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INSIDE

Acid Trauma at the Cretaceous-Tertiary Boundary in Eastern Montana

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ABSTRACT

Acid is a likely consequence of many of the catastrophic events postulated for the Cretaceous-Tertiary boundary: nitric acid from atmospheric shock by bolide and from burning of trees, sulfuric acid from volcanic aerosols and from impact vaporization of evaporites, hydrochloric acid from volcanic aerosols, and carbonic acid from carbon dioxide of volcanoes and fires. The amount of acid is here estimated from base cation leaching of boundary beds and paleosols in eastern Montana. The thin boundary claystone consumed so much more acid than the overlying impact layer and associated paleosols that strong acids are indicated. Vigorous early neutralization of hot acid by silicate ejecta may explain the distinctive kaolinitic composition, and the microspherulitic and vuggy texture of the boundary bed, in which impact evidence such as shocked quartz has been destroyed by profound chemical leaching. This early buffering of impact-generated acid was fortunate for life in terranes with high acid-buffering capacity such as the calcareous and smectitic floodplains of Montana, which were not acidified to less than pH 4, thus sparing small mammals, amphibians, and fish, but affecting plants, nonmarine molluscs, and dinosaurs.

Figure 1. The K-T boundary (arrow) in the sequence of paleosols in Bug Creek (NW¼NW¼SE¼, sec. 17, T. 22 N., R. 43 E.), McCone County, Montana. The iridium anomaly is weak here because of bioturbation into a moderately developed paleosol beneath the dark gray band exposed in the trench excavated low in the bluffs to the left.

INTRODUCTION

Catastrophic impact of a large bolide at the Cretaceous-Tertiary (K-T) boundary is now established from evidence of iridium anomalies (Alvarez et al., 1980; Orth et al., 1990), shocked quartz (Izett, 1990), dramatic changes in fossil plants (Wolfe and Upchurch, 1987; Nichols et al., 1990; Johnson and Hickey, 1990), and a large impact crater in Yucatán (Hildebrand et al., 1991; Sharpton et al., 1993; Kring, 1995). Also occurring at this time were flood-basalt eruptions of the Deccan Traps in India (Duncan and Pyle, 1988; Courtillot et al., 1990) and widespread wildfires (Wolbach et al., 1988; Tinus and Roddy, 1990). Acid is a likely consequence of all these events: nitric acid from atmospheric shock by the bolide and from burning of trees (Zahnle, 1990), sulfuric acid from volcanic aerosols and impact vaporization of evaporites (Hildebrand et al., 1991; Sigurdsson et al., 1992; Brett, 1992; Sharpton et al., 1993), hydrochloric acid from volcanic aerosols (Caldeira and Rampino, 1990), and carbonic acid from carbon dioxide of volcanoes and fires (Wolbach et al., 1988; Tinus and Roddy, 1990). All this acid should have left a record in paleosols or boundary beds. This study has been a search for direct evidence of acid leaching and an exploration of the role of acid in the still-controversial topic of selective extinctions at the K-T boundary (Williams, 1994; Ward, 1995).

PALEOSOLS AND K-T BOUNDARY BEDS IN MONTANA

Paleosols in the Bug Creek and Brownie Butte areas of eastern Montana (Retallack et al., 1987; Retallack, 1994) are a remarkably complete fossil record of K-T boundary events (Smit et al., 1987; Rigby and Rigby, 1990; Swisher et al., 1993). Only a weak iridium anomaly and no distinctive boundary beds have been found in Bug Creek, but the K-T boundary can be located there by means of unusually abundant fern spores and fossil plant extinctions. The "zone of death" in Bug Creek is the carbonaceous surface of a moderately developed paleosol into which the thin ejecta layers were presumably mixed by the action of later roots and burrows (Fig. 1). At Brownie Butte, the K-T meteoritic ejecta include an impact bed, which is 1 cm thick, gray, smectitic, and layered, with shocked quartz and an iridium anomaly (Figs. 2 and 3). It directly overlies the boundary bed, which is 2 cm thick, pink to white, kaolinitic, micro-

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spherulitic, and vuggy. These two distinctive thin beds have been discovered at 30 sites from Alberta and Saskatchewan south to New Mexico at the radiometrically and palynologically determined K-T boundary (Izett, 1990). The boundary bed at Brownie Butte has been interpreted as a paleosol (Fastovsky et al., 1989; Izett, 1990), but is now regarded as an early-settling fraction of altered ejecta from bolide impact (Alvarez et al., 1995). By either interpretation, its distinctive kaolinitic composition requires reaction with acid, quantification of which is contingent on the exact origin of these boundary layers. Alvarez et al. (1995), explained the distinctive composition of the boundary bed by postulating a glassy parent material or high temperature. These factors would kinetically favor base leaching, but there remains a need for acid to carry out this marked chemical mass transfer.

The boundary and impact beds have been interpreted as fallout from separate impacts within months of one another because the boundary bed has plant remains interpreted as root traces truncated by the impact bed (Fastovsky et al., 1989; Izett, 1990). By this view the boundary bed represents ejecta from the Chicxulub crater, and the source of the impact bed was thought to be the Manson crater, Iowa (Izett, 1990). However, the Manson crater is now known to be about 10 m.y. older than the K-T boundary (Izett et al., 1993). In addition, shocked zircons from the K-T impact layer have crystallization ages much younger than found near the Manson crater, and they are compatible with the age of target rocks around Chicxulub (Kamo and Krogh, 1995). Furthermore, isotopic measurements of Sr, O, and Nd on K-T impact glasses are similar to Chicxulub, rather than Manson melt (Blum et al., 1993). In view of this evidence against two impacts, Alvarez et al. (1995) interpreted the root traces as truncated plant stalks and proposed that the boundary bed is altered glassy ejecta from an early ejecta blanket of melt, shocked rocks, and admixed sea water, followed within hours by fallout from a warm fireball with volatiles, rocks, and shocked quartz.

Decisive evidence for either view is the nature of fossil plant debris in the boundary layer. The concertinalike deformation of the plant material is an indication that it was there in life position before burial and compaction of the sediments (Fastovsky et al., 1989), as would be true for either plant stalks or root traces. However, the structures in the boundary bed are plant stalks, because they are 5 mm or more in diameter and lack the fine rootlets that accompany large roots. Decisive evidence that these are not roots is the way some of these carbonaceous structures branch and are frayed upward (Figs. 2 and 3). My preference is to interpret both impact and boundary beds as different phases of a single impact, but acid consumption for double impact and local derivation also has been calculated.

COMPUTING ACID CONSUMPTION

Both weak acids of weathering and strong acid rain have the effect of displacing basic cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) with hydronium (H^+) by hydrolysis. Using procedures from studies of modern soil acidification (Fölster, 1985), the loss of basic cations can be used to calculate the moles of hydronium consumed from weight percent analytical values and bulk density compared with parent materials of K-T boundary beds and paleosols (Appendix 1; data from Fastovsky et al., 1989; Retallack, 1994). Units of equivalents to hydronium were used rather than moles because of the differing hydronium contents of the likely acids (HNO_3; H_2SO_4).

These estimates of acid consumption are conservative for the following four reasons. First, acid consumption by C horizons was not included, because these sediments were considered parent materials.

Second, allowances were not made for acid-induced aluminum loss, because the paleosols retained clay and had little variation in alumina/silica ratios, with no chemical or petrographic indications of podzolization (Retallack, 1994). Third, potential loss of soil material by landscape denudation was not included because the paleosols were in a large sedimentary basin (Smit et al., 1987; Rigby and Rigby, 1990). Fourth, coaly horizons were not included, because their low mineral content was probably original rather than due to hydrolytic destruction of minerals (Retallack, 1994).

The most critical assumption of these calculations is parent-material composition, against which base loss was assessed. Separate samples were taken as parent materials for Cretaceous and Paleocene paleosols (Table 1), because of changes in alluvial source areas (Retallack, 1994). Because the boundary claystone paleosol formed on an airfall deposit whose ultimate origin can be interpreted in several ways (Izett, 1990; Fastovsky et al., 1989; Alvarez et al., 1995), all conceivable parent materials were estimated: local Cretaceous and Paleocene sediments (Retallack, 1994), the impact bed at Brownie Butte (Fastovsky et al., 1989; Izett, 1990), melt rock from Chicxulub crater, Mexico (Hildebrand et al., 1991), impact glasses from Beloc, Haiti (Sigurdsson et al., 1991, 1992) and Mimbral, Mexico (Smit et al., 1992), and glasses, microbreccias, and target rocks from the Manson crater, Iowa (Koeberl and Hartung, 1992). These various calculations were done to cover a variety of potential interpretations.

TABLE 1. TOTAL ACID CONSUMPTION OF K-T BOUNDARY AND IMPACT BEDS AT BROWNIE BUTTE, MONTANA, FOR VARIOUS ASSUMED PARENT MATERIALS AND HYPOTHESES

Assumed parent material	Number of analyses	Bulk density g/cm^3	Acid consumption, boundary claystone keq/ha	Acid consumption, impact bed keq/ha	Data source*
Hypothesis of single impact (favored here)					
Chicxulub melt, Mexico	2	2.5†	299.7	158.5	1
Tektite, Beloc, Haiti	19	2.8†	647.8	318.5	2
Tektite, Mimbral, Mexico	3	2.5†	327.9	144.5	3
Hypothesis of multiple impact					
Glass, Manson, Iowa	6	2.5†	159.9	74.6	4
Country rock, Manson, Iowa	16	2.5†	276.5	132.9	4
Hypothesis of local derivation					
Paleocene, Montana (R513)	1	1.93 ± 0.05	136.0	62.6	5
Cretaceous, Montana (R610)	1	2.07 ± 0.05	158.7	73.8	5
Relative acidification for all hypotheses					
Impact bed, Montana	2	2.02 ± 0.08	5.4	0	6
Boundary bed, Montana	2	1.92 ± 0.01	0	–10.8	6

*1: Hildebrand et al. (1991); 2: Sigurdsson et al. (1992); 3: Smit et al. (1992); 4: Koeberl and Hartung (1992); 5: Retallack (1994); 6: Fastovsky et al. (1989).

†Estimated values: other densities were measured (Retallack, 1994).

BACKGROUND ACID CONSUMPTION

Potentially exceptional acidification at the K-T boundary must be compared with background acidification due to normal weathering. The calculations (Fig. 4) show that the total amount of acid consumed by mineral horizons of the paleosols was not much different from Late Cretaceous to early Paleocene. This result is supported by Bell (1965), who found base-rich clay near the boundary (Fig. 4). It is also supported by the lack of change in paleosol depth functions of barium/strontium and base/alumina ratios, of trace metals such as Cu, Ni, and Zn, and of rare earths across the K-T boundary (Retallack, 1994). There is no significant difference between four Cretaceous paleosols analyzed that used on average 5297 ± 3758 keq/ha acid (error of 1σ) and nine Paleocene paleosols that used 2069 ± 1481 keq/ha.

Estimated total acid consumption of the paleosols does not take into account their different times for formation. Some paleosols retained clear relict bedding, and are effectively sediments disrupted by only a few seasons of root growth. Other paleosols had well-mixed clayey subsurface horizons of the kind that form over thousands of years. Estimates of the rate of acid consumption (in keq · ha^{-1} · yr^{-1}) used maximum values for duration of ancient soil formation estimated by comparison with studies of morphological *(not chemical)* differentiation of Quaternary soils. These time estimates are discussed elsewhere (Retallack, 1994). The calculated minimal rates of acid consumption of Late Cretaceous and early Paleocene paleosols are not appreciably different from each other or from those of Holocene soils (Fölster, 1985), which generally fall between limits of 0.2 and 2.3 keq · ha^{-1} · yr^{-1}. The four latest Cretaceous paleosols had an average rate of acid consumption of 2.0 ± 1.7 keq · ha^{-1} · yr^{-1}, and the nine earliest Paleocene paleosols had a rate of 0.9 ± 0.4 keq · ha^{-1} · yr^{-1}.

These unsurprising rates and total acid consumption for paleosols above and below the boundary are evidence against a long-term volcanic or meteoritic contribution to paleosol acidity in Montana. In addition, paleosols near the boundary in Bug Creek are somewhat less calcareous but more smectitic than paleosols earlier in the Cretaceous or later in the Paleocene (3-26 m in Fig. 4). Eruption of the Deccan Traps has been proposed to have released 5×10^{17} moles CO_2, 1.7×10^{17} moles H_2SO_4, and 7.4×10^{15} moles HCl (Caldeira and Rampino, 1990), but the effect of this acid was mitigated by smaller doses spread out over about 600,000 yr (Courtillot et al., 1990).

MINIMAL ACID CONSUMPTION AT THE K-T BOUNDARY

An estimate of minimum acid consumption from the boundary bed indicates that strong acid was involved, rather than merely weak acids such as carbonic acid. The unique arrangement of impact over boundary bed allows assessment of minimal acid use of the boundary bed in excess of that used by the overlying impact bed at Brownie Butte (Table 1). The boundary claystone and its plant debris is more acidified by at least 5.4 keq/ha than the sharply overlying, well-bedded, smectitic impact layer (Figs. 1 and 2, Table 1). This significant acidification could not have been created by deposition or alteration early during burial, for the following reasons. There are no local kaolinitic source beds or diagenetic mechanisms that would form the boundary bed in so many separate depositional basins (Izett, 1990). The boundary claystone may have been leached downward from overlying lignitic paleosols at Brownie Butte, as argued for other kaolinitic coal partings (Staub and Cohen, 1978; Demchuck and Nelson-Glatiotis, 1993), but this would have affected the overlying impact bed as well. The boundary bed was much more profoundly leached than the overlying impact bed.

This minimal value of 5.4 keq/ha for the boundary claystone is evidence for strong acid leaching. It is significantly greater than for paleosols at the boundary, which could have consumed as little as an unexceptional 0.2 ± 0.006 keq · ha^{-1} · yr^{-1}. The boundary bed is an order of magnitude thinner than the paleosols, yet this small volume consumed more than twice as much acid. This leaching would have been in place within a soil over a period of months by the two-impact model of Fastovsky et al. (1989), and Izett (1990), but it is more likely that it was leached during emplacement and within hours

K-T Boundary *continued on p. 4*

K-T Boundary *continued from p. 3*

before the later-settling bed of high-energy ejecta from the same impact (Alvarez et al., 1995). For comparison, a modern soil from near Unadilla in upstate New York, after experimental application of rain of pH 3.5, maintained a pH of 4.1 in mineral horizons and lost 7.8 keq · ha^{-1} · yr^{-1} from these horizons (Cronan, 1985), which is comparable to the loss estimated here for the boundary bed in Montana and about three times the loss from weak acids (Fölster, 1985). The calculated 5.4 keq/ha spread out over a year proposed by the two-impact model (Fastovsky et al., 1989) is comparable to modern soils locally polluted by mine waste or industrial acid. By the single-impact model (Alvarez et al., 1995), this is a dramatic short-term acidification.

MAXIMUM ACID CONSUMPTION AT THE K-T BOUNDARY

There are several ways of assessing upper limits to acid consumption of soils and boundary beds at the K-T boundary in Montana. A direct calculation for two paleosols at the boundary in Bug Creek gives an average consumption of 6585 ± 199 keq/ha. These paleosols show profile differentiation and little remaining relict bedding compatible with some 15 ka of soil formation, which would give a rate of acid consumption of 0.2 ± 0.006 keq · ha^{-1} · yr^{-1}. These values are normal for Late Cretaceous, early Paleocene, and late Quaternary soils, as already mentioned. There is no indication of podzolization in the petrographic or chemical composition of the boundary bed or other paleosols of Montana (Retallack, 1994), so that pH is likely to have been buffered to above 4. This figure is supported by the pattern of extinction of different kinds of organisms across the K-T boundary in Montana. Considering acid tolerances of related living creatures (Howells, 1990; Weil, 1994), groundwater pH in Montana was probably less than 5.5 but no less than 4.

