of the New England Conservatory of Music, an easy 10-minute walk from the Hynes Convention Center and the Marriott Hotel. The Bravo Boston GSA Chorale, with a professional orchestra and conductor, will perform the melodic and moving Mozart Requiem, popularized in the film *Amadeus.* In addition, the performance will feature two double concertos by Vivaldi, featuring your musical colleagues as soloists. This is an evening not to be missed!

For those wishing to sing with the Bravo Boston GSA Chorale, contact Holly Stein, U.S. Geological Survey, MS 981, National Center, 12201 Sunrise Valley Drive, Reston, VA 22092, (703) 648-5326. You must be an active, accomplished singer who reads music. ***Spouses and guests, particularly those with soprano and alto voices, are also welcome.***

For those wishing to attend this very special performance, ticket purchase in advance is highly recommended. Seating is limited, and given the sell-out performance by the GSA Centennial Orchestra, a ticket purchase with your meeting preregistration assures you a seat. You won't want to miss the excitement!

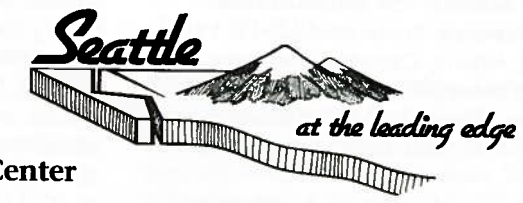
Transportation. Jordan Hall is within walking distance of the Marriott, Lenox, Copley Square, Hilton, and Colonnade hotels. Bus service will not be provided; however, taxi service will be available.

PRE-CONCERT WINE AND CHEESE AT THE COLONNADE

5:30 to 7:00 p.m.; Colonnade Hotel

As a special addition to this special evening, join us for wine, cheese, and other tasty hors d'oeuvres just before the concert.
A glass of wine and hors d'oeuvres come with the fee.
Additional drinks will be on a cash basis.
The Colonnade Hotel is located conveniently between the Marriott and Jordan Hall.

■ 1994



Seattle, Washington
Washington State
Convention and Trade Center
October 24–27

Chairman: Darrel S. Cowan, Dept. of Geosciences, University of Washington

For information call the GSA Meetings Department, (303) 447-2020.

Theme for 1994 Seattle Meeting

Geology *At the Leading Edge* will be the scientific theme of the 1994 GSA Annual Meeting in Seattle. The theme will draw emphasis both to the geographical position of Seattle, situated on the leading edge of a convergent plate margin, and to the application of "leading edge" theoretical approaches to and technological advances in the elucidation of geological problems. Theme sessions and symposium proposals are sought in all aspects of Pacific Rim and convergent margin geology, with particular emphasis on the utilization of new technology. The Seattle Program Committee will sponsor a GSA Symposium titled "The Birth and Death of a Plate," which will include invited talks on topics such as arc volcanism, kinematics of plate motion, accretionary wedges, and evolution of ocean-ridge spreading centers. Speakers will illuminate these issues with results from remote sensing, geodesy, seismic imaging, experimental studies of geologic materials, and computational advances in modeling geologic systems. Theme sessions will have the option of being organized with more flexibility. One proposal is to lead off a theme session with an invited speaker who will review the subject of the theme and set the tone and organization of the abstracts in the remainder of the session. The Seattle Program Committee also proposes to have several less formal evening sessions aimed at bringing attendees up-to-date on new techniques such as GIS (Geographical Information Systems), GPS (Global Positioning System), and major nationally funded research projects such as the RIDGE initiative and the Continental Drilling Program. The 1994 GSA Annual Meeting in Seattle promises an exciting opportunity to discuss important geological questions in a nontraditional way. Plan to join us *At the Leading Edge*.

NEW NEW NEW

Call for Continuing Education Course Proposals

PROPOSALS DUE BY OCTOBER 1

The GSA Committee on Continuing Education (*formerly the Short Course Committee*) invites those interested in proposing a GSA-sponsored or cosponsored course or workshop to contact GSA headquarters for proposal guidelines.

Continuing Education courses may be conducted in conjunction with all GSA annual or section meetings. We are particularly interested in receiving proposals for the 1994 Seattle Annual Meeting OR 1995 New Orleans Annual Meeting.

NEW DEADLINE—Proposals must be received by **October 1, 1993.** Selection of courses for 1994 will be made by February 1, 1994. For those planning ahead, we will also consider courses for 1995 at that time.

For proposal guidelines or information contact:
Edna A. Collis, Continuing Education Coordinator,
GSA headquarters, 1-800-472-1988.

■ FUTURE

Boston	October 25–28	1993
Seattle	October 24–27	1994
New Orleans	November 6–9	1995
Denver	October 28–31	1996
Salt Lake City	October 20–23	1997

For general information on technical program participation (1993 or beyond) contact Sue Beggs, Meetings Manager, GSA headquarters.

GSA SECTION MEETINGS

South-Central Section, University of Arkansas, Little Rock, Arkansas, March 21–22, 1994. Philip L. Kehler, Department of Earth Sciences, University of Arkansas—Little Rock, 2801 S. University Ave., Little Rock, AR 72204, (501) 569-3546, fax 501-569-8020. *Abstract Deadline: November 30, 1993.*

Cordilleran Section, California State University, San Bernardino, California, March 21–23, 1994. Joan E. Fryxell, Department of Geological Sciences, California State University, 5500 University Parkway, San Bernardino, CA 92407-2397, (909) 880-5311. *Abstract Deadline: November 29, 1993.*

Northeastern Section, SUNY at Binghamton, Binghamton, New York, March 28–30, 1994. H. Richard Naslund, Department of Geological Sciences, SUNY, Binghamton, NY 13902-6000, (607) 777-4313. *Abstract Deadline: December 2, 1993.*

Southeastern Section, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, April 7–8, 1994. Lynn Glover, III, and Robert J. Tracy, Department of Geological Sciences, Virginia Tech, Blacksburg, VA 24061-0420, Glover's direct (703) 231-6213, Tracy's direct (703) 231-5980, fax 703-231-3886. *Abstract Deadline: December 1, 1993.*

North-Central Section, Western Michigan University, Kalamazoo, Michigan, April 28–29, 1994. Alan Kehew, Department of Geology, Western Michigan University, Kalamazoo, MI 49008, (616) 387-5495, fax 616-387-5513. *Abstract Deadline: January 6, 1994.*

Rocky Mountain Section, Fort Lewis College, Durango, Colorado, May 4–6, 1994. Douglas Brew, Geology Department, Fort Lewis College, Durango, CO 81301, (303) 247-7254, fax 303-247-7310. *Abstract Deadline: January 13, 1994.*

STUDENT TRAVEL GRANTS

The GSA Foundation will award matching grants up to a total of $3500 each to the six GSA Sections. The money, when combined with equal funds from the Sections, will be used to assist GSA Student Associates traveling to the 1993 GSA Annual Meeting in Boston in October and to the 1994 Section meetings. Contact your Section secretary for application procedures.

Cordilleran	Bruce A. Blackerby	(209) 278-3086
Rocky Mountain	Kenneth E. Kolm	(303) 273-3800
North-Central	George R. Hallberg	(319) 335-1575
South-Central	Rena M. Bonem	(817) 755-2361
Northeastern	Kenneth N. Weaver	(410) 554-5503
Southeastern	Michael J. Neilson	(205) 934-2439

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MEETINGS

GSA Penrose Conferences

March 1994

From the Inside and the Outside: Interdisciplinary Perspectives on the History of Earth Sciences, March 19–21, 1994, San Diego, California. Information: Léo F. Laporte, Dept. of Earth Sciences, University of California, Santa Cruz, CA 95064, (408) 459-2248, fax 408-459-3074; Naomi Oreskes, Dept. of Earth Sciences, Dartmouth College, Hanover, NH 03755, (603) 646-1420, fax 603-646-3922; Kenneth L. Taylor, Dept. of the History of Science, University of Oklahoma, Norman, OK 73019-0315, (405) 325-2213, fax 405-325-2363.

June 1994

Fractured Unlithified Aquitards: Origins and Transport Processes, June 15–20, 1994, Racine, Wisconsin. Information: John A. Cherry, Waterloo Centre for Groundwater Research, University of Waterloo, Ontario N2L 3G1, Canada, (519) 885-1211, ext. 2892, fax 519-746-5644; David M. Mickelson, Dept. of Geology and Geophysics, University of Wisconsin, 1215 W. Dayton St., Madison, WI 53706, (608) 262-7863, fax 608-262-0693; William W. Simpkins, Dept. of Geological and Atmospheric Science, 253 Science I, Iowa State University of Science and Technology, Ames, IA 50011, (515) 294-7814, fax 515-294-6049.

1993 Meetings

August

Intraplate Volcanism International Workshop, The Polynesian Plume Province, August 1993, Tahiti, French Polynesia. Information: Workshop Tahiti 1993 Organization Committee, H.G. Barsczus, Centre Géologique et Géophysique, Case 060, Université de Montpellier II, 34095 Montpellier Cedex 5, France, phone 33-67-634-983, fax 33-67-523-908.

Hydrometallurgy—Milton E. Wadsworth International Symposium, August 1–5, 1993, Salt Lake City, Utah. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162, (303) 973-9550, fax 303-979-3461.

Geochemistry of the Earth Surface 3rd International Symposium, August 1–6, 1993, University Park, Pennsylvania. Information: Lee Kump, Dept. of Geosciences, Pennsylvania State University, 210 Deike Bldg., University Park, PA 16802, (814) 863-1274, fax 814-865-3191.