A dramatically different view emerges from calculations based on the impact and boundary beds at Brownie Butte, for which a maximal acid consumption of 986 keq/ha can be calculated by using parent material with the composition of tektites from Beloc, Haiti (Table 1). By the model of Alvarez et al. (1995), this amount of acid would have been consumed within hours; by the model of Fastovsky et al. (1989), it would have been consumed within a year. This more serious acid load is compatible with prior theoretical estimates of acid production. Estimates on the production of NO_2 by a bolide capable of creating K-T geochemical anomalies have varied from 1×10^{14} to 1.2×10^{17} moles (Lewis et al., 1982; Prinn

Figure 2. The K-T boundary and impact beds near Brownie Butte (SE¼ SW¼ SW¼ SW¼, sec. 32, T. 21 N., R. 37 E., Garfield County), Montana. The branching and upward-forked brown carbonized material in the pink boundary bed (arrow) is a frayed shoot, as predicted by the model of Alvarez et al. (1995), not a root, as interpreted by Fastovsky et al. (1989).

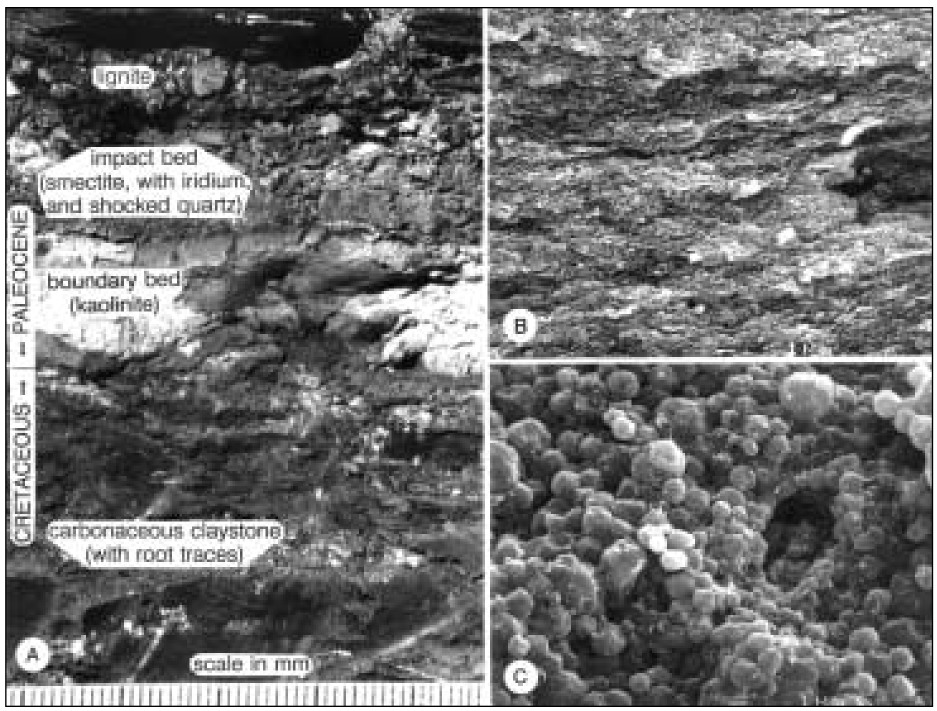

Figure 3. Annotated field photograph of the K-T boundary beds at Brownie Butte (A), with scanning electron micrographs of the impact bed (B) and boundary claystone (C). The pelletoidal and vuggy microstructure of the boundary claystone reflects vigorous acid leaching, which the later-settling laminated impact bed largely escaped. Scales are in millimeters for the field photograph and in micrometers for the micrographs.

and Fegley, 1987; Zahnle, 1990) or some 2–2350 keq/ha of Earth's surface area. An additional source of acid on short time scales is vaporization of anhydrite evaporites under the impact crater of Chicxulub, Mexico (Hildebrand et al., 1991; Sigurdsson et al., 1992; Brett, 1992; Sharpton et al., 1993). This may have produced 4×10^{17} to 1.3×10^{19} g SO_2 (Brett, 1992; Sigurdsson et al., 1992), which is 6.2×10^{15} to 2.0×10^{17} moles, or 254–7840 keq/ha globally. Wildfires would produce comparable amounts of NO and CO_2 (Zahnle, 1990), perhaps focused at the boundary

(Wolbach et al., 1988; Tinus and Roddy, 1990). An additional estimate from hypothetical oceanic titration (d'Hondt et al., 1994) is a total acid load of no more than 5×10^{16} moles, or 980 keq/ha globally. The maximal acidification of the boundary bed estimated here indicates that the lower estimates of acid load are reasonable, but the higher estimates are excessive.

If generated, then where did all this acid go to leave associated paleosols only mildly acidified? One possibility is consumption by reaction with impact ejecta. Assuming the single-impact model of Alvarez et al. (1995), rock of the low-energy ejecta curtain would have been attacked by acid generated from entrained SO_2 and NO_x as it cooled during or shortly after ballistic emplacement, unless quenched and diluted by fallout in the deep ocean (as for glasses of the Carribean area described by Sigurdsson et al., 1992; Smit et al., 1992). The volume of ejecta thrown up by the impact at Chicxulub has been estimated to be $1–2.2 \times 10^4$ km^3 (Kring, 1995). If all of this were leached to the degree seen in the boundary bed from a composition similar to Haitian tektites, it would consume 7.1×10^{11} eq of acid. The remainder of the broadcast acid could easily be accommodated by the mild acidification seen in the paleosols at Bug Creek. This is the most optimistic atmospheric scrubbing of acid imaginable, so some of the hypothetical estimates of acid production cited above can be still regarded as excessive.

A short burst of acidic leaching not only explains the base-poor, kaolinitic composition of the boundary bed, but also its anomalously low Ni, Co, and Ir content for either meteoritic or volcanic material (Izett, 1990) and its peculiar spherulitic and vuggy microtexture (Fig. 3). Because iridium concentrations would be dispersed and shocked quartz, spherules, and other indicators of impact origin obliterated by this chemical leaching, their absence in the boundary bed does not require hypotheses of ballistic sorting (of Alvarez et al., 1995). Such acidic leaching of iridium and shocked quartz from impact ejecta could explain weak to nonexistent geochemical and mineralogical signatures at other major extinction events (Orth et al., 1990). Thus, acid generated by impact could make some impacts geochemically "self cleaning."

Increased weathering induced by acid has been invoked to explain anomalous enrichment of crustal strontium in marine foraminifera at the K-T boundary (MacDougall, 1988; Martin and MacDougall, 1991). Crustal strontium also could have been leached to the ocean from the hot fallout preserved as the boundary bed.

K-T Boundary *continued on p. 6*

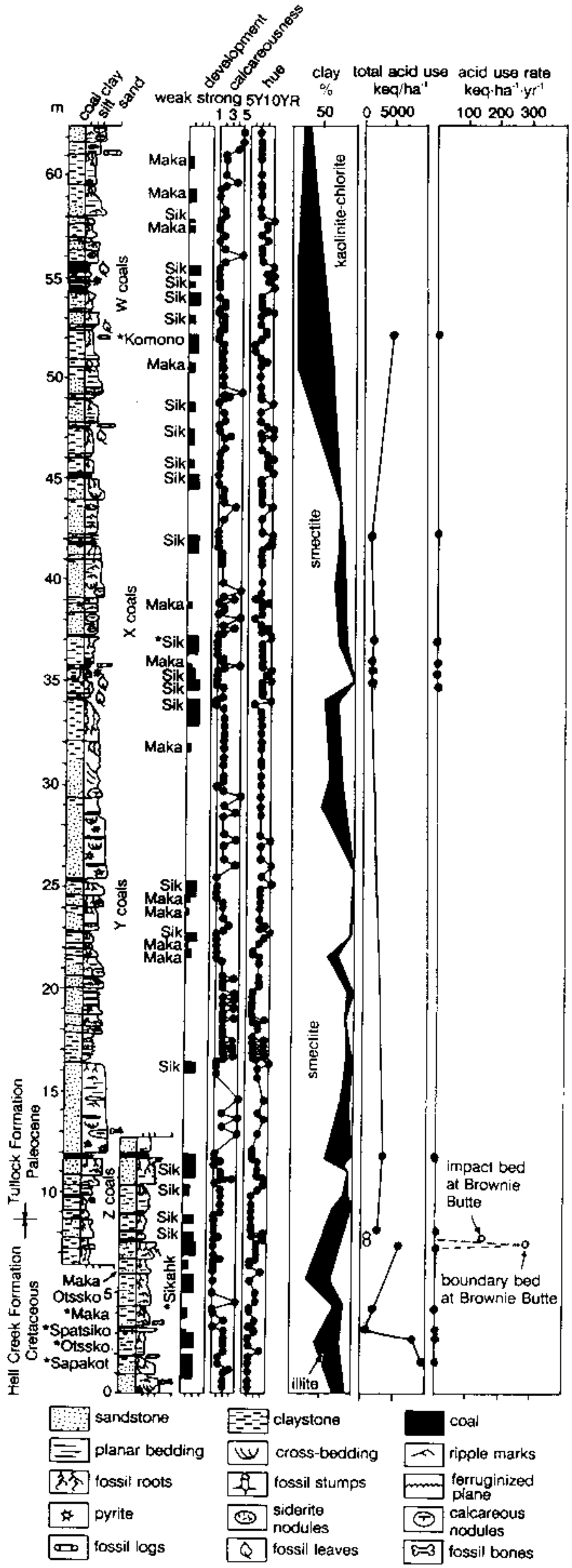

Figure 4. Measured section of paleosols and selected indices of weathering across the K-T boundary in cliffs and a low knoll north of Bug Creek (NW¼ NW¼ SE¼, sec. 17, T. 22 N., R. 43 E., McCone County), Montana. Black boxes indicate positions of the paleosols; lengths of boxes correspond to degree of development (Retallack, 1990). The calcareousness scale is for field reaction with 1.2M HCl (Retallack, 1990), hue data are from Munsell charts, and clay mineral data are by X-ray diffraction (Bell, 1965). The impact bed and boundary claystone (open circles) were not preserved in Bug Creek, but are known from Brownie Butte, Montana. Their acid use is plotted assuming derivation from Chicxulub melt, but calculated use varies with other assumed parent materials (Table 1).

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BIOTIC EFFECTS

The amount of NO_2 produced by the bolide at the K-T boundary has been estimated at globally averaged atmospheric concentrations of about 0.5 ppm V (Lewis et al., 1982) or 21 μmol/m^3. A comparable amount of SO_2 is known to injure leaves directly (Whitmore, 1985; Howells, 1990). Doses near the source would have been much higher than this globally mixed average. The high-temperature acid vapor and melt ejecta proposed by Alvarez et al. (1995) would have been particularly lethal, its effects tapering off with distance from the impact.

In Montana, reconstructed at 3330 km from the Chicxulub crater (Kring, 1995), noxious gases, acid, and warm leached ejecta raining out to a 2 cm layer would still have had a significant effect on large plants and animals. Scalding by later cool acid rain, darkening of the sky by dust, chilling of the atmosphere by dust shielding, and then warming by a greenhouse effect (Prinn and Fegley, 1987; Zahnle, 1990) would thus have been additional insults to a biota already traumatized by acidic fluids and ejecta. Acidic trauma may explain the transition in Montana from eutrophic angiosperm-dominated semievergreen forests to a fern-dominated recovery flora and then to oligotrophic conifer-dominated swampland (Wolfe and Upchurch, 1987; Nichols et al., 1990; Johnson and Hickey, 1990), and from herbivorous to insectivorous vertebrates (Sheehan and Fastovsky, 1992).

Even within a single area such as Montana, different organisms fared differently across the K-T boundary. The aquatic molluscs were severely affected (Morris, 1990), but amphibians and fish were little affected (Archibald and Bryant, 1990; Weil, 1994). Molluscs would have been excluded by pH less than 5.5, but greater losses of fish and amphibians would have been expected at pH less than 4 (Howells, 1990; Weil, 1994). Acid buffering by calcareous smectitic soils may have been important to the survival of small birds, mammals, reptiles, amphibians, and fish. Similarly, oceanic mixing and buffering may have diluted acid to no less than pH 7.6, so that many of the ammonites and coccolithophores died, but other molluscs, radiolarians, and acid-sensitive dinoflagellates survived (d'Hondt et al., 1994). Biotic effects of acid rain would have been more severe in less well buffered soils of humid granitic terrains and in shallow seas receiving runoff from such regions. Thus, impact-generated acid could have been a selective kill mechanism from place to place, and within the same ecosystem, if buffered to reasonable levels by wide dispersal and reaction with ejecta, soils, and the ocean.

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APPENDIX 1. FORMULAE FOR CALCULATING ACID CONSUMPTION OF SOILS AND PALEOSOLS

$$B = 2\rho(0.01783C + 0.02481M + 0.01062K + 0.01613N)/100$$

$$T_i = [(D_i + D_{i-1}) - (D_i + D_{i+1})]/2$$

$$A = \Sigma\, T_i(B_p - B_i)$$

Symbols:
- A = acid consumption of profile (eq/cm^2)
- B = base content of sample (eq/cm^3)
- C, M, K, N = CaO, MgO, K_2O, Na_2O, respectively (wt%)
- D = depth to sample (cm)
- T = thickness represented by sample (cm)
- ρ = bulk density (g/cm^3)

Subscripts:
- i = for sample i
- i + 1 = for sample or surface above i
- i – 1 = for sample or parent material below i
- p = for parent material

Constants:
- 0.01738,0.02481, 0.01062,0.01613 = element in oxide (mole)
- 2 = equivalence adjustment
- 100 = weight percent adjustment

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In Memoriam

Dan Davis
Honolulu, Hawaii
October 30, 1995

Peter Dehlinger
Issaquah, Washington
June 1994

Robert W. Fields
Columbia Falls, Montana
August 23, 1995

Hugo Greiner
Tübingen, Germany

Ihsan Ketin
Istanbul, Turkey
October 16, 1995

Irving Neder
South Pasadena, California
January 2, 1996

Eugene Simpson
Tucson, Arizona

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

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FORUM

Bruce F. Molnia

Forum is a regular feature of *GSA Today* in which many sides of an issue or question of interest to the geological community are explored. Selection of future Forum topics and participants is the responsibility of the Forum Editor. Suggestions for future Forum topics are welcome and should be sent to: Bruce F. Molnia, Forum Editor, U.S. Geological Survey, 917 National Center, Reston, VA 22092, (703) 648-4120, fax 703-648-4227, E-mail: bmolnia@usgs.gov.

Modeling Geology— The Ideal World vs. the Real World

PERSPECTIVE 1:
Introduction

Bruce F. Molnia, Forum Editor

Hundreds of years ago, the science of geology was founded on real-world observations. Over the centuries, as the science has matured, it has continued this tradition and maintained this practical grounding in the real world of Earth's natural experiences. The reverence for and importance of field work is but one manifestation of this tradition. Models seek to explain the phenomena of the real world by postulating an ideal world. With models, things can be presented quantitatively or at least with logical clarity to distinguish truth from falsehood and to predict future phenomena. These desirable goals are very difficult to achieve in the real world, with its uncontrolled complexities.