Belt Symposium III: Field Conference on New Geologic Perspectives of the Middle Proterozoic Belt–Purcell Basin, August 14–21, 1993, Whitefish, Montana. Information: Belt Symposium III, c/o Western Experience, Inc., 4881 Evening Sun Lane, Colorado Springs, CO 80917.

Carboniferous to Jurassic Pangea: A Global View of Environments and Resources, August 15–19, 1993, Calgary, Alberta, Canada. Cosponsored by the Canadian Society of Petroleum Geologists and the Global Sedimentary Geology Program. Information: Benoit Beauchamp or Ashton Embry, Geological Survey of Canada, 3303 33rd St. NW, Calgary, Alberta T2L 2A7, Canada, (403) 292-7126, fax 403-292-4961.

18th Chemical Oceanography Gordon Conference, Global Fluxes, Climate Change and Ocean Chemistry, August 15–20, 1993, Meriden, New Hampshire. Information: Philip Froelich, Lamont-Doherty Earth Observatory, Palisades, NY 10964, (914) 365-8485, fax 914-365-2312.

Mine Design International Congress, Mining into the 21st Century, August 23–26, 1993, Kingston, Ontario, Canada. Information: Peter Scott, Public Relations, ICMD/Relations publiques, CICM, Dept. of Mining Engineering/Département de génie minier, Queen's University/Université Queen's, Kingston, Ontario K7L 3N6, Canada, (613) 545-2212, fax 613-545-6597.

Hydrothermal Reactions Fourth International Symposium, August 31–September 3, 1993, Nancy, France. Information: 4th ISHR, CREGU, BP-23, 54501-Vandoeuvre-lès-Nancy Cedex, France, telex: 960934, fax 33-83-44-00-29, E-mail: internet CREGU ciril.fr, or FRciiL71.bitnet.

September

Mineralization Related to Mafic and Ultramafic Rocks, International Symposium, September 1–3, 1993, Orléans, France. Information: Daniel Ohnenstetter, Symposium Secretary, CRSCM-CNRS, 1a, rue de la Férollerie, 45071 Orléans Cedex 2, France, phone 33-38-51-54-01, fax 33-38-63-64-88.

Rocky Mountain Friends of the Pleistocene, September 10–12, 1993, Mission Valley–Flathead Lake area, northwest Montana. Information: Dan Levish, Bureau of Reclamation, P.O. Box 25007, D-3611, Denver, CO 80225-0007, (303) 236-8532.

Coal Science 7th International Conference, September 12–17, 1993, Banff, Alberta, Canada. Information: David Brown, P.O. Bag 1280, Devon, Alberta T0C 1E0, Canada, (403) 450-5200, fax 403-987-3430.

Fractography, Geological Society of London Thematic Meeting, September 13–14, 1993, London, United Kingdom. Information: M. S. Ameen, GeoScience Limited, Silwood Park, Buckhurst Road, Ascot SL5 7QW, UK, phone 44-344-872220, fax 0344 872438.

AAPG Hedberg Research Conference—Salt Tectonics, September 13–17, 1993, Bath, England. Information: AAPG Continuing Education Dept., P.O. Box 979, Tulsa, OK 74101, (918) 584-2555, fax 918-584-0469.

WORLDTech I, International Congress on Mining Development, September 15–17, 1993, Philadelphia, Pennsylvania. Information: Meetings Dept., SME, P.O. Box 625002, Littleton, CO 80162, (303) 973-9550, fax 303-979-3461.

American Association of Petroleum Geologists Eastern Section Meeting, September 19–21, 1993, Williamsburg, Virginia. Information: Arthur D. Cohen, Dept. of Geological Sciences, University of South Carolina, Columbia, SC 29208, fax 803-777-6610.

Contaminated Soils: Analysis, Fate, Environmental & Public Health Effects, and Remediation, Eighth National Conference, September 20–23, 1993, Amherst, Massachusetts. Information: Paul Kostecki or Linda Rosen, Division of Public Health, University of Massachusetts, Amherst, MA 01003, (413) 545-2934, fax 413-545-4692.

10th Annual International Pittsburgh Coal Conference, September 20–24, 1993, Pittsburgh, Pennsylvania. Information: Ann McDonald, Conference Secretary, Pittsburgh Coal Conference, University of Pittsburgh, 1140 Benedum Hall, Pittsburgh, PA 15261, (412) 624-7440, fax 412-624-1480.

Andean Geodynamics 2nd International Symposium, September 21–23, 1993, Oxford, England. Information: P. Soler, ISAG 93, ORSTOM, CS1, 213 rue Lafayette, 75480 Paris Cedex 10, France, fax 33-1-48-03-08-29.

Clay Minerals Society Annual Meeting, September 25–30, 1993, San Diego, California. Information: Richard Berry, Dept. of Geological Sciences, San Diego State University, San Diego, CA 92182-0337, (619) 594-6394, fax 619-594-4372.

International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) General Assembly, Ancient Volcanism and Modern Analogues, September 25–October 1, 1993, Canberra, Australia. Information: IAVCEI General Assembly, ACTS, GPO Box 2200, Canberra, ACT 2601, Australia, phone 61-6-2573299, fax 61-6-2573256.

Association of Earth Science Editors Annual Meeting, September 26–29, 1993, Madison, Wisconsin. Information: Mindy James, Wisconsin Geological and Natural History Survey, 3817 Mineral Point Road, Madison, WI 53705, (608) 263-7394.

Global Boundary Events (Interdisciplinary Conference of IGCP Project 293, Geochemical Marker Events in the Phanerozoic), September 27–29, 1993, Kielce, Poland. Information: Barbara Studencka, Muzeum Ziemi PAN, Al. Na Skarpie 20/26, 00-488 Warszawa, Poland, phone 48-22-217-391, fax 48-22-297-497; or Helmut H.J. Geldsetzer, Geological Survey of Canada, 3303 33rd St. N.W., Calgary, Alberta T2L 2A7, Canada, (403) 292-7155, fax 403-292-5377.

Accelerator Mass Spectrometry 6th International Conference, September 27–October 1, 1993, Canberra and Sydney, Australia. Information: AMS-6, ACTS, GPO Box 2200, Canberra ACT 2601, Australia, phone 61-6-249-8105, fax 61-6-257-3256.

■ **German Geological Society 145th Annual Meeting,** September 28–October 1, 1993, Krefeld, Germany. Information: P. Neumann-Mahlkau, K. Steuerwald, H. D. Hilden, Geological Survey North-Rhine-Westfalia, P.O. Box 10 80, D-47710 Krefeld, Germany.

October

Basin Inversion International Conference, October 4–9, 1993, Oxford, England. Information: Peter Buchanan, CogniSeis Development, Stanley House, Kelvin Way, Crawley, West Sussex, RH10 2SX, UK.

■ **Environmental Hydrology and Hydrogeology, Second USA/Hungary Joint Conference,** October 7–14, 1993, Budapest, Hungary. Information: AIH, 3416 University Ave. S.E., Minneapolis, MN 55414-3328, (612) 379-1030, fax 612-379-0169.

Society for Organic Petrology 10th Annual Meeting, October 9–13, 1993, Norman, Oklahoma. Information: Brian Cardott, Oklahoma Geological Survey, 100 E. Boyd St., Rm. N-131, Norman, OK 73019-0628, (405) 325-3031, fax 405-325-7069.

Association of Engineering Geologists Annual Meeting, October 9–15, 1993, San Antonio, Texas. Information: Association of Engineering Geologists, 323 Boston Post Rd., Suite 2D, Sudbury, MA 01776, (508) 443-4639.

Geothermal Resources Council Annual Meeting, October 10–13, 1993, Burlingame, California. Information: Geothermal Resources Council, P.O. Box 1350, Davis, CA 95617-1350, (916) 758-2360, fax 916-758-2839.

International Association for Mathematical Geology, October 10–15, 1993, Prague, Czechoslovakia. Local Chairman: Vaclav Nemec, K. Rybinickum 17, Praha 1–Strasnice, Czechoslovakia; Technical Program Committee cochairmen—North and South America: John C. Davis, Kansas Geological Survey, University of Kansas, Lawrence, KS 66047, (913) 864-3965, fax 913-864-5317, E-mail: john_davis.moore_hall@-msmail.kgs.ukans.edu; Europe, Africa, and Asia: Jan Harff, Institute for Baltic Sea Research, Seestr. 15, 0-2530 Warnemuende, Germany, phone 49-381-58-261, fax 49-381-58-336, E-mail: harff@-geologie.io-warnemuende.dbp.de.

Seismological Society of America, Eastern Section Meeting, October 13–15, 1993, Weston, Massachusetts. Information: John E. Ebel, Weston Observatory, Dept. of Geology & Geophysics, Boston College, 381 Concord Road,

Weston, MA 02193-1340, (617) 899-0950, fax 617-552-8388, E-mail: EBEL@-BCVMS.BC.EDU. *(Abstract deadline: September 10, 1993.)*

Federation of Analytical Chemistry and Spectroscopy Societies 20th Annual Meeting, October 17–22, 1993, Detroit, Michigan. Information: FACSS, P.O. Box 278, Manhattan, KS 66502, (301) 846-4797.

New Developments in Geothermal Measurements in Boreholes, October 18–23, 1993, Klein Köris, Germany. Information: E. Hurtig, GFZ Potsdam, Telegrafenberg A45, 0-1561 Potsdam, Germany, phone 49-331-310-347, fax 49-331-310-610, E-mail: gth@gfz-potsdam.dbp.de.