For the past decade, spectacular advances in computer technology have provided unprecedented opportunities to model Earth processes. The models can be produced so quickly and with such complexity that they easily outstrip any practical ability to check the reality of the results. It is important for students and professionals alike to recognize the significance of this limitation. Students can become enraptured with the ease with which these models can generate apparent problem solutions. For that matter, so can professionals. The profession needs to be careful that students don't neglect developing the field experience necessary to explore the real world. Over all else, it also must be careful to ensure that the proper balance continues between real-world observations and increased computer solutions to geological problems.

The three Perspectives that follow present examples of the real world versus the ideal world from the beach-behavior-, ground-water-, and Earth-system-science disciplines. The general message these Perspectives convey is applicable to all of the earth sciences.

PERSPECTIVE 2:
Modeling Global Change: Why Geologists Should Not Let "System" Come Between Earth and Science

Victor Baker, University of Arizona, Tucson, AZ

It was 30 years ago that the Austrian biochemist Ludwig von Bertalanffy observed that model building had become "a fashionable and generously supported indoor sport." Von Bertalanffy was an eloquent advocate of the systems thinking that facilitates the human construction of mathematical models. This thinking has now entered a golden age, supported by the accelerating power and versatility of digital computing technology. Predictive computer modeling has revolutionized the ability of scientists and engineers to consolidate knowledge into convenient conceptual packages that can be used to simulate system behavior over the ranges of conditions presumed to operate in the real world. For those sciences that used to bear the label "natural history," including geology, ecology, and the physical geography of land, air, and water, this revolution conveys the promise of experimental rigor that was formerly limited to pure physics and chemistry. Nowhere is this promise better exemplified than in the "earth-system science" that is increasingly being advocated as a unifying theme for sciences of Earth. As boldly proclaimed by the 1993 National Research Council (NRC) report, *Solid-Earth Sciences and Society*: "The study of the whole earth system provides a research framework essential to the solution of global problems."

In a time of increasing public scrutiny of science, decreasing resources for the support of research, and the need to justify science for its short-term contributions to society, there is inevitable pressure for sciences to provide policy makers, regulators, and those responsible for public action with information upon which to base environmental decisions. The decision makers want their policies to be perceived by those impacted to be based on the certainty of "absolutely bullet-proof science." The rigor and exactitude of quantitative model predictions seem to fulfill this need. However, when the models project to conditions of immense environmental consequence and expense of remedial action, as in the case of the general circulation model (GCM) predictions of global warming, there is heightened emphasis placed on credibility of the model as a representation of the real world. Similar examples of pressure to justify model credibility can be elaborated in the areas of nuclear waste isolation and the prediction of natural disasters. Thus, one sees a convergence in which the enhanced ability to quantify system behavior for earth science is coinciding with an enhanced demand that science provide rapid solutions of maximum credibility, applicable to the vital concerns of a society that increasingly is at risk to environmental hazards.

Models are often defined as analogies or abstractions that are drawn in verbal, physical, logical, and/or mathematical terms for rationalizing the necessary structure, connections, and changes in a system. Two elements of the definition, abstraction and system, are so important that discussion must be deferred until some background has been developed. Instead, it must be noted at the outset that models comprise an absolutely essential component of scientific reasoning. The real world is far too complex for description alone to ever capture its essential workings. A scientifically useful model embodies abstracted components of reality's totality. These are the components that the model's inventor perceives to be important, and the ordered structure of these components is what is meant by the "system" that is modeled.

Modern computer models, such as the GCMs used for future climate prediction, have become so complex that they are often viewed by scientists and decision makers alike as entities in their own right, rather than as conceptual abstractions that exist only as part of a continuing process of scientific reasoning. The very power of such models and their ability to compel belief calls for increased attention to their role in the overall reasoning process. Indeed, there is increasing concern among

Symposium Will Focus on Continental Profiling

The 7th biennial International Symposium on Deep Seismic Profiling of the Continents will convene in Asilomar, California, September 16–20, 1996. Stanford University and the U.S. Geological Survey will cohost the conference; GSA will be a cosponsor. For information, contact Simon Klemperer, Dept. of Geophysics, Stanford University, Stanford, CA 94305-2215, (415)723-8214, E-mail: klemp@pangea.stanford.edu. ***The abstract deadline is June 1.***

Send Abstracts for the GSA Annual Meeting in Denver via the World Wide Web

Jim Clark, GSA Production and Marketing Manager

Starting May 1, abstracts for this year's GSA Annual Meeting in Denver can be sent to GSA via the World Wide Web (Web). At that time, our new electronic system for abstract submission will be available, to be used at first for annual meeting abstracts only. In development for more than a year, the system has been tested extensively. Note that you can only send abstracts to GSA via the Web or as paper copies via the U.S. mail. Abstracts may *not* be sent by ordinary E-mail.

For the present, this system will accept only abstracts containing pure ASCII content; no graphics, tables, symbols, Greek, superscripts, etc. may be included. If you must use any of that in your abstract, use the paper form for now. We hope to be able to include non-ASCII material in the future, but for most users the technology for that is not yet in place.

However, if your entire content—title, addresses, and abstract body—is pure ASCII and you have access to the Web, the new system will make life much easier by eliminating the more onerous tasks usually connected with preparation of paper forms: scrambling for blank forms; printing and reprinting, then cutting and pasting to fit boxes; making multiple copies to send; and often paying a heavy toll for express-service delivery to meet the deadline.

We recommend that you compose your abstract in your favorite word processor. When you have finished, "save" it as "text." This will convert your data into pure ASCII. Then copy and paste this into the appropriate fields of the GSA Web form. Complete the personal information on the form, and you'll be ready to send it. We've included instructions, pull-down lists, and helpful hints on the Web form to save you time and confusion. There's even an error checker to make certain you include all the information we must have.

The best part is that it takes only a few seconds to send an abstract, and even less to get feedback from GSA. There will be no more mystery about whether we received your submission. You'll receive an *immediate* confirmation of receipt from GSA, with an abstract number assigned, while you're still on the Web.

The new system will not yet replace the familiar paper version of GSA's abstract form. Rather, the two systems will operate in parallel for another year, or until it is clear that most authors prefer the electronic method. Paper forms already have been distributed for 1996, and still can be obtained from GSA's Abstracts Coordinator (E-mail: ncarlson@geosociety.org).

The success of this new system will determine whether, and how soon, it may be used for meetings of GSA Sections, as well. Watch this publication for further announcements.

some policy analysts and philosophically oriented scientists that the current trend to base policy on modeling predictions is not yielding better decision making, but rather is revealing the shortcomings of various models.

A well-established reasoning mode for the employment of quantitative modeling is engineering design. In this reasoning, one first establishes an artificial set of specified problem criteria. These problem criteria comprise a closed system within which judgment can be made of the model that is formulated to project a problem solution. Engineering includes the model construction, its testing against the criteria, and its modification sequentially until the design criteria are met. Moreover, the good engineer recognizes that a set of artificial design criteria (the "system") does not constitute the real world. Engineering models can only apply to those restricted parts of the world where one knows that the same criteria apply as in the original model formulation criteria. The famous engineering design failures of history rarely derived from mistakes in model formulation and testing. Rather, it is when design criteria do not capture real-world complexities that humankind experiences collapsed bridges, failed dams, and other such disasters.

Another well-established reasoning mode is that of science. Horace Freeland Judson, in his delightful book, *The Search for Solutions*, observes that in science, models comprise part of an upward spiral between analogic reasoning and the testing of that reasoning with scientific observations of the real world. In this reasoning spiral, models are rejected, modified, or transformed in the light of further reasoning and testing. At some point, a model may begin to abstract from raw data the facts that its inventor perceives to be fundamental and controlling, placing these in relation to each other in ways that were not previously understood, and thereby generating predictions of surprising new facts. The scientist might then be inclined to say that his or her model now has the qualities of a theory, but there is still a missing element. True theories bind diverse consequences together in such an elegant manner that they compel belief by the scientific community. Various laws of physics certainly have this quality, but geologists are a more contentious community in this regard; far fewer geological models have become true theory.

Note that, in engineering, models serve to resolve a problem only for the artificial closed system of design criteria. In science, models do not serve ultimately to resolve problems at all. Rather, they are useful conceptualizations that are fruitful of further productive scientific study. In both engineering and science, models are not products of indubitable certainty, but rather are fallible tools employed in the quest to achieve loftier goals: design solutions for engineering and new theories for science.

The study of global environmental change is dominated by a philosophy centered upon reducing the uncertainties associated with models. The study of geologic indicators of past climate is increasingly being viewed as though the goal of earth science is to establish model credibility by showing the ability of GCMs to simulate accurately changes that have occurred in the past. I emphasize that this is a philosophy, because one does not test a viewpoint. A viewpoint involves assumptions used by its holder without thinking about them. Instead of scientific testing, viewpoints must be evaluated by philosophical questioning. Given the established modes of engineering and scientific reasoning, described above, it is clear that the model-centered viewpoint of Earth-system science embodies a highly questionable hybridization of engineering and scientific reasoning. The engineering component employs predictive models to "solve" global problems. Unlike engineering, however, the models are not tested against artificial design criteria. As in science, the models are tested against the real world. But the real world is not the closed system that is required for the engineering design problem. It is true that we

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have provided a scientific-sounding name, “Earth system,” to this world, but this “system” that is presumed to be required between Earth and science is only an abstraction. Why is this abstraction needed? In the engineering problem one can believe in the model design, but not as applied for the whole world. The model only applies to the closed system of design criteria. In science one does not believe in the validity of models at all. Rather, in science it is the fruitfulness of models for further inquiry that counts. One establishes credibility for engineering, not for science. One tests model predictions against the real world for scientific reasoning, not to achieve solution to problems. One is led to the disturbing conclusion that the modeling philosophy of earth-system science is that of neither science nor engineering, but rather is a hybrid of selected aspects of both scientific and engineering reasoning, which conflict with (rather than complement) each other.

Of course, the above conclusion is surely controversial. There are reductionist philosophers (including many scientists) who hold that geology will eventually reduce to physics, the science that is most passionately devoted to abstraction. Physics, John Ziman notes in his book *Reliable Knowledge*, is “devoted to discovering, developing, and refining those aspects of reality that are amenable to mathematical analysis.” However, only a Pythagorean mystic would claim that such analysis is able to encompass the totality of reality. Yet, reductionism is part of a scientism that holds the public imagination that infallible Earth science is as possible as is the astronomical prediction of a solar eclipse. Physics achieves its predictive success because controlled experimentation provides for a system against which models of abstracted reality can be tested. Controlled experimentation comes very close to the closed system of engineering design criteria, in part because only the abstracted bits of nature are evaluated and modeled. The complex bits are ignored. In geology, unlike physics, one cannot ignore the complexity, and controlled experimentation is impossible. Models cannot be certified for engineering prediction. They can only be evaluated for productive, fruitful inquiry.

The claim that the philosophy of Earth-system science is not compatible with sound scientific or engineering reasoning in no way implies that scientific discoveries and environmental problem solutions will not derive from it. There is a long historical record of good science being done against the constraints of wrong-headed philosophy. However, there are very profound implications of this philosophy for the public credibility of science and its resulting support. Consider the ethical dilemma posed by the rigorous-appearing but experimentally flawed scientific argument that might be taken as a basis for policy and legal action. A well-known example concerns the risk associated with nuclear power plants. Rigorous scientific modeling showed that the probabilities of plant failure and radionuclide release to the environment are very small. It was also argued that failure consequences were not immensely large. The product of a moderately large consequence times near-zero probability yields a very small risk. However, failure consequence also depends on public perception of radionuclide release to the environment, and no controlled experiments were conducted (nor, arguably, can they be conducted) on public perception. Nuclear accidents at Three Mile Island and Chernobyl are reality, despite their improbability. Public perception of their consequences is immense, despite models to the contrary. The result is a general discrediting of nuclear technology, despite scientific evidence that its risks can now be immensely reduced and that its newer designs can provide tremendous environmental benefit in a “greenhouse world.”

In those predominant geological situations where controlled experimentation, in the manner of pure physics, is precluded by limited access to or control of natural processes, one must conclude that models cannot be verified in the strong sense that is required to constitute problem solution, as in design engineering. This conclusion is elaborated upon extensively by Oreskes and coauthors in a 1994 article in *Science*, (v. 263, p. 641–646). Allowing the public to believe that a problem can be resolved in the strong sense through elegantly formulated (but unverifiable) models is the moral equivalent of a lie. This “lie” may have the short-term benefit to science of financial support “to reduce uncertainties,” but, when the implied benefits to society do not accrue in a timely fashion, the long-term result may be detrimental to science. Happily, there are alternatives to the model-centered philosophy of documenting global change for policy action. Human perception, including that of nonscientists, is naturally attuned to the importance of problems reflected not in abstractions, but in real-world manifestations. These manifestations, reconstructed from the past, occupy the central concern of geologists and may well be the appropriate central concern for global-change science, at least to the extent that it aspires to generate wise public action.

The philosophical implications for the role of models in Earth-system science, and particularly for the policy-making aspirations of that science, may not be as dire as I have suggested here. Nevertheless, unless the question is asked and adequately resolved, we geologists run a grave risk. The short-term benefits of promised model predictions and uncertainty reduction may translate to long-term detriments of diminished quality of science and shattered public confidence in the promises of that science.

PERSPECTIVE 3:

Mathematical Modeling of Beach Behavior: An Impossible Task?

Orrin H. Pilkey, Duke University, Durham, NC

Mathematical models of beach processes fail as predictive tools for practical applications. Currently, the most important coastal management use of such models is the prediction of costs and required sand volumes of prospective replenished beaches. But we are no closer to predicting the 10 year behavior of a beach than we are to the prediction of 10 years of weather.

Mathematical modeling of shorelines, invented mostly by coastal engineers, with some help from physicists (and too little help from geologists and oceanographers), is spilling over into coastal geology. Some academic coastal geologists are swayed by the smoothing of rough edges and the simplification of complex systems afforded by models. Many coastal scientists, unfamiliar with the real details of beach-behavior models, fall into the trap of assuming that mathematics, sophistication, and modern geology are all synonymous. Consulting coastal geologists are more or less forced to use mathematical models in order to present their results in the same apparently sophisticated fashion as engineers. But such practitioners of the quantitative way would do well to consider the impossible geologic assumptions behind beach-behavior models.

What are the problems with models? The first type of problem with current beach behavior models is that they are deterministic, not probabilistic. Like so many earth-surface processes, randomly occurring and unpredictable extreme events are responsible for most nearshore shape changes. On beaches these extreme events are storms. Their occurrence must be recognized by some sort of uncertainty (e.g., error bars) in model results, especially for estimates of project cost. The counter-argument goes that the Congress or city councils can't handle cost estimates with error bars. That's a political problem, not a technical one. We should not produce definitive numbers we cannot defend and that in fact don't exist.

The second problem is that we don't clearly understand how sand is transported on the inner continental shelf and in the surf zone. In the real world, surf-zone processes are extremely complex, especially during storm conditions. Waves, currents, and wind all interact with the sea floor to move sand. Events such as sea-floor liquefaction at wave breakpoint and the well-documented presence of strong seaward-directed bottom currents (such as storm surge ebb, wind set-up currents and rip currents) are not even considered in most models and are not realistically characterized in any model. These currents are very poorly understood in nature and thus defy mathematical description. Even the amount of sand carried by the relatively well documented longshore current system is poorly known. We have no measurements of total longshore sand transport except by highly indirect means (e.g., accumulation behind jetties).

The third problem is that all beach modeling depends heavily upon a shoreface profile of equilibrium whose shape is assumed to depend entirely on sediment grain size. Yet no relationship has been demonstrated to exist between grain size and shoreface shape. Moreover, recent studies have demonstrated that shoreface shape and large-scale coastal evolution are often controlled by the underlying geologic framework of the shoreface. Most absurdly of all, the shoreface is assumed to be bounded by a shallow (4 to 10 m) closure depth, an imaginary sediment fence beyond which little on no sediment escapes in a seaward direction.