Gulf Coast Association of Geological Societies and Gulf Coast Section of SEPM 43rd Annual Convention, October 20–22, 1993, Shreveport, Louisiana. Information: Roger Berg, Arkla Exploration Co., P.O. Box 21734, Shreveport, LA 71151, (318) 429-2713.

Overthrusting into Foreland Basins: Sedimentological Consequences, October 20–22, 1993, Troy, New York. Information: Gerald M. Friedman, Northeastern Science Foundation, Rensselaer Center of Applied Geology, 15 Third Street, P.O. Box 746, Troy, NY 12181-0746.

Geological Society of America Annual Meeting, October 25–28, 1993, Boston, Massachusetts. Information: GSA Meetings Dept., P.O. Box 9140, Boulder, CO 80301, (303) 447-2020, fax 303-447-1133.

World Energy Engineering 16th Congress, October 26–28, 1993, Atlanta, Georgia. Information: Ruth M. Bennett, 4025 Pleasantdale Road, Suite 420, Atlanta, GA 30340, (404) 447-5083, fax 404-446-3969.

Asociación de Ingeniéros de Minas, Metalurgistas y Geólogos de México XX Convención, October 26–29, 1993, Acapulco, Guerrero, Mexico. Information: Fernel Arvizu Lara, AIMMGM, A.P. 4073, C.P. 06400 Mexico, D.F., Mexico.

Rocky Mountain Ground Water Conference, October 27–29, 1993, Albuquerque, New Mexico. Information: Michael E. Campana, Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131-1116, (505) 277-3269, fax 505-277-8843.

Geological Association of New Jersey, Precambrian Traverse of Northern New Jersey, October 29–30, 1993. Information: John Marchisin, P.O. Box 5145, Trenton, NJ 08638, (201) 200-3162, fax 201-200-2298.

November

International Circum-Pacific and Circum-Atlantic Terrane Conference VI, November 5–21, 1993, Guanajuato, Mexico. Information: Fernando Ortega-Gutiérrez, fax 52 (5) 548-0772; or David G. Howell, fax 415-353-3224.

24th Annual Underwater Mining Institute, November 7–9, 1993, Estes Park, Colorado. Information: Karynne Chong Morgan, UMI Conference Coordinator, 811 Olomehani Street, Honolulu, HI 96813-5513, (808) 522-5611, fax 808-522-5618, Internet: morgan@uhunix.uhcc.hawaii.edu, Compuserve: MMTC, 70673,534.

Third International Congress of the Brazilian Geophysical Society, November 7–11, 1993, Rio de Janeiro, Brazil. Information: SBGf-Divisão Centro-Sul, Secretaria do 3º CISBGf, Av. Rio Branco 156, sala 2510, 20043-900 Rio de Janeiro, RJ, Brasil, phone 55-21-533-0064, fax 55-21-533-0064.

Mineral Resources of Russia, International Symposium and Exhibition, November 9–13, 1993, St. Petersburg, Russia. Information in the USA: (505) 291-9812. Information in Russia: Organizing Committee, P.O. Box 215, 199004, St. Petersburg, Russia, E-mail: vsg@sovamsu.sovusa.com., phone 7-812-218-9224, fax 7-812-355-7952.

Basement and Basins of Eastern North America, AAPG Hedberg Research Conference, November 10–13, 1993, Ann Arbor, Michigan. Information: AAPG Continuing Education Department, P.O. Box 979, Tulsa, OK 74101, (918) 584-2555, fax 918-584-0469.

Eastern Oil Shale Symposium, November 17–19, 1993, Lexington, Kentucky. Information: Geaunita H. Caylor, University of Kentucky/OISTL, 643 Maxwelton Court, Lexington, KY 40506-0350, (606) 257-2820, fax 606-258-1049.

December

American Geophysical Union Fall Meeting, December 6–10, 1993, San Francisco, California. Information: AGU—Meetings Dept., 2000 Florida Avenue, N.W., Washington, DC 20009, (202) 462-6900, fax 202-328-0566, E-mail: dsolomon@kosmos.agu.org. *(Abstract deadline: September 9, 1993.)*

■ **World Organization of Volcano Obseratories—IAVCEI Commission,** December 13–17, 1993, Guadeloupe Island, West Indies. Information: Catherine Netter, Observatoires Volcanologiques, IPGP, phone 33-1-44-27-24-00, fax 33-1-44-27-24-01.

1994 Meetings

January

■ **Remote Sensing and GIS International Symposium,** January 27–28, 1994, location to be determined. Information: Vern Singhroy, Canada Centre for Remote Sensing, 588 Booth Street, Ottawa, Ontario K1A 0Y7, Canada, (613) 947-1215, fax 613-947-1385; or Ivan Johnson, 7474 Upham Court, Arvada, CO 80003, (303) 425-5610; and Doug Nebert, Water Resources Division, USGS National Centre, MS 445, Reston VA 22092, (703) 648-5691, fax 703-959-5691.

Remote Sensing for Marine and Coastal Environments, 2nd Thematic Conference, January 31–February 2, 1994, New Orleans, Louisiana. Information: Robert Rogers, ERIM, Box 134001, Ann Arbor, MI 48113-4001, (313) 994-1200, ext. 3234, fax 313-994-5123.

February

■ **Geological Society of Australia Field Conference,** Deformation Processes in the Earth, February 6–11, 1994, Jindabyne, New South Wales, Australia. Information: Stephen Cox, RSES, ANU, Canberra, ACT 0200, Australia, phone 61 6 249 4076, fax 61 6 249 0738, E-mail: jdf152@cscgpo.anu.edu.au. *(Abstract deadline: September 15, 1993.)*

New Developments Regarding the K/T Event and Other Catastrophes in Earth History, February 9–12, 1994, Houston, Texas. Information: K/T Event, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058-1113, (713) 486-2149, fax 713-486-2160, E-mail (Internet): holley@lpi.jsc.nasa.gov.

Breakthroughs in Karst Geomicrobiology and Redox Geochemistry, February 16–19, 1994, Colorado Springs, Colorado. Information: Arthur Palmer, Earth Sciences Dept., SUNY Oneonta, Oneonta, NY 13820-4015, (607) 436-3064, fax 607-436-2107.

March

■ **GSA South-Central Section Meeting,** March 21–22, 1994, Little Rock, Arkansas. Information: Philip L. Kehler, Dept. of Earth Sciences, University of Arkansas, 2801 S. University Ave., Little Rock, AR 72204, (501) 569-3546, fax 501-569-8020. *(Abstract deadline: November 30, 1993.)*

Meetings *continued on p. 218*

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■ **GSA Cordilleran Section Meeting,** March 21–23, 1994, San Bernardino, California. Information: Joan Fryxell, Dept. of Geological Sciences, California State University, 5500 University Parkway, San Barnardino, CA 92407-2397, (909) 880-5311, fax 909-880-7005. *(Abstract deadline: November 29, 1993.)*

Seventh Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), March 27–31, 1994, Boston, Massachusetts. Information: EEGS, Mark Cramer, P.O. Box 4475, Englewood, CO 80112, (303) 771-6101. *(Abstract deadline: October 1, 1993.)*

■ **GSA Northeastern Section Meeting,** March 28–30, 1994, Binghamton, New York. Information: H. Richard Naslund, Dept. of Geological Sciences, SUNY, Binghamton, NY 13902-6000, (607) 777-4313, fax 607-777-2288. *(Abstract deadline: December 2, 1993.)*

April

■ **GSA Southeastern Section Meeting,** April 7–8, 1994, Blacksburg, Virginia. Information: Lynn Glover, III, and Robert J. Tracy, Dept. of Geological Sciences, Virginia Tech, Blacksburg, VA 24061-0420, Glover's direct (703) 231-6213, fax 703-231-3886, Tracy's direct (703) 231-5980. *(Abstract deadline: December 1, 1993.)*

Toxic Substances and the Hydrologic Sciences, April 10–13, 1994, Austin, Texas. Information: American Institute of Hydrology, 3416 University Ave. S.E., Minneapolis, MN 55414-3328, (612) 379-1030, fax 612-379-0169.

Transport and Reactive Processes in Aquifers IAHR Symposium, April 11–15, 1994, ETH-Zürich, Switzerland. Information: Th. Dracos or F. Stauffer, Institute of Hydromechanics and Water Resources Management (IHW), ETH-Hönggerberg, CH-8093 Zürich, Switzerland, phone 41-1-377 30 66 or 41-1-377 30 79, fax 41-1-371 22 83.

Extractive Industry Geology, April 17–20, 1994, Sheffield, England. Information: The Conference Office, The Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England, phone 44-71-580-3802, fax 44-71-436-5388.

European Association of Science Editors 5th General Assembly and Conference, April 24–28, 1994, Budapest, Hungary. Information: EASE Secretariat, 49 Rossendale Way, London, NW1 0XB, UK, phone 44-71-388 9668, fax 44-71-383 3092.

■ **Third International Conference on the Abatement of Acidic Drainage,** April 25–29, 1994, Pittsburgh, Pennsylvania. Information: D. Lowanse, U.S. Bureau of Mines, P.O. Box 18070, Pittsburgh, PA 15236, (412) 892-6708, fax 412-892-4067.

■ **GSA North-Central Section Meeting,** April 28–29, 1994, Kalamazoo, Michigan. Information: Alan Kehew, Dept. of Geology, Western Michigan University, Kalamazoo, MI 49008, (616) 387-5495, fax 616-387-5513. *(Abstract deadline: January 4, 1994.)*

May

■ **GSA Rocky Mountain Section Meeting,** May 4–6, 1994, Durango, Colorado. Information: Douglas Brew, Geology Dept., Ft. Lewis College, Durango, CO 81301, (303) 247-7254, fax 303-247-7310.