A fourth problem is model imperfections such as the use of averaged values (e.g., average wave height), the automatic assumption of linearity, and the use of constants (empirical coefficients) that are nothing more than "fudge factors" to come up with "reasonable" numbers. A 1995 NRC report notes that "the agreement between the measured shoreline and that computed by GENESIS [a widely used shoreline erosion model] was excellent. However, the result represents a calibration of the model that involved some adjustment of empirical coefficients to optimize the fit." Oreskes and others argue that the process of verification of models of earth-surface processes is an impossibility. The mathematical models of beach behavior also lack the means to evaluate error, because the processes being modeled are poorly understood.

Who's minding the store? If it is true that models fail to predict beach behavior for engineering or applied purposes, why isn't this failure perfectly obvious to the public? Certainly if a replenished beach costs more or requires more sand than predicted, this should be readily apparent. Ocean City, Maryland, for example, has in three years used one-third of the volume of sand predicted to be needed over 50 years. Such alarming model mispredictions, which are the norm for beach replenishment, are dismissed in several ways, including: (1) The beach was lost due to unusual or unexpected storms (during which a huge amount of property damage was prevented by the beach); and (2) the sand is just out of sight offshore and is still protecting property. The latter is an unimpressive argument for local politicians trying to lure tourists to their beaches.

The modeling community does recognize that there are fundamental problems with the assumptions behind mathematical models. But it is only a token recognition. A careful reading of the large 1989 U.S. Army Corps of Engineers manual describing GENESIS reveals a long list of devastating model weaknesses scattered throughout the document (including the fact that GENESIS doesn't take into account storms!). It would seem

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Mile-High GSA Chorale and Concert at 1996 Annual Meeting

Following upon the tradition of musical excellence exhibited at the GSA annual meetings in Denver (1988—Centennial Orchestra) and Boston (1993—Bravo Boston Chorale), GSA will offer a performance of John Rutter's moving Requiem at the annual meeting this fall, again in Denver, on Tuesday, October 29. Thus, musical geologists will again have the opportunity to perform together in the Mile High City. We anticipate that the performance will take place in St. John's Cathedral, a major venue for vocal performances and easily accessible from the central downtown area.

Those wishing to sing with the Denver Mile-High GSA Chorale should contact Carla Montgomery, Geology Department, Northern Illinois University, 312 Davis, DeKalb, IL 60115, (815) 753-9402. You must be an active, accomplished singer who reads music. Spouses and guests with comparable talent are also welcome.

In addition, we seek instrumentalists or vocalists among the GSA family who are interested in performing pieces that would complement the chorale program either as solos or accompanied by the supporting ensemble. If you are interested in such an opportunity, please contact Greg Bush, Mile-High GSA Chorale Conductor, (303) 592-1714 (mornings), or (303) 670-2349 (home office).

Consider joining us for what promises to be another "evening not to be missed" at the Denver GSA meeting. The Centennial Orchestra sold out and the Boston Chorale was well attended, so advise your friends and colleagues that a ticket purchase with meeting preregistration will assure a seat. Don't miss this mile-high exciting event!

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that a prudent modeler wouldn't touch the model with a 10 foot (3.3 m) pole. But the authors ignore their own admonitions! Again and again in the beach-modeling literature, we see model weaknesses pointed out as though acknowledging their existence was an adequate response. Somehow a different standard for scientific truth and validity is accepted for a principle tucked away as a subroutine in a beach-behavior model than would be accepted for the same assumption if evaluated singly and in isolation.

Criticism of modeling is usually not well received by modelers; a constructive dialogue between model developers and critics is missing. Resistance to objective oversight is stiff, perhaps in part because it is a highly sensitive bread-and-butter issue. Critical review of models of earth surface processes can be difficult to publish. A common reviewer's response is that "we are already aware of these problems." My coworkers and I have recently published several papers criticizing coastal models, pointing out what are clearly problems fatal to their application. So far we haven't found anyone who disagrees with our criticisms. We also believe that we have had close to zero impact on the use of models. Common responses to our criticisms include the "don't throw the baby out with the bath water" argument or "this is the best model we have, and until something better comes by we should use it."

There are alternatives to models in replenished beach design. For example, estimates of cost and sand volumes could be based on experience with neighboring replenished beaches. While not perfect, this approach would be far more accurate than the current one. Even Dutch coastal engineers, strong advocates of models, do not use them to design beaches. Instead they predict replenished beach behavior by observing the behavior of the natural beach in question for a few years and assuming the newly pumped-in beach will behave something like its natural predecessor.

In my view, mathematical modeling of beaches is in a far worse state than the modeling of fluvial systems or the modeling of ground-water movement. We know that ground water flows downhill or in response to a head, and we know how sand is picked up and transported by a unidirectional current. But at this point in time we don't even understand the basic mechanisms of sand transport in the surf zone (especially during storms), and we don't have ways to measure total sand transport in the surf zone. As yet we have neither a physical nor empirical basis for mathematical models of beach behavior.

Predictive earth-surface-process modeling in a time frame of use to humankind may well be an impossibility. In many cases, as in beach behavior, modeling such processes at our current state of knowledge may be a useless academic exercise as well. The time has come for applied beach-process modelers to take stock of reality, to closely evaluate their assumptions, and to look back at the results of their predictions.

PERSPECTIVE 4:
Ground-water Modeling: The Digital Back of the Envelope

Stuart Rojstaczer, Duke University, Durham, NC

Most of the ground-water hydrology community is currently spending a majority of its time assessing and predicting the fate of contaminants in the subsurface. This effort ranges from fundamental understanding of the processes controlling contaminant transport to site-specific studies of contaminant migration and the design of clean-up strategies. Regardless of the scope of a ground-water study, ground-water modeling will generally be used. In purely theoretical studies or conceptual studies of generic aquifers, ground-water modeling will often be the primary tool of investigation. This computer-based approach is warranted because these efforts have a strong mathematical basis and frequently require the solution of differential equations that can only be solved computationally. The use of ground-water modeling to examine site-specific cases of ground-water contamination is also at least partially warranted. Ground-water modeling at specific sites allows for a partial test of conceptual models of the site-specific geologic and hydrologic controls on the migration of contaminants.

In site-specific investigations, ground-water models have several major alluring characteristics. They are cheap to use, and they deliver a quantitative result. Increasingly, they are also easy to use, and through the use of sophisticated computer graphics and animation, their results can be presented in a visually captivating manner. Ground-water models of both flow and transport are relatively inexpensive (several hundred dollars for commercial software; negligible cost for government-derived models) and can be used again and again without incurring additional cost. The computers and computer time necessary to run this software are relatively modest, except for a few highly sophisticated computer models that incorporate complex chemical reactions or multiphase aspects of flow. In essence, the requirements for ground-water modeling, irrespective of any data collection, are a personal computer and the electricity to run it. More than 100 million Americans have relatively easy access to the computational requirements necessary for most ground-water modeling. So in theory, we have the capability to have more than 100 million ground-water modelers.

Most of the major ground-water modeling software has been in existence for a long period of time, so problems associated with computer programming errors are generally absent. Hence, the quantitative results derived by one piece of software and one computer can generally be expected to be the same as quantitative results derived by another piece of similar software and another computer. Ground-water models, in terms of their computational reliability, are not quite in the same class as spreadsheets, but they can generally deliver highly repeatable results. This computational reliability and repeatability are often mistaken as an indication of the quality of real-world model results. Nothing could be further from the truth.

In real-world assessment, one goal is to understand in a qualitative sense the influence of site-specific geology and hydrology on ground-water flow. I emphasize that our understanding can never be expected to be more than qualitative in nature, because real-world geology and hydrology are generally far too complex to quantify in detail. We may understand the physics and chemistry of ground-water flow and transport very well and may be able to write ground-water models that accurately and efficiently incorporate our current theoretical knowledge. However, while our models generally have a sound basis, events in the real world are beyond any current and likely future data-collection capability. For example, our knowledge of permeability at a real site is generally a volume-averaged quantity at a scale far larger than the scale necessary to use for accurate prediction of contaminant transport and at a spatial resolution orders of magnitude too coarse. Thus, while we can use ground-water models to help us understand ground-water flow at a given site, our degree of understanding can never be expected to be quantitatively precise. Despite the quantitative basis of these models, we can use them only as a means to make qualitative inferences.

Increasingly, we are also asked to make predictions of future ground-water flow and transport. In a strict sense, accurate predictions of ground-water flow over time are not possible. There are so many external influences on ground-water flow and transport whose future cannot be predicted—recharge and future human influences being two—that even if we could accurately characterize the subsurface in excruciating detail, we could never predict future behavior. We can, however, make assumptions about those external influences. We can run a variety of likely scenarios based upon our knowledge of the history of these external influences and get a qualitative feel for future behavior. In doing so, we are assuming that the future external influences will be similar to those in the past and that our very

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1996–1997 Section Officers And Past Chairs

GSA has six regional North American sections, generally including GSA members who live within the geographical limits of each section. (Members who live in one section but have professional interest in another section can declare membership in the section of interest rather than their geographical section.) Each section holds annual technical and business meetings. The number of voting members shown for each section is as of December 31, 1995.

CORDILLERAN Voting members: 3892
Geographic area: Alaska, Arizona south of lat 35°N, California, Hawaii, Nevada, Oregon, Washington, British Columbia, Yukon and Northwest Territories.
Officers: J. Casey Moore, Chair (pending election); To be elected, Vice-Chair; Bruce A. Blackerby, Secretary; Catherine J. Hickson, Past Chair

ROCKY MOUNTAIN Voting members: 1888
Geographic area: Arizona north of lat 35°N, Colorado, Idaho, Montana, New Mexico, North Dakota, South Dakota, Utah, Wyoming, Alberta, Saskatchewan.
Officers: Nancy J. McMillan, Chair; Timothy F. Lawton, Vice-Chair; Kenneth E. Kolm, Secretary; Colin J. Paterson, Past Chair; Perry H. Rahn, Past Vice-Chair

NORTH-CENTRAL Voting members: 1421
Geographic area: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, Wisconsin, Manitoba, Ontario west of 89th meridian.
Officers: Thomas J. Evans, Chair; Alexander Zaporozec, Vice-Chair; George R. Hallberg, Secretary; Carl F. Vondra, Past Chair; Paul G. Spry, Past Vice-Chair

SOUTH-CENTRAL Voting members: 1235
Geographic area: Arkansas, Kansas, Oklahoma, Texas.
Officers: Mark Cloos, Chair; Elizabeth Y. Anthony, Vice-Chair; Rena M. Bonem, Secretary-Treasurer; Page C. Twiss, Past Chair

NORTHEASTERN Voting members: 2297
Geographic area: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, New Brunswick, Newfoundland, Nova Scotia, Prince Edward Island, Quebec, Ontario east of the 89th meridian.
Officers: Susan D. Halsey, Chair; John C. Boothroyd, Vice-Chair; Kenneth N. Weaver, Secretary-Treasurer; Barry L. Doolan, Past Chair

SOUTHEASTERN Voting members: 1660
Geographic area: Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia.
Officers: Robert Whisonant, Chair; Mark Steltenpohl, Vice-Chair; Harold H. Stowell, Secretary-Treasurer; P. Geoffrey Feiss, Past Chair

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simplified depiction of the real world contained in our ground-water model is good enough to provide us with a predictive tool. Both assumptions are poor, and so we can expect that our predictions will be poor. They are, at best, very qualitative predictors. They provide us with a knowledge of problems that may occur in the future. But even then, the knowledge we have is flawed. Depending upon ground-water models to accurately predict future contaminant transport defies all logic.

Most ground-water scientists are fully aware of the limitations of using ground-water models. Yet, many continue to use them as if they were an accurate depiction of the real world, capable of making accurate predictions. Worse yet, they are sometimes being sold as a means of assessing real-world ground-water problems cheaply and effectively, without the expense of time-consuming data collection. These computer-generated visions of the real world are often so beautifully presented that they are being sold as if they were the real world. We seem to be undergoing a trend where our results are so visually beautiful that we substitute that beauty for accurate depiction.

Why do we continue to sell ground-water models as accurate tools for assessment and prediction? Partly, we may do so in the interests of financial gain, but it is also true that the public at large (government agencies, corporations, etc.) needs quantitative results for legislation and legal issues. For example, in order to store high-level radioactive waste in Nevada, we need to set some quantitative standards for site performance. It is not good enough to say that the site "looks fairly safe" or "looks largely unsuitable." Statements like these may be an honest assessment of our ability to predict, but they inadequately address a regulator's needs. Instead, the regulatory world requires quantitative predictions to examine whether they meet quantitative standards for site performance. In the case of high-level radioactive waste, we must make an effort to predict the behavior of ground water at Yucca Mountain, Nevada, for the next 10,000 years. Our efforts in such endeavors are probably not unlike those of economists predicting a nation's economic future for the next decade. Economic predictions over such a long time span are bound to contain poor assumptions and a great deal of error, but economists still produce them because someone needs them for planning purposes. Our need to manage our hazardous waste requires us to use quantitative tools in a manner that is unsuitable.

We predict the future with models because we need predictions, no matter how poor these predictions will be a priori. In ground water, we use models because we assume that predictions based upon our knowledge of physics and chemistry and admittedly inadequate data are better than predictions that don't incorporate data or don't incorporate physics and chemistry. This assumption is probably a good one, but it is really an inappropriate comparison. We need to compare our ability to predict with the capability necessary for our predictions to be truly useful to society and not simply to provide any kind of a number to those who make policy and legal decisions. We need to inform legislators and lawyers that we cannot provide them with accurate assessment and prediction. We can provide them with qualitative assessment. If legislators and lawyers need quantitative predictions, then they need to rethink their needs.

What is the worth of ground-water modeling in assessment? At its core, ground-water modeling is a sophisticated way of obtaining a back-of-the-envelope result, and like such a calculation, modeling results require the use of many assumptions and simplifications. Also, the numbers we obtain from such an effort are, at best, order of magnitude estimates. I suggest that rather than presenting elaborate graphs and computer-generated videos of our modeling results, we instead present them to interested parties in a manner commensurate with their value. We may use the most expensive computer in the world and write the most elaborate computer code in our work, but perhaps we should present our results by transcribing them onto the back of an envelope. This suggestion is obviously tongue in cheek, but I hope it serves to make the point that the results of modeling have a very modest, but useful, value. We need to find a way to show our results in a way that does not obscure their humble origins.

We should also present our interested parties with maps showing the measurements by which the modeling was constrained. We should point out that our results are based upon measurements that sample only a tiny fraction of the area of interest, and that many key parameters

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weren't measured anywhere but that "reasonable guesses" were made. We should emphasize that we cannot possibly incorporate all of the complexity necessary for accurate assessment.

Predicting the future of any endeavor is always a dicey business, but I will make a few qualitative predictions concerning the field of applied ground-water modeling. Our models will become increasingly easier to use. They will run on much faster computers, and the computer programs upon which our results will be based will incorporate more complex biology, chemistry, and physics. The visualization of the modeling results will be much more alluring. More people will incorporate ground-water models into their studies. Our real-world models will be better, but they will still have at least one major shortcoming. We still will not have the appropriate data to incorporate into these models to make accurate predictions of ground-water flow and associated contaminant fate and transport.

These predictions, which are simply based upon extrapolating the recent history of ground-water modeling, are not all that alarming. There is still an increasing role for ground-water modeling in such a future scenario. Ground-water models will continue to provide us with a means of gaining increased understanding of ground-water flow at a particular site. However, the degree of understanding we obtain can generally be expected to fall significantly short of that necessary for prediction. The credibility of the ground-water community depends upon us confining applied ground-water modeling to the realm of a tool that helps in the development of a simplified understanding of the real world. It is not nor will it likely be a useful tool to accurately predict the future. ■

GSAF UPDATE

Robert L. Fuchs

A Second Century Fund Primer for Members

Have you been asked to make a pledge to the Second Century Fund membership campaign? Have you received literature, phone calls, and personal notes asking for a contribution? Are you wondering what it's all about? Herewith, a fact sheet that can help you survive the onslaught and make a considered decision that will best benefit you and GSA.

- The goal of the Second Century Fund for Earth • Education • Environment is to increase the financial strength of GSA by $10 million, from a variety of sources—industry, foundations, government, major individual donors, employees, and the GSA membership. The Foundation has been successful in raising over $4 million since late 1992. The funds committed to date fall into three categories—endowment funds, program funds to support science, education, and outreach activities, and capital for bricks, mortar, and equipment.
- The Second Century Fund is the first widespread capital campaign ever conducted by GSA. A successful campaign in the early 1980s, for the Decade of North American Geology, was principally directed toward industry. The Foundation conducts annual campaigns which have been regularly supported by members for many years.
- The reason for the Second Century Fund is that GSA today is a much different organization from what it was 15 or 20 years ago. Membership has grown by 50% and there are strong education and public outreach programs, such as SAGE and IEE. These are in addition to publications, meetings, and research grants, which have also grown substantially.
- Only 60%–65% of GSA's expenditures each year are paid for by member dues, meeting fees, and publication sales. The remaining money comes from investment income, contributions, and grants. Another way to say this is that members benefit from an additional $1 for every $2 they pay. Contributions either to programs or the endowment are vital to keeping the Society operating at the level and in the types of activities expected by the membership. The addition of new education and public outreach programs in the nineties has only reemphasized the need for this outside money.
- GSA's track record over 108 years is exemplary. Six thousand students have received research grants totaling $6 million. Recent annual meeting attendance has been in the range of 5000 to 6000, and 2000 to 2500 papers are presented each year. The 1996 annual meeting in

Donors to the Foundation, February 1996

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*Century Plus Roster (gifts of $150 or more)

Denver will be the 109th. More than 1200 partners are engaged in K–12 partnering programs. Geologists have received media training in order to be better prepared to deal with the press on matters of public interest. Since 1969 GSA has conducted 121 Penrose Conferences dealing with a myriad of current geological topics and problems. The Decade of North American Geology, with its 34 volumes plus maps and transects, has proven to be a major scientific and educational resource. In recent years GSA has published an average of 11,000 pages of science per year. More and more aspects of GSA's publications and programs are appearing on the Internet. Additional outreach activities in the planning stages include a center for advanced technological education, a GSA rock park, cooperative education with the U.S. National Park Service, and workshops on mine drainage and the USGS/NBS consolidation.

- GSA's six Sections are an important part of the organization, particularly because of their emphasis on students and education. Section meetings each year draw 3000 to 4000 attendees. These meetings provide an accessible forum for student presentations. The Sections are active in supporting students, through field trips, awards, and grants. In conjunction with the GSA Foundation, during the past eight years the Sections have paid $210,000 to 1400 students in the form of travel grants to GSA annual and Section meetings.
- The Second Century Fund membership campaign is being conducted by the six GSA Sections. The goal for the membership campaign is $1.5 million, or 15% of the total goal for the fund. Each Section has an individual goal, derived from the number of members in the Section. There is a Second Century Fund team in each Section, headed by a chair and including area coordinators and workers. GSA members who wish to assist the Section teams should contact the Foundation office.
- There are significant benefits for the Sections from the membership campaign. From every unrestricted gift, 20% will go to the Section's endowment fund at the Foundation. In addition, members may specify their entire gift for the Section endowment. Once a Section has reached its goal, 50% of all subsequent unrestricted gifts will go to the Section endowment. The income from Section endowments will be used for student support—travel grants for meetings, research, field camps, undergraduate programs, awards, and similar activities that benefit the education and field training of earth science students.
- A principal objective of the membership campaign is participation by as many members as possible. When outside contributors consider granting money to GSA, there is one question that is invariably asked, "What are members doing for themselves?" A large number of donors from the membership will enable us to give a positive answer to that question.
- Contributors may give at any level with which they feel personally comfortable. A pledge over a period of up to five years is the recommended form of gift. While any size gift is welcome, to reach Section goals a pledge of at least $50 per year for five years is suggested. Of course, $250 or any other gift can be paid in one lump sum, but for many members, stretching this out over several years is an easier way. Payment can be by check, credit card, appreciated securities, personal property, or even real property. All members contributing $250 or more will be eligible for a drawing at the 1996 annual meeting in Denver, a GeoVenture trip courtesy of GSA and the Foundation.
- Many employers provide matching gifts. Please bring this information, if applicable, to the attention of the Foundation staff when making your gift.
- There are many other ways of taking part in the membership campaign. The Foundation offers several planned gift opportunities, such as the Pooled Income Fund. These can be particularly attractive in planning for retirement income. The Foundation staff can provide a complete list of planned gifts along with details about participation.
- If GSA is asking you to contribute to the Second Century Fund, what has GSA done for you as a member and a scientist to deserve this support? The answer can be found in many places—a student research grant, a Penrose conference, a published paper, professional contacts at annual or Section meetings, field trips for science and pleasure, employment, help networking, a short course, media training, peer recognition, an appreciative fourth grade science teacher, part of your personal career record. For some people, there have been major personal turning points at which GSA played a key role. Think about your own personal history as you think about the Second Century Fund.

We hope that your questions about GSA and the Second Century Fund have been answered by the preceding fact sheet. If not, a call to the GSA Foundation, a Councilor, a GSA officer, or a Section officer should produce the answer. Think of GSA as more than a scientific society. It is a charitable organization like a university, church, or arts group, deriving one-third of its financial support from contributions. GSA deserves and needs your support in the same manner that you support other charitable organizations. ■

GEO STAR
Supporting The Advancement of Research

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☐ Enclosed is my contribution in the amount of $_________ for:
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☐ I am interested in helping my Section reach its Second Century Fund goal by working on the Committee. Please ask the Section SCF Chair to contact me.

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Edward E. Geary, Educational Programs Coordinator

GSA Educational Programs 1995–1996

Partnerships, Science Education Standards, New Technologies, Equity, and Public Outreach

The **Science Awareness through Geoscience Education** (SAGE) program represents the Geological Society of America's commitment to help improve scientific understanding for all citizens and to create a greater appreciation of Earth's resources, processes, and history. To achieve these objectives, the SAGE program has developed K–16 educational initiatives in the areas of partnering, teacher enhancement, teacher and student awards, educational materials, networking, and information dissemination. In addition, SAGE has developed numerous collaborative efforts with other scientific and education organizations to help implement the National Science Education Standards, to promote the development of new earth science curriculum and career materials, and to explore effective uses of computer-based technologies in K–12, undergraduate, and graduate geoscience education.

1995 HIGHLIGHTS

Programs

During 1995, the first year of a three-year funding commitment to the **Partners for Education Program** (PEP) by supporters outside GSA, PEP efforts were concentrated on increasing communication with and among PEP members and creating a framework for future PEP initiatives. During this period PEP grew from approximately 780 to more than 1100 members. In 1996, in addition to maintaining communication, emphasis is on developing supportive products and services for PEP members and establishing a firm funding base for future years. We are also strengthening collaborations with other scientific, educational, and public organizations to increase the impact of educator-scientist partnerships.

In September 1995, GSA received funding from the National Science Foundation to support the **Geological Education Through Intelligent Tutors** (GET-IT) project. During the next three years GSA, in collaboration with Cambrian Systems Incorporated, will develop an integrated, interactive, multimedia, computer-based geoscience curriculum for middle schools. GET-IT modules will provide students with real data and data analysis tools to explore the world around them, to think critically, and to solve real problems.

On February 1, 1996, GSA submitted a proposal to the National Science Foundation for the **Earth and Space Science Technological Education Project** (ESSTEP). This project is designed to unite undergraduate faculty from two- and four-year institutions and secondary faculty with professional societies, businesses, and government agencies in a partnership to provide faculty in grades 8 through 14 with: (1) hands-on experience in state-of-the-art data acquisition, manipulation, and presentation technologies for the earth and space sciences, (2) innovative strategies for using technology in classrooms and laboratories, (3) internship opportunities in earth and space science technology fields, and (4) improved access to a wide variety of technology-based education resources.

Meetings and Workshops

The K–16 Education Program at the **GSA annual meeting in New Orleans** was outstanding in both the variety of offerings and the quality of presentations. Workshops covered the solar system, the atmosphere, earthquakes, rocks and minerals, grant writing, and effective teaching. Educational symposia and theme sessions ranged from "Assessing Teaching and Learning" to "Environmental Geosciences Across the Curriculum" to "Making Connections: Ties Between K–12 and University Education." The field trips "Geology of New Orleans" and "Urban Stormwater in New Orleans" proved to be popular. The third Earth Science Share-a-thon featured a dozen presenters and, coupled with the first GSA-NESTA Rock Raffle, attracted hundreds of curious scientists, students, and teachers. Several workshops and field trips for K–16 educators and scientists were also held at GSA's 1995 section meetings, at state science teacher meetings, and in some school districts. In 1996, in addition to the normal education workshops, we will conduct multidisciplinary workshops, based on national and state Science Education Standards, for teachers, administrators, and scientists.

In December 1995, GSA, with support from the Amoco Foundation, convened the **Minority Access and Participation** (MAP) **Planning Meeting.** This meeting brought together representatives of several scientific, educational, and minority organizations to develop a strategic plan for working more effectively with underserved students, teachers, and parents. From these discussions several points emerged:

- We (the earth science community) need to be able to articulate what we have to offer to underserved individuals, organizations, and communities.
- We need to look at problems in different ways. Different communities have different needs, and the "one size fits all" model is not adequate to address these different needs.
- We need to recognize that the impetus for participation must come primarily from the populations and cultures we wish to work with, not from our own community. Our focus should be on learning about and responding to the needs and interests of these different groups, not promoting our own agenda.

Action is now being taken on several of these points.

Collaborative Efforts

SAGE has been and continues to be very active in collaborative efforts with other organizations. Among the 1995 SAGE collaborations were:

- Representation on the advisory committees for the Coalition for Earth Science Education (CESE), the Denver Earth Science Project (DESP), and the American Geological Institute (AGI);
- Participation in "Professional Career Pathways in the Geosciences," a careers project coordinated by AGI

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The Coalition for Earth Science Education
Announces

Geo Sci Ed II

Second International Conference on Geoscience Education

July 28-August 1, 1997
University of Hawai'i at Hilo

LEARNING ABOUT THE EARTH AS A SYSTEM

This conference follows on the success of the first international conference in Southampton, England in 1993. The Conference focus on Earth System Science is further explored through conference subthemes: Earth Science Education for All; Role of Business, Industry, and Government agencies in Education; The Need for Public Literacy in the Earth Sciences.

For information contact:
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American Geophysical Union
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SAGE Remarks *continued from p. 16*

and supported by the Alfred P. Sloan Foundation;
- Working with CONNECT, the Colorado Statewide Systemic Initiative in mathematics and science, and members of CESE to support standards-based science education reform;
- Financial support of the National Association of Geology Teachers Outstanding Earth Science Teachers;
- Organization of two meetings of the Colorado Earth and Space Science Education Network;
- Participation in the American Geophysical Union's teacher education programs in San Francisco;
- Working with the Space Science Institute and the University of Colorado at Boulder to develop the Center for Advanced Technological Education in Earth, Space, and Environmental Science;
- Working with the Coalition for Earth Science Education steering committee to plan the Second International Geoscience Education Conference scheduled for July 28–August 1, 1997, in Hilo, Hawaii.

Information Dissemination

During 1995 SAGE handled 1248 requests for information from students, teachers, scientists, and organizations on topics ranging from earthquakes, crystals, and National Science Education Standards, to careers, internship opportunities, and awards. With financial support from the Department of Energy, GSA also began work on a plate tectonics resource packet for secondary school teachers. Finally, with the help of numerous science teachers and Colorado-based organizations, SAGE also published "Earth and Space Science Education Resources in Colorado: A Directory and Field Trip Guide for K–16 Educators."

1996 DIRECTIONS

In the second half of 1996, SAGE will continue to focus its attention and energy on the integration of earth science research, education, and technology in K–16 classrooms and on the development of a dynamic education program for the GSA annual meeting in Denver, Colorado. We will also strengthen communications, services, and opportunities for all Partners for Education, act collaboratively to promote standards-based earth science education for all students, and begin development of a pilot program with the National Park Service to enhance public understanding and appreciation of Earth's natural features, processes, and history.

If you would like to learn more about SAGE programs, please contact Ed Geary, Barb Mieras, Vicki Harsh, or Beth Klocek at GSA headquarters, (303) 447-2020, fax 303-447-1133, E-mail: egeary@geosociety.org. ■

Penrose Conference Report

The Tectonic Development of the Canada Basin and Surrounding Basins

Conveners
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Shiri Srivastava, *Geological Survey of Canada, Dartmouth, Nova Scotia, E-mail: srivasta@agcrr.bio.ns.ca*
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The tectonic origins of the Canada Basin of the Arctic Ocean have long been a puzzle. The literature is replete with models for its origins, and they encompass all possible modes from trapped ocean basins, ranging in age from Proterozoic to Tertiary, through all possible directions of internal sea-floor spreading. If a vote had been taken at the start of this Penrose Conference (Banff, Alberta, September 28–October 3, 1995), models involving a rotation of Arctic Alaska away from the Canadian Arctic Islands would probably have won, but not by much. At the end of the meeting, a similar poll would have gathered more votes for the rotation model, but still with a very vocal opposition.

The most convincing new data in favor of sea-floor spreading in the Canada Basin come from new gravity and magnetic data. The new gravity data presented at the meeting came from airborne measurements presented by John Brozena and Skip Kovacs, data collected by Bernie Coakley on cruises in a nuclear-powered attack submarine, and data derived from satellite-borne radar altimeters. The satellite data are the most complete (except for the 8° hole around the pole, a result of the satellite orbits available) and, as presented by Seymour Laxon and David McAdoo, show a well-defined feature between the Canadian and Alaskan margins which is most easily interpreted as a fossil spreading center. It lies in the basin between the two margins, but with an orientation that is still somewhat ambiguous as to the role played by the Alaskan continental margin. The satellite gravity models shown were considerably clearer than those already published, and the promise is that even higher resolution data will soon be available as more satellite passes are included in the database.

The most recent compilations of magnetic data for the Arctic made by the Atlantic Geoscience Centre group of the Canadian Geological Survey were presented by Walter Roest, and clearly show linear magnetic anomalies parallel to the gravity anomaly. The interpretation here is also somewhat ambiguous since it depends, first, on the assumption that these linear anomalies were the result of magnetic polarity reversals and sea-floor spreading, and, second, on which kinks in the anomalies are joined together to show "flow lines" for the spreading. The ages assigned to the stripes are also contentious, particularly in regard to their relation to the Cretaceous normal-polarity chron. However, the very existence of the linear magnetic anomalies may be a major new constraint on spreading models. If they do indeed represent polarity changes in the geomagnetic field, then the spreading could not have taken place in the Cretaceous normal-polarity chron (about 118 to 84 Ma). It is, of course, remotely possible that they represent magnetic signals due to the topography, perhaps generated by the sea-floor spreading process. Other magnetic data from the Makarov Basin presented by V. Glebovsky also show evidence of magnetic stripes. The high-resolution data along a transect through the Makarov Basin provide a strong suggestion that that basin was also formed by a sea-floor-spreading process.