■ **Geologic Remote Sensing Tenth Thematic Conference,** May 9–12, 1994, San Antonio, Texas. Information: ERIM/Thematic Conferences, P.O. Box 134001, Ann Arbor, MI 48113-4001, (313) 994-1200, ext. 3234, fax 313-994-5123, Internet: wallman@vaxb.erim.org.

Geological Association of Canada and Mineralogical Association of Canada Annual Meeting, May 15–18, 1994, Waterloo, Ontario, Canada. Information: Alan V. Morgan, Dept. of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada, (519) 885-1211, ext. 3231, fax 519-746-7484.

■ **High-Level radioactive Waste Management International Conference,** May 22–26, 1994, Las Vegas, Nevada. Information: Tom Sanders, Attn: Transactions Office, American Nuclear Society, 555 N. Kensington Avenue, La Grange Park, IL 60525.

■ **Glacial Cycles at High Latitudes,** May 29–June 1, 1994, Fjærland, Norway. Information: Berit H. Barkley, Dept. of Geology, P.O. Box 1047 Blindern, 0316 Oslo, Norway, 47-22-856691, fax 47-22-854215.

June

■ **1st North American Rock Mechanics Symposium,** June 1–3, 1994, Austin, Texas. Information: NARM Symposium, Continuing Engineering Studies, Cockrell Hall 10.324, University of Texas, Austin, TX 78712; or Priscilla Nelson, (512) 471-5664, or Stephen Laubach, fax 512-471-0140. *(Abstract deadline: September 30, 1993.)*

■ **Geochronology, Cosmochronology, and Isotope Geology Eighth International Conference (ICOG-8),** June 5–11, 1994, Berkeley, California. Information: Garniss H. Curtis, Institute of Human Origins–Geochronology Center, 2453 Ridge Road, Berkeley, CA 94709, (510) 845-4003, fax 510-845-9453.

■ **First International Symposium on Protection and Development of Mountain Environment,** June 20–24, 1994, Ponte di Legno, Italy. Information: Man & Mountain '94, c/o Valdepur Service s.r.l., via Seradello 225, 25068 Serezzo (BS), Italy.

July

FORAMS '94: International Symposium on Foraminifera, July 5–9, 1994, Berkeley, California. Information: FORAMS '94, Museum of Paleontology, University of California, Berkeley, CA 94720, (510) 642-1821, fax 510-642-1822.

Earthquake Engineering Fifth U.S. National Conference, July 10–14, 1994, Chicago, Illinois. Information: Claudia Cook, Newmark Civil Engineering Laboratory, University of Illinois, 205 N. Mathews, Urbana, IL 61801-2397, (217) 333-0498.

Basement Tectonics 11th International Conference, July 25–29, 1994, Potsdam, Germany. Information: Onno Oncken, Conference Chairman, GeoForschungsZentrum, Telegrafenberg, D-0-1561 Potsdam, Germany, phone 49-331-310601, fax 49-331-310306. *(Abstract deadline: March 1, 1994.)*

August

V.M. Goldschmidt Conference, August 29–September 2, 1994, Edinburgh, Scotland. Information: B. Harte or P. Symms, V.M. Goldschmidt Conference 1994, Dept. of Geology and Geophysics, University of Edinburgh, Grant Institute, West Mains Road, Edinburgh EH9 3JW, Scotland, UK.

September

Cyclicity in Global Geology, Australian Geological Convention Symposium, September 1994, Perth, Australia. Information: Bryan Krapez, C.McA. Powell, Dept. of Geology, University of Western Australia, Nedlands, 6009, Australia.

■ **Prospecting in Areas of Glaciated Terrain—Tenth Conference,** September 5–7, 1994, St. Petersburg, Russia. Information: The Conference Office, The Institution of Mining and Metallurgy, 44 Portland Place, London W1N 4BR, England, phone 44-71-580-3802, fax 44-71-436-5388.

■ **International Conference on Arctic Margins,** (ICAM '94), September 5–9, 1994, Magadan, Russia. Information: Kirill V. Simakov, North East Science Center, Russian Academy of Sciences, 16 Portovaya St., Magadan, Russia 685000, (907) 474-7219 (USA) or 7-41-3-223-0953 (Russia); or Dennis K. Thurston, Minerals Management Service, 949 E. 36th Ave., Anchorage, AK 99508-4302, (907) 271-6545, fax 907-271-6565.