Another highlight of the meeting was Art Grantz's presentation describing the new seismic data collected by using the U.S. Coast Guard ice-breaker *Polar Star.* The data presented included a long profile across the Canada Basin from the Northwind Ridge to the northern end of the Canadian Lithoprobe profile near the Mackenzie River delta. This and other profiles across the Northwind Ridge and Chukchi Borderland, including sections of refraction profiling, have led to a brand-new set of constraints on the origins of the Chukchi Borderland. The results of piston coring near the Northwind Ridge, combined with the seismic data, clearly indicate that the ridge has not been an integral part of a continental margin since it was rifted away from its original location, and the disposition of the sediments at the base of the ridge indicates relatively recent (late Tertiary) compression with respect to the Canada Basin. This means that since the rifting occurred, the Northwind Ridge, and presumably the rest of

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Canada Basin *continued from p. 17*

the Chukchi Borderland, must be treated as more or less independent blocks.

Although the new information available for the most southern third of the Canada Basin has increased dramatically, there is still considerable ignorance about the nature and origins of the Makarov, Alpha, and Lomonosov ridges. Although there is a paucity of data, notwithstanding the new work presented at the meeting by Wilfried Jokat and others, there is no shortage of ideas regarding the origins of the various features!

In addition to the data related to the Arctic Ocean basins themselves, a lot of new and reinterpreted data from the surrounding continents was presented. Of particular interest is the emerging model for the tectonic development of northeastern Russia, with its passive margins and numerous accreted terranes. One of the most important and enigmatic areas is the South Anuyi suture, the poorly defined presumed boundary between the terranes from the Arctic and those from the Pacific.

One of the major problems that still faces attempts to reconstruct the tectonic history and paleogeography of the Arctic is a lack of information regarding the timing. As mentioned above, the magnetic lineations seem to indicate that opening (in whatever direction) took place prior to the start of the Cretaceous normal chron (118 Ma). Onshore and offshore studies of the evidence for rifting now seem to point to the Hauterivian (124 to 131 Ma) as the time at which spreading began in the Canada Basin. This leaves somewhere between 6 and 13 m.y. for the opening to take place, on the assumption that the magnetic anomalies represent polarity reversals.

Discussions of the timing and style of opening of the Canada Basin led to another significant topic of discussion; what drives the opening? This question was introduced primarily by David Scholl, but to answer it really requires that definitive models of the surrounding paleogeography are available. One theme that came up over and over again was that the opening of the Canada Basin was in response to tectonic activity in the North Pacific. More specifically, Elizabeth Miller suggested that it may have been driven by some form of back-arc spreading, perhaps in response to the subduction of the Angayucham ocean along the present-day southern margin of the Brooks Range. If this is the case, then such places as the Sea of Japan become analogs, and a similar complexity of magnetic anomalies representing complicated spreading-direction changes should be expected. Lawrence Lawver discussed the track of the present-day Iceland hotspot related to the formation of the Alpha and Mendeleev ridges and suggested that the hotspot may have been "the straw that broke the camel's back" with regard to the initiation of the opening of the Canada Basin. Other driving models included the reactivation of aborted extensions of the North Atlantic rift system. Unfortunately, even though our understanding of the paleogeography of the circum-Arctic region has improved dramatically in the past few years, there are still too many gaps to allow convincing argument for or against any particular model.

The topics mentioned here are merely a sampling of the whole. There were excellent contributions in all the disciplines represented, and all the participants greatly appreciated the scientific contributions made by our Russian colleagues and by industry personnel, who are often underrepresented at meetings of this type. We also appreciated the financial contributions from Exxon, Saga, and Mobil Oil companies.

Although there was no formal discussion of the future of research in the Arctic, it was obvious from the enthusiasm of all participants that it would take more than a fiscal crisis or two to stop us. On a practical level, many discussions revolved around potential multinational efforts, which are still quite rare in the Arctic in comparison with the Antarctic. For some of these it may be practical to use the Russian nuclear-powered ice-breakers. These ships can go where the work needs to be done more or less regardless of the ice conditions, and they can maintain reasonable transit speeds. In these same discussions there was no lack of target areas. The most popular targets in terms of solving significant Arctic Ocean problems were studies of the Alpha and Lomonosov ridges, and detailed studies of the Siberian shelf. Included in these were searches for evidence of the missing transform faults that nearly all Canada Basin models require.

As must be evident from the discussion above, there are still many, many unanswered questions and problems, and definitive answers seem to elude us. Perhaps Randell Stephenson summed it up best in a response to our collective attempts to put together large-scale comprehensive models: "Mother Earth is headstrong and not easily seduced. Success may be more likely by taking a subtle but persistent approach, teasing small concessions out one at a time, rather than insisting on everything at once." ■

Participants

Arlene Anderson	Dave Forsyth	Larry Lane	Warren Nokleberg
Gerald Baum	Vladimir Glebovsky	Marcus Langseth	Donald Norris
Steve Bergman	Jan Golonka	Seymour Laxon	Ian Norton
Kenneth Bird	Arthur Grantz	Kevin Mackey	Snorre Olaussen
John Brozena	Eckart Hakansson	David McAdoo	Leonid Parfenov
Michael Cecile	J. Chris Harrison	Elizabeth Miller	Walter Roest
Bernard Coakley	Ruth Jackson	Thomas Moore	David Scholl
Francis Cole	Chris Johnson	C. G. Mull	Robert Scott
Stephen Crumley	Wilfried Jokat	John Murphy	Randell Stephenson
John Decker	Anatoly Kaplan	Lev Natapov	Irving Tailleur
Jim Dixon	Simon Klemperer	Brad Nelson	Patrick Taylor
Arthur Donovan	Mikhail Kos'ko	Eric Nelson	Franz Tessensohn
Sergei Drachev	L. C. Kovacs	Tor Nilsen	Jaime Toro

AMS 1997 Annual Meeting To Emphasize Interdisciplinary Science

The American Meteorological Society 1997 annual meeting will feature an assortment of symposia and conferences, including sessions on hydrology, atmospheric radiation, global change, climate variations, atmospheric chemistry, education, and interactive information and processing systems. The meeting will be in Long Beach, California, February 2–7, 1997. GSA will be a cosponsor. For further information, contact Evelyn Mazur, AMS, 45 Beacon St., Boston, MA 02108, (617)227-2426, ext. 204, fax 617-742-8718.

PEP at the 1996 GSA Annual Meeting

See next month's *GSA Today* and examine the variety of opportunities available to PEP Partners at the upcoming 1996 Annual Meeting in Denver. There are a multitude of terrific workshops, field trips, theme sessions, and educators' events that are simply not to be missed! We encourage each of our PEP Partners to consider submitting an abstract to one of the theme sessions related to K–12 geoscience education. Don't forget the July 9, 1996, abstracts deadline. If you need assistance getting the appropriate forms, give us a call. We hope to see each of you in Denver this fall—register early and watch for your fabulous Rock Raffle coupons!

Penrose Conference Report

Mesozoic Evolution of the Cordilleran Continental Margin in Central and Southern California

Conveners
***Andrew P. Barth**, Department of Geology, Indiana/Purdue University, Indianapolis, IN 46202*
***J. Douglas Walker**, Department of Geology, University of Kansas, Lawrence, KS 66045*
***Jason B. Saleeby**, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125*

Since the advent of the theory of plate tectonics, the western U.S. Cordillera has been central to models of the evolution of ocean-continent convergent plate margins and the role of these margins in the growth of continental crust. These models evolved from the classic association of trench, fore-arc basin, magmatic arc, and foreland fold-thrust belt which characterized the Late Jurassic and Cretaceous paleogeography of central California. This classic association of convergent plate margin structural elements is obscure or inapplicable, however, when considered in a broader spatial and temporal context. It is difficult to apply to earlier Mesozoic convergent margin evolution because of the obscuring effects of younger tectonism, or to the Mesozoic of southern California, where elements of the classic convergent margin association appear to be superimposed or absent. This change in style is coincident with a transition in basement type, as the Proterozoic craton approaches the Mesozoic plate margin.

In an attempt to focus attention on current research relevant to evolution of this continental margin arc, its foreland, and along-strike variations, a Geological Society of America Penrose Conference, Mesozoic Evolution of the Cordilleran Continental Margin in Central and Southern California, was held October 6 to 11, 1995, in Tehachapi, California. Participants included structural geologists, stratigraphers, petrologists, and geophysicists actively engaged in interpreting the Mesozoic and Cenozoic crustal evolution of the southern Cordillera. The conference was divided into three main topic areas: arc and foreland deformation and metamorphism, magmatic arc evolution, and Cretaceous-Tertiary tectonics of the waning and extinct arc.

The conference began with an evening discussion of the regional tectonic framework of the western United States. An opening address by Lee Silver focused on the state of the crust in southern California. Silver presented many broad geochronologic and petrologic constraints, and possible scenarios for Mesozoic and Cenozoic evolution of southern California. Jason Saleeby presented an overview of the role of accretionary terranes in growth of the North American Cordillera and described possible interactions between these terranes and the California continental margin during margin-parallel translation.

Discussion of deformation and metamorphism was initiated with reviews of the Precambrian and Paleozoic geologic setting of the southwestern United States by Joe Wooden and Jack Stewart. Wooden emphasized the Precambrian truncation of the southwest-trending, Proterozoic Mazatzal and Yavapai provinces by the Mojave province, and the isotopic imprint of these crustal provinces on Mesozoic magmatism. Stewart reviewed the paleogeography of the Paleozoic miogeocline and its implications for late Paleozoic and Mesozoic strike-slip faulting. Cal Stevens and Paul Stone followed up by reviewing stratigraphic and structural evidence bearing on models for late Paleozoic truncation of these Precambrian and Paleozoic elements and establishment of the northwest-trending plate margin. These talks set the stage for a poster session, which summarized abundant new structural and geochronologic data bearing on regional deformation in the Mesozoic arc and foreland. The poster session was reviewed and discussed by the group during a panel discussion led by Tom Anderson, Dave Miller, and Steve Reynolds. New U-Pb geochronologic work closely tied to detailed mapping and kinematic studies is shedding new light on regionally extensive fold-thrust regimes, such as the East Sierran and Maria belts. These discussions were followed up by a day-long whirlwind tour of roof pendants in the southern Sierra Nevada, led by George Dunne and Doug Walker, which highlighted problems of understanding eugeocline-miogeocline juxtaposition throughout this region. Brief glimpses of batholithic rocks, in various states of preservation among the pendants, also served to provide a transition to discussions of the origin of Mesozoic batholiths.

Discussions of Mesozoic arc evolution were kicked off by Jonathan Miller's review of abundant new geochemical and geochronologic data bearing on Permian-Triassic arc initiation. As a bonus beyond their petrologic import, these data also continue to focus attention on structural juxtapositions in prebatholithic rocks in the southern Sierra Nevada and northern Mojave Desert. Drew Coleman and Allen Glazner summarized the results of comparative studies of batholithic rocks and xenolith suites in the east-central Sierra Nevada batholith. Models of batholith generation continue to spark debate, but the compositional variety of Sierran plutonic rocks and the heterogeneity of the crust and mantle are sobering realities to those engaged in modeling crustal growth as a result of this magmatism. A poster session and panel discussion led by Allen Glazner, Basil Tikoff, and Joe Wooden followed, drawing attention to the multiple end members involved in formation of batholithic rocks. New contributions of geophysical results by Peter Malin and xenolith studies by Mihai Ducea and Drew Coleman renewed interest in the still poorly known compositional structure and dynamics of the Sierran sub-arc mantle lithosphere.

The third major topic of interest was the timing and mechanism(s) of Late Cretaceous arc extinction. Discussion began on a field traverse through the Rand Mountains and eastern Tehachapi Mountains led by Carl Jacobson, Lee Silver, D. J. Wood, and Jason Saleeby. This traverse exposes the warped core of the southern Sierra Nevada batholith and the underthrust Rand schist, a juxtaposition that is also characteristic of the lower arc crust along the western perimeter of the Mojave Desert and in the Transverse Ranges. Unraveling the kinematics and dynamics of this juxtaposition remains key to understanding arc extinction and the Sevier-

Cordillera *continued on p. 20*

Cordillera *continued from p. 19*

Laramide transition in the western United States. Perry Ehlig summarized many workers' sense that advanced models of this event, and subsequent Paleogene marine incursions, remain hostage to uncertainties in palinspastic reconstructions of Cenozoic extension and strike-slip displacements. A poster session and a panel discussion led by Ray Ingersoll, Gary Fuis, and Steve Lund highlighted new data on the structural and thermal state of the dying arc and its schist substrate, as well as up-to-date paleomagnetic constraints on reconstructing the positions of Salinia and the Peninsular Ranges.

The conference ended with newly converging opinions in some areas and persistent disagreement in others. For example, it seems that new ideas about the geophysical nature of Sierran crust and upper mantle are approaching agreement with inferences derived from petrologic constraints on Cretaceous arc development. Future interdisciplinary cooperation should lead to a more realistic picture of the structure and composition of arc lithosphere and mass transfer during arc magmatism. On the other hand, a recurring question is the role of margin-parallel displacements in shaping the prebatholithic framework, interacting with the evolving magmatic arc, and subsequently disrupting terminal Mesozoic tectonic patterns. Such questions can only be addressed effectively as large-scale magmatic and deformation patterns of the arc and foreland are clarified through continued collaborative efforts involving geochronology, petrology, and structural geology. Collaborations like these were the highlights of the Tehachapi conference and hold promise for future progress in understanding Cordilleran evolution. ■

Participants

Lawford Anderson
Tom Anderson
Stan Ballard
Andy Barth
Stefan Boettcher
Nik Christensen
Diane Clemens-Knott
Drew Coleman
John Crowell
Roy Dokka
Mihai Ducea
George Dunne
Carol Dupuis
Perry Ehlig
Bob Fleck
Moritz Fleidner
Zorka Foster
Lydia Fox
Gary Fuis
Allen Glazner
Marty Grove
Darrell Henry
Keith Howard
Ray Ingersoll
Carl Jacobson
Dave Kimbrough
Simon Klemperer
Steve Lund
Peter Malin
Craig Manning
John Marzolf
Brendan McNulty
Calvin Miller
Dave Miller
Jonathan Miller
Sven Morgan
Jonathan Nourse
Steve Reynolds
David Rothstein
Jason Saleeby
Ron Schott
Lee Silver
Sorena Sorensen
Sharon Stern
Cal Stevens
Jack Stewart
Paul Stone
Basil Tikoff
Mike Walawender
Doug Walker
Peter Weigand
Rich Whitmarsh
D. J. Wood
Joe Wooden

GSA-AGI Relationships

Eldridge M. Moores, GSA President and Robert D. Hatcher, Jr., AGI President

What is AGI (American Geological Institute), and what does it have to do with GSA? AGI is a federation of geoscience societies and associations with its headquarters in Alexandria, Virginia, near Washington, D.C. AGI was established nearly 50 years ago to provide a collective voice and action for geosciences at the national level. It is similar to other scientific umbrella organizations, such as the American Chemical Society (ACS) and American Institute of Physics (AIP). At present, AGI consists of 29 member societies, GSA and AAPG being the largest. Each member society pays to AGI dues in proportion to the number of its members.

GSA and most other associated societies also contribute directly to AGI's Government Affairs Program, now directed by David Applegate, a former American Geophysical Union (AGU) Congressional Science Fellow. The goal of this office is to serve as the main geoscience congressional liaison in Washington. Compared with the programs of ACS and AIP, AGI's Government Affairs Program (along with that of AGU—not at present a member of AGI) is relatively new and still small. Both ACS and AIP attach major importance to the value of their government affairs programs: ACS has a full-time staff of more than 10 and a budget of more than $1 million to support their program; AIP has a comparable investment. Both ACS and AIP have welcomed AGI's efforts with open arms. These and other governmental affairs programs collectively are attempting to educate Congress about science. For example, when the the U.S. Geological Survey was threatened with elimination in 1995, AGI's Government Affairs director, then Craig Schiffries, arranged face-to-face meetings between geoscience leaders and members of Congress and their staffs. These meetings helped to persuade Congress not to abolish the USGS.

In addition to this important function, AGI publishes *Geotimes,* a monthly newsmagazine for the geosciences; the *Bibliography and Index of Geology;* the *Glossary of Geology;* the *Directory of Geoscience Departments,* now in its 34th edition; and several other publications. AGI also maintains GEOREF, the largest and most comprehensive computerized reference resource in geoscience, and distributes an annual report on faculty salaries. AGI also coordinates improvements in earth science education in concert with programs in several member societies (including GSA's SAGE program), offers scholarship assistance to minority students, administers cooperative exchange programs with Russian universities, and works to increase public awareness of the vital role of geology in our society.

Funding of AGI comes principally from royalties and outside contributions, with a smaller but very important component from member society dues. In addition, AGI is successfully pursuing outside grant funding to support its outreach programs in education, the National Data Repository Program, and other activities.

A close relationship has long existed between the leadership of GSA and of AGI. Currently one of us (Bob Hatcher) is president of AGI and a former GSA president. Many other former members of the GSA Council have served as AGI officers. GSA and AGI are working to strengthen their ties and coordination in response to the desire of GSA for an enhanced presence in Washington. In contrast to several other scientific societies (e.g., AGU, ACS, and AIP), which have their headquarters in the Washington area, GSA has no permanent presence in the nation's capital. GSA thus depends upon AGI to act on its behalf "inside the beltway." In this era of foment, downsizing, budgetary uncertainty, and public and congressional skepticism about science, GSA more than ever needs some connection with the Washington scene. To that end, GSA participates in two organizations: AGI and the Council of Scientific Society Presidents (CSSP).

Because GSA helps support AGI financially and because AGI performs such an important function for GSA, we encourage GSA members to learn about AGI activities and GSA's role in them. If you have any thoughts about this relationship and how to make it more effective, please contact either one of us (E-mail addresses: Eldridge Moores—moores@geology.ucdavis.edu; Bob Hatcher—bobmap@utkvx.utcc.utk.edu).

To learn more about AGI's Government Affairs Program and other activities, visit AGI's home page on the World Wide Web (http://agi.umd.edu/agi/agi.html) or gopher server (agi.umd.edu:71).

ENVIRONMENT MATTERS

Institute for Environmental Education

Scientists, Stakeholders, and the South Florida Ecosystem

Sarah Gerould, Bureau Ecosystem Coordinator, U.S. Geological Survey, MS 918, National Center, Reston, VA 22092, E-mail: sgerould@usgs.gov

Over a century ago, the first European settlers of south Florida found an expanse of wetland—"a River of Grass," in author-activist Marjory Stoneman Douglas's words. To the settlers who set down roots, it was a barely habitable place; too much water in the wet season and too many fires during droughts. Most settlement occurred on the Atlantic ridge to the east of the Everglades. Flooding from devastating hurricanes brought increasing artificial hydrologic controls until the Everglades was crisscrossed by canals and divided into isolated blocks of land. The land south of Lake Okeechobee and west of the urbanizing Atlantic ridge, formerly part of the "river of grass," could now be farmed. Nutrient-laden water flowing out of the agricultural areas helped to change plant communities from native sawgrass to cattails. Loss of wetlands to agriculture and urbanization reduced the area's water-storage capacity, needed during hurricanes and tropical depressions. The extensive system of canals efficiently moved the water to the east and the west, but less and less to the south. An area that once sustained millions of birds could now support only one-tenth that number. Increased nutrients and salinity of water in Florida Bay caused seagrasses and corals to die off. Water that was a fisherman's paradise was now cloudy with sediment; fish populations were greatly reduced and fisheries closed because of mercury contamination.

Public opinion gradually began to move toward the realization that the greater Everglades system, including Florida Bay, should be revitalized. People gradually accepted the idea that a different management strategy was required, one that was in the long-term interest of the people and ecology of south Florida.

Many agencies, groups, and individuals were already actively working toward the restoration of the greater Everglades. Scientists in academia, state government, and federal agencies were describing different pieces of the scientific puzzle. Resource managers in the Park Service and Fish and Wildlife Service were acquiring scientific information to stem the invasion of exotic species and restore decimated fish and wildlife populations. The Environmental Protection Agency and the State of Florida were gathering data on the extent and causes of mercury contamination in fish. The South Florida Water Management District and the Corps of Engineers were starting to develop plans for restoring the historical annual hydrologic regime in south Florida. The U.S. Geological Survey, in addition to its discipline-specific research, worked within its tradition of interdisciplinary studies in south Florida. For instance, Parker et al. (1955) took a landscape approach encompassing ground water, water quality, geology, soils, and vegetation in the urban, agricultural, and environmentally sensitive lands of south Florida.

National Trends in Resource Management

On the national scene a different approach to managing ecosystems such as the Everglades was taking shape. This landscape approach grew out of highly contentious legal battles in the Pacific Northwest, south Florida, and elsewhere over resource management. Such an approach goes by different names—place-based management, ecological stewardship, ecosystem management—and involves managing a region in a more holistic manner. Water, birds, and rocks do not stop at the boundary of an agency's land, and neither can the management of those resources. Of all of the definitions I've seen, I like the one from a September 1994 National Park Service document entitled "Ecosystem Management in the National Park Service" and published on the BENE home page (http://straylight.tamu.edu/bene/home/ bene.docs.html):

> Ecosystem management is a collaborative approach to natural and cultural resource management that integrates scientific knowledge of ecological relationships with resource stewardship practices for the goal of sustainable ecological, cultural, and socioeconomic systems.

In practice, ecosystem management brings stakeholders (individuals, groups, and agencies that have an interest in the outcome) and scientific information into management decision making, so that managers can make informed decisions about the physical, biological, social, and economic responses of ecosystems, resources, and communities to alternative management strategies. The approach is also adaptive in that it requires improving those strategies as better scientific information becomes available. Economic and social sciences also offer vital contributions, because people are a dynamic part of the mix that we call an ecosystem. Market forces (the value placed on a resource by the market), if ignored, can seriously undermine the best intentions and efforts of resource managers. Many managers have begun to believe that adaptive ecosystem management is necessary to resolve environmental problems before such problems begin to polarize the stakeholders and undermine the ability of resource managers to craft long-term solutions and strategies.

Role of the USGS

In south Florida, the USGS, long a member of the scientific community in the area, is one of the agencies at the ecosystem management table. In environmentally complex areas like south Florida, the USGS can assemble interdisciplinary forces so that appropriate disciplines can work together. With the addition of the biological wing of the Department of the Interior, the Survey now has the capability to integrate biological, chemical, cartographic, geological, and hydrological studies where they are needed to answer scientific questions. For instance, the USGS is integrating information on algae with geochemical information to better understand the cycling of mercury. Likewise, the USGS produced a satellite image map of south Florida which included an interpretive key to major vegetation types.

The position of the Survey facilitates the provision of scientific information but also presents the USGS with major challenges. Whereas many agencies that have scientific capabilities also have responsibility to manage and in some cases protect certain resources, the USGS is an earth and natural science information agency with no direct resource management responsibilities. As such, it can effectively provide impartial scientific information and analysis on some of the most contentious environmental issues—science that can be acceptable to all sides. However, this objectivity is not without cost. Its separation from management requires the Survey to make a greater effort to communicate with resource managers so that (1) the USGS can provide science that is understandable, timely, and relevant to resource managers' needs, and (2) Survey science is used in resource and policy decision making. Many resource management agencies have their own stable of scientists. In some cases, these scientists work in close collaboration with their resource managers, understand their managers' needs, and can readily supply them with answers to their scientific questions.

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A View of the River. *Luna B. Leopold, Harvard University Press, Cambridge, Massachusetts, 1994, 298 p., $39.95.*

Newcomers to the study of the physical forms and processes of rivers are fortunate in that Luna Leopold, the preeminent investigator of fluvial systems, has condensed his extensive knowledge in *A View of the River*. Writing for managers of research, users of the resource, and the general public, Leopold characterizes his book as a "primer," that is, an elementary textbook. His presentation uses a minimum of mathematics, relying instead on a series of graphs to establish relationships, presented together with sound, logical discussions. Although a list of references is given at the end of the book, only in rare instances are specific papers cited; more commonly, the material discussed is noted as being the work of certain individuals, permitting the identification of the relevant references. This does make reading comfortably casual as desired in a primer for a general audience, though at times I found myself struggling to find the source references for certain material.

In addition to providing a summary of the physical forms and processes important in rivers (chemical and biological aspects are not included), the book presents a general hypothesis of river action—"Random chance plays a major role in local changes. As a result, the forms assumed and the adjustments made all tend toward the most probable form, expressed as the form having the least total variance" (from the Preface). Enter-

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IEE *continued from p. 21*

Even in the best of situations, however, the credibility of science from management agencies can be questioned by other stakeholders simply because of the appearance of a conflict of interest in this relationship.

Approach Taken by the USGS Ecosystem Program

How can a science agency like the USGS best identify the kind of scientific studies that are needed, and effectively deliver that scientific information to resource managers so that it can be used in making good management decisions? One example is the USGS Ecosystem Program. The Ecosystem Program builds on the Survey's tradition of interdisciplinary studies in south Florida. The program is blessed by the existence of strong regional groups that include stakeholders (e.g., resource managers, the Army Corps of Engineers, the general public, and other scientists). The South Florida Ecosystem Restoration Task Force and associated work groups have been actively engaged in helping the USGS program to set priorities. The USGS primarily works though the Science Subgroup, which coordinates the large array of scientific activities of agencies. The USGS can reach another stakeholder group, the general public, through the Outreach and Education Subgroup. Without this regional coordination mechanism, the USGS would have a much harder time targeting its energies where they are most needed and avoiding duplication of effort.

The Ecosystem Program uses these stakeholder groups in many ways. The Task Force and the Science Subgroup help to guide the overall content of the scientific work, and follow-up activities bring together specific projects and specific clients for that work. The USGS consults with the Task Force and the Science Subgroup in the development of proposals and solicits their priorities for scientific information. These stakeholders are further consulted to help prioritize proposals for work. After the projects are selected, the Survey holds a general meeting with stakeholders to ask for input to ensure that the projects are well coordinated with agency activities, do not duplicate activities of other agencies, and will meet specific needs in a timely manner. Program meetings acquaint project leaders with their specific client agencies and inform these agencies of our scientific activities. Periodically during data collection and analysis, the project investigators meet with client agencies to bring them up to date on their progress, to ensure that the information is available to the managers who need it and that the project is on track.

A vital part of the USGS Ecosystem Program consists of working with agencies to ensure that they get the scientific information they require. We solicit the views of stakeholders (for general priority setting) and specific clients (for specific projects) at critical decision-making junctures, a process that cannot be left as an afterthought in scientific management. Success of the program also depends on the willingness of scientists to interact and develop working relationships with resource managers. The traditional output formats for scientists' work—peer-reviewed publications and scientific meetings—are still necessary, but they are not sufficient. The program also takes a more personal approach and includes small meetings with client agencies and articles written specifically for an audience of resource managers.

Other changes in our way of doing business have also been necessary. All of these efforts require time, and our scientists must be prepared to incorporate these steps into their plans. Our reward system is changing to account for altered expectations of scientists. We are not just in the business of providing new information: if some of the information needed is already in the traditional scientific literature, it is our duty as scientists to make it available in a format that is understandable to the nonscientific audiences that will use it.

These types of changes are necessary in order for us to adequately communicate science to resource managers, but it is worth keeping in mind why they are necessary. Without these changes, our research will be ignored, and the reputation of our science will be tarnished because costly scientific information went unused. More important, policy will be made that leads our society to waste its resources, unnecessarily damage the environment, and reduce the quality of the life of its citizens.

Reference Cited

Parker, G. G., Ferguson, G. E., Love, S. K., et al., 1955, Water resources of southeastern Florida: U.S. Geological Survey Water-Supply Paper 1255, 965 p. ■

USA/CIS Conference on Environmental Hydrology Slated for Uzbekistan

The third USA/Commonwealth of Independent States Conference, Water: Sustaining a Critical Resource, will be held in Tashkent, Uzbekistan, September 22–27, 1996. It is a continuation of a series of joint meetings on problems of environmental hydrology and hydrogeology in the United States and the countries of the former Soviet Union. The Tashkent meeting will be hosted by the American Institute of Hydrology, the U.S. Geological Survey, and the Uzbekistan Academy of Sciences Institute of Water Problems. GSA will be a cosponsor. For information, contact American Institute of Hydrology, Third USA/CIS Conference, 2499 Rice St., Suite 135, St. Paul, MN 55113, (612) 484-8169, fax 612-484-8357, E-mail: AIHydro@aol.com.

ing the realm of entropy, these discussions likely will challenge the general reader, yet inclusion of entropy provides a unifying theme for the book as a whole so that it goes beyond a simple review of fluvial processes. Leopold warns the reader that this presentation expresses his own interpretations, a second meaning for "View" within the title.

The topics covered by *A View of the River* are comprehensive, providing the overview desired in an introductory text. The first chapter focuses on the geomorphic forms of river channels and includes interesting discussions of the roles of climate and human impacts. The next two chapters summarize measurement techniques, the availability of discharge data, the development of hydrographs, and analyses of flood routing (with a sample calculation). These chapters illustrate the practical nature that is maintained throughout this book, never permitting the material to become totally an academic exercise. Chapter 4 (Meanders and Bars) returns to the theme of channel form, now in three dimensions, with the first discussion of the theory of minimum variance. The next three chapters relate to river discharge, first examining the variation in space and time, then providing a summary of the characteristics of the major rivers of the world, and then the occurrence and probabilities of floods. Chapters 8 and 10 relate the channel form to the discharge, stressing the importance of the bankfull condition and presenting the hydraulic-geometry empirical relationships. Chapter 9 summarizes the characteristics of the Watts Branch, a tributary of the Potomac River in Maryland, providing an example that illustrates many of the relationships discussed in general terms within other chapters. Although some passing discussion of sediments is provided in the earlier chapters, in Chapter 11 full consideration is given to the sediment load, including the sources, the modes of transport, the forces of flow responsible for sediment entrainment, techniques of transport measurements, the development of sediment-rating curves for a river, and finally a general discussion of computations of sediment transport rates. Chapter 12 returns to geomorphic aspects with a review of the complete drainage network. Chapter 13, "Energy Utilization," is the most mathematical of the presentations in that summary derivations are provided for the Chezy and Manning equations, with discussions of the various friction factors, equations for the velocity distribution above the bed, and the effects of bed-form changes on the hydraulic parameters. The book concludes with a discussion of the most probable state of rivers, ideas alluded to throughout the book but presented here as a unifying hypothesis to account for the observed forms of channels and their relationships to physical processes.

Leopold has accomplished what he set out to do, presenting a synthesis of the hydraulics and geomorphology of rivers to a broad audience. The book would be suitable as an introductory text in university courses, and I recommend it to people well advanced in the subject, because it provides a comprehensive overview and the mature thoughts of a scientist who has made so many contributions to our understanding of rivers. We can also take a lesson from Leopold in the masterfully lucid presentation of complex material, and the sweeping generalizations like the one that ends the text: "The river, then, is the carpenter of its own edifice."

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Crustal Evolution of Singhbhum North Orissa, Eastern India.

A. K. Saha, Geological Society of India Memoir 27, 1994, 342 p., $50 (softcover).

Although the Precambrian accounts for nearly 88% of Earth's history, our knowledge of its geologic evolution is sparse. To address such fundamental problems as the temporal evolution, spatial extent, and formation mechanism of Earth's early crust, detailed geological studies of Precambrian shields, such as the Indian subcontinent, are crucial. The Singhbhum–North Orissa region, covering an area of about 50,000 km^2, is one of the six provinces constituting the Indian shield. The region exposes rocks ranging in age from 3700 to 1000 Ma, and is also an important site of economic mineral ores such as iron and copper.

Because of its location close to Calcutta, headquarters of the Geological Survey of India (established in 1851), the Singhbhum region is one of the best studied Precambrian provinces of India. Classical knowledge of the region was synthesized by J. A. Dunn and A. K. Dey in 1942 in a Memoir of the Geological Survey of India. *Crustal Evolution of Singhbhum* is the second most comprehensive effort in documenting the geology of this region. A. K. Saha, an emeritus professor of the Presidency College in Calcutta, has devoted the past 40+ years to the study of Singhbhum. As a result, this in-depth monograph is authoritative, up-to-date, and comprehensive, discussing not only the geology, structure, and metallogeny of the Singhbhum rocks but also relevant geochemical and geochronological data, a major part of which has been contributed by Saha and his former students.

Saha meticulously documents the available data on Singhbhum in Chapters 2 through 18. Tectonic evolution of the region, especially in the context of global Precambrian geology, is relatively less expounded upon. In Chapter 19, based on K. C. Condie's concept of Archean continental crust genesis, Saha discusses a model for the geologic evolution of Singhbhum. This model, taken at face value, is restricted in space to the "greenstone-granite" cratonic rocks and in time to 3.8 to 3.0 Ga. The model hardly considers the "Singhbhum mobile belt" and the granulite-facies "Eastern Ghat belt" of ~1 Ga that have affected the northern and southern margins, respectively, of the Singhbhum region. The region also underwent events at ~2 Ga (the so-called "Iron Ore orogeny").

Saha's book represents a major synthesis of Singhbhum geology and a stepping-stone to tackling many detailed questions of Indian Precambrian geology, including those requiring more complete geophysical profiles, high-resolution geochronological and geochemical data, and detailed structural mapping. Those interested in Precambrian geology in general and in the Indian shield in particular will find this volume very informative and handy. Its reasonable cost should also encourage readers to obtain a personal copy.

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Meteorite Craters and Impact Structures of the Earth.

Paul Hodge, Cambridge University Press, New York, 1994; $49.95.

The idea that great meteorites occasionally zoom down from space, blast out huge craters, and wreak havoc on Earth is a relatively new one. Less than a century ago most geologists dismissed such ideas as pure fantasy. However, in 1906 Barringer and Tilghman argued strongly that the 1-km-diameter Arizona meteor crater was created by the impact of a large iron meteorite. But it was not until the Apollo era in the early 1970s that the ubiquity and importance of meteorite impact began to be appreciated. Images from unmanned spacecraft showed that cratering is a dominant geologic process on the moon and other planets. In the present decade, impacts have been implicated in the birth of the moon and the death of the dinosaurs. The threat to civilization of

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possible future impacts has generated congressional hearings and much public debate. Topping off this intellectual revolution, the impact of comet Shoemaker-Levy 9 with Jupiter in July 1994 made nearly everyone aware of the awesome power of great impacts.

Although Earth has relatively few impact craters compared to the other planets—a consequence of the vigor of fluvial erosion and tectonic unrest—these few craters are the most accessible for study, and so they have played a major role in shaping our understanding of the impact process. Furthermore, although erosion has spoiled the pristine form of all but the very youngest craters, it has also exposed the deeper levels of large craters, giving us a peek at the underlying structure that we lack for extraterrestrial craters. At present, there are about 150 well-established impact structures on Earth, and the recognition of impact features has almost reached the geological mainstream.

The publication of Paul Hodge's book on terrestrial impact craters is thus well timed. A comprehensive treatise on terrestrial impact structures has long been needed; unfortunately, Hodge's book is not that treatise. It is, instead, a travelogue that could have been titled "Craters I Have Visited (Plus a Few More)." The mechanics of impact cratering are discussed in a brief two-page introductory section, in which the discussion is outdated and in several places simply wrong. The principles of shock metamorphism are given a few meager paragraphs. Hodge has thus missed an opportunity to give interested amateurs some insight into how craters are excavated, what processes create their peculiar structures, and how one distinguishes impact craters from other holes in the ground. The reference bibliographies on individual craters are incomplete, and most do not include the current literature.

In spite of these negative aspects, the book does have some virtues if you accept it as a popular guidebook and not as a scientific treatise. Hodge has organized descriptions of the 140 or so impact craters known at the time of publication into seven chapters, one each for North America, Canada, Latin America, etc. Within each chapter the craters are described in alphabetical order. Each description includes the crater's location (latitude and longitude), diameter, age, and condition. The descriptions range from a few sentences to several pages, depending on the crater and, evidently, Hodge's familiarity with it. Photographs, from the ground in or around the crater, accompany many of the descriptions, and I found these photographs to be among the most useful parts of the book. The most revealing of these are not, I think, the ones that show obvious crater form structures, but rather those that show rolling hills and swales or picturesque French castles (incidently built of impact breccia). These decidedly nonlunarlike scenes bring home the point that impact craters are not always (or even usually) easy to recognize on Earth, and that detailed geologic study by impact-aware geologists is often necessary to establish an impact origin for otherwise rather ordinary-looking landscapes or lakes.

Hodge also gives directions on how to reach most of the craters described. These directions vary considerably, ranging from connecting through O'Hare airport in Chicago (to "visit" the completely buried Des Plaines structure) to a 1400 km helicopter ride from the nearest city to the El'gygytgyn crater in Siberia. This information will, however, probably encourage amateurs and perhaps professional geologists to visit at least a few of the craters in their own vicinity, and may thus make the community of people interested in geology more aware of the existence and importance of impact craters.

Both amateur and professional geologists, students, and professors may find this book useful as a spur to visit some of the craters. Furthermore, the geological literature often contains references to particular craters, and *Meteorite Craters* serves as a quick reference to a few of the basic facts about most known craters. Several times I have found myself reaching for this book to get a fact or two about some crater, so the book may have a place in geological reference libraries. Until a definitive treatise on terrestrial impact craters is finally written, this book, despite its many technical shortcomings, will serve as a useful source of information about these craters.

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Exploration Seismology, *Second Edition. Robert E. Sheriff and Lloyd P. Geldart, Cambridge University Press, New York, 1995, 592 p., $49.95 (paperback).*

This book is designed to give a comprehensive picture of the applications of seismology in exploration. It is an updated revision of the first edition originally published in 1982, and it includes many improvements that have occurred in the seismic method since that time. The book can serve as a reference work as well as a textbook and guide for practicing geophysicists. For readers who want to skip parts that do not fit their current needs, the authors provide cross-referenced sections, equations, and figures. Each chapter begins with an overview to orient the reader as to the various topics discussed, and all chapters except the first end with problems. Each problem is designed to illustrate a specific point, and helpful hints are included.

In this edition Sheriff and Geldart have expanded their treatment of seismic theory from that given in the first edition. The partitioning of energy at interfaces, a central phenomenon of seismic exploration, has been given a prominent position. Some items, merely mentioned in the first edition, such as anisotropy, AVO (amplitude variation with offset), Stoneley waves, and tube waves, are now discussed in detail. One of the most notable advances in seismic exploration has been the increased use of three-dimensional (3-D) methods. The topics of 3-D acquisition, processing, and interpretation now occupy an entire chapter. Another chapter on specialized techniques includes VSP (vertical seismic profiling), S-wave methods, channel waves, tomography, and geostatistics. Also in this volume is a valuable chapter devoted to nonpetroleum applications, including not only coal and engineering seismic work but also groundwater, environmental, and reservoir geophysics.

In the interpretation of geophysical data, it is necessary to separate geologic features from artifacts of acquisition or processing. A special feature of the book is the determined effort made to define and use the specialized vocabulary of seismology precisely. Because a seismic interpreter must have a thorough understanding of geophysical principles in order to determine the validity of the seismic data, this book emphasizes seismic fundamentals. Sheriff and Geldart take pains to express concepts in words as well as by equations. They give systematic derivations of relationships from first principles, except for a few cases where the derivations are excessively lengthy or involve higher mathematics, in which instances they refer the reader to other sources. Of special interest is the final chapter on background mathematics, intended to refresh a reader's forgotten mathematical concepts. Mathematical conventions, definitions, and the symbols used throughout the book are listed in a table at the front.

This book is truly impressive in the insight that the authors offer on the various aspects of the seismic method. Almost anyone involved with geophysics will find the book useful. Sheriff and Geldart are to be congratulated for providing the geoscience community with a valuable resource.

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Coastal Evolution: Late Quaternary Shoreline Morphodynamics.
R. W. G. Carter and C. D. Woodroffe, Cambridge University Press, New York, 1995, 517 p., $79.95.

This book is intended to be a major contribution to the International Geological Correlation Program Project 274, Coastal Evolution in the Quaternary. One of the primary goals of this program, which ran from 1988 through 1993, was to produce numerical and conceptual models to explain local and regional variability in coastal and continental shelf evolution. To this end, the book presents some of the latest research and most recent models for coastal evolution in response to changing relative sea level, sediment supply, and other coastal and oceanographic processes. One introductory chapter gives an historical perspective on the subject of coastal evolution, and a second discusses morphodynamics and enhancement of coastal evolution research through computer modeling. These chapters are followed by 11 papers dealing with terrigenous clastic coasts: deltas, wave dominated, macrotidal, lagoon and microtidal, paraglacial, and Arctic coastal plain; biogenic coasts: coral atolls, continental shelf reefs; rocky coasts: cliffs and platforms, tectonic coasts; and human-altered coasts: developed coasts. The authors, internationally recognized scientists, are, for the most part, from the European, Canadian, and Australian research communities; thus, many of the examples and studies cited in the book are from areas outside the United States. This is a decided advantage for many wishing to compare their research to other regions around the world. The chapter entitled "Wave-dominated Coasts" is particularly comprehensive in its content and "Coastal Cliffs and Platforms" and "Paraglacial Coasts" are other good contributions to the book.

One approach taken by many authors in the book was to discuss the advances in a particular field in terms of their own study areas. Although other regions with similar settings in different parts of the world are commonly mentioned in most chapters, the findings of these research efforts are not always fully integrated into the discussions and evolutionary models, leading to a somewhat provincial treatment of the subjects. In addition, some of the evolutionary models for the different coastal systems cover only the late Holocene, rather than the late Quaternary as the title of the book indicates. Despite chapters with similarities in subject material (e.g., "Lagoons and Microtidal Coasts" and "Wave-dominated Coasts") the amount of overlap is minimal. The reference lists throughout the book are not exhaustive but do supply a good starting point for most literature reviews. Overall, the volume provides a good summary of the evolutionary concepts of many coastal systems, and despite the lack of geographical coverage in many chapters, I recommend it as a good reference book.

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Modern Glacial Environments: Processes, Dynamics and Sediments.
Edited by John Menzies, Butterworth-Heineman, Oxford, UK, 1995, 621 p., $69.95.

Menzies' objective for this text is to "provide a current and comprehensive survey ... of modern glaciers and ice sheets through an appreciation of the processes, dynamics and sediments found in these environments." Toward that end he succeeds, and this book could serve equally well as a textbook for glacial geology courses or as a basic reference for any Quaternary geologist for several years. The independently authored chapters cover most glacial environments to similar depth, with little overlap. Interwoven with the numerous, informative examples are past and current hypotheses about the various glacial processes and attempts to integrate individual processes into larger models, each chapter identifying current problems. This approach works.

P. E. Calkin's chapter on global glacial chronology, which is probably better suited in the companion volume, *Past Glacial Environments*, offers a balanced introduction to current stratigraphic thinking. T. J. Hughes's chapter on ice sheet modeling and reconstruction gives

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readers the essential philosophy of modeling but spares them most of the mathematics.

Menzies' introduction to glaciers and ice sheets unifies many past observations into a holistic model. The chapter on ice-flow dynamics furnishes the reader with a practical feel for glacier behavior from numerous examples of flow properties. One interesting aspect is the presentation of glacier flow as a thermomechanical model, allowing the reader to consider the interrelationship among various contributors to glacier dynamics. The chapter on hydrology is likewise illuminating. N. R. Iverson summarizes the theoretical aspects of various erosion processes, but the treatment of the resulting glacial features is too sparse. M. P. Kirkbride covers the various transport paths within the glacier system and how they may affect glacial behavior. C. A. Whiteman's coverage on terrestrial deposition is too brief an overview of modern glacial sediments. Glaciotectonism receives a much needed treatment by F. M. van der Wateren, who shows the essential contribution of structural principles to glacial processes. D. E. Lawson gives the reader a solid feel for sediment and water processes. J. Maizels and G. M. Ashley contribute well-rounded, comprehensive reviews of the outwash and glaciolacustrine environments, respectively. R. Powell and E. Domack convey a good global synopsis of the complex glaciomarine system. W. C. Mahaney attempts to interpret features on quartz grains resulting from glacial and other processes.

These individual chapters combine to provide a solid, comprehensive, and integrated survey of the modern glacial system.

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River Geomorphology. *Edited by Edward J. Hickin, John Wiley & Sons, Chichester, UK, 1995, $89.95.*

This volume represents a collection of papers presented at the Third International Geomorphology Conference (1993) in Hamilton, Ontario. The volume contains a diverse collection of 12 papers with no common theme beyond the general one of river geomorphology. Individual chapters cover slope erosion from agricultural soils in Britain; dunes and sediment transport in the Fraser River estuary; bedload tracers in a step-pool channel; micro- and macroscale depositional patterns along a mountain channel; effective discharge for bedload transport in a sand-bed channel in Spain; a flow model of a braided, gravel-bed, proglacial river in Switzerland; a model of flood-plain sedimentation developed for an English channel; discontinuous hydraulic geometry along a gravel part of the Fraser River, resulting from a scour threshold; the adjustments of ephemeral channels in Spain to extreme discharges; historical channel change in northern Italy, and on the Vistula River in Poland; and modeling morphologic changes along the Brahmaputra River. Each chapter is well written and well edited, and the volume has a thorough subject index. Besides presenting interesting results from numerous individual studies, the volume provides an impression of current European research in river morphology; nine of the 12 chapters were contributed by Europeans (two chapters are from Canada and one from the United States). Because of the rather tenuous links between the individual chapters, this volume is probably most useful as a supplement to collections of papers focused on a single specific topic.

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Introduction to Geological Data Analysis. *A. R. H. Swan and M. Sandilands. Blackwell, Cambridge, Massachusetts, 1995, $39.95 (paperback).*

As in other sciences, data analysis plays a critical role in the geosciences. Considerable effort has thus gone into simplifying and making basic data analysis techniques accessible. Current software packages provide an amazing array of data analysis tools, which can often be applied to data with a simple point and click of a computer mouse. This not only provides an opportunity for detailed graphical and statistical analysis, but also the potential for abuse by the uneducated user.

In *Introduction to Geological Data Analysis,* Swan and Sandilands attempt to provide a background to avoid such abuse. They also aim to show that data analysis is an essential tool for hypothesis testing, which in turn is the basis of scientific reasoning. Another of their main themes is to show that geological data, often interpreted only in a qualitative manner, can be quantitatively analyzed.

For the most part, the book achieves its goals because it is intended for a true introductory audience. In this respect, many topics are covered too superficially to allow detailed application of a method. What is provided instead are excellent