■ **12th Australian Geological Convention,** September 26–30, 1994, Perth, Australia. Information: Secretary, 12AGC, P.O. Box 119, Cannington, WA 6107, Australia, 61-9-351-7968, fax 61-9-351-3153. *(Abstract deadline: January 14, 1994.)*

October

German Geological Society (DGG) Annual Meeting, October 4–7, 1994, Heidelberg, Germany. Information: Th. Bechstädt and R. O. Greiling, Geologisch-Paläontologisches Institut, Ruprecht-Karls-Universität, Im Neuenheimer Feld 234, D-6900 Heidelberg, Germany.

November

Geology and Resources of the Eastern Frontal Belt, Ouachita Mountains, Oklahoma, November 15–17, 1994, Poteau, Oklahoma. Information: Neil H. Suneson, Oklahoma Geological Survey, Sarkeys Energy Center Room N-131, 100 East Boyd St., Norman, OK 73019-0628, (405) 325-3031.

Send notices of meetings of general interest, in format above, to Editor, *GSA Today*, P.O. Box 9140, Boulder, CO 80301.

August *BULLETIN* and *GEOLOGY* Contents

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BULLETIN

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The Department of Geosciences at Penn State intends to fill a junior level tenure track faculty position in geodynamics. We seek an individual who investigates the physics of lithospheric processes, crustal deformation, or mantle dynamics, and will consider scientists utilizing observational, theoretical, and modeling approaches in their research. The successful candidate will join an active group of faculty and researchers committed to excellence in both teaching and research in tectonics, lithospheric geodynamics, seismology, and basin evolution. Applicants should demonstrate potential for developing a funded research program in conjunction with a commitment to education at both the undergraduate and graduate levels. Interested individuals should submit a current vita, a statement of research and teaching interests, and the names and addresses of three references. Reprints and preprints of recent publications are welcome. This position is available starting January, 1994, and a Ph.D. is required at the time of appointment. Files will be reviewed beginning July 1, 1993, and the search will continue until the position is filled. Applications should be directed to: Professor Michael A. Arthur, Head, Department of Geosciences, 503 Deike Building, Pennsylvania State University, University Park, PA 16802.

Penn State is an equal opportunity/affirmative action employer.

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FIELD MAPPER wanted for 3 to 6 months of full-time employment mapping at 1:24,000 scale in structurally complex areas of western Arizona that consist largely of Cenozoic volcanic rocks. Duties include preparation of maps and associated reports. Start in November or December, 1993. Send resume, references, and samples of past geologic maps to Personnel Division, Arizona Geological Survey #100, 845 N. Park Ave., Tucson, AZ 85719.

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Opportunities for Students

University of Texas at Austin. Institute for Geophysics, Ewing/Worzel Fellowship in Geology/ Geophysics, Seismic Processing, Seismology, or Tectonics. Candidates are expected to have a bachelors or masters degree in geology, geophysics, physics, computing, or other related field, and must be accepted in a graduate program of one of the University of Texas at Austin academic departments.

The Institute for Geophysics is an organized research unit of the University of Texas. Fellows are expected to ally themselves with a member of the Institute research staff and either generate an original research project or join an existing project during their first year. The Fellowship amount is $12,000 per academic year, which is intended to cover tuition, fees, and stipend. Additional support may be awarded after the first year, depending on the research performance of the individual.

Questions about the fellowship program should be directed to Dr. Thomas A. Davies, Chairman, UTIG Fellowship Committee, 8701 N. MoPac Expy,. Austin, Texas, 78759 (tel. 512-471-6156, fax 512-471-8844). Application materials for admission as a graduate student may be obtained from the Graduate Studies Office of the appropriate academic department of The University of Texas at Austin. The Spring 1994 deadline for graduate admission and fellowship applications is October 1, 1993. The Fall 1994 deadline is February 1, 1994.

Student Travel Grants. The GSA Foundation will award matching grants to each of the six GSA Sections to assist students wishing to travel to GSA Section and Annual meetings. For applications contact individual Section secretaries. For Section information, contact GSA (1-800-472-1988).

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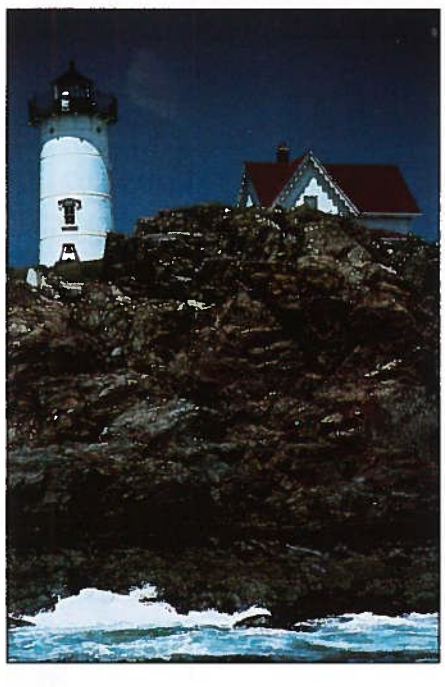

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For more information:
GSA Meetings Department,
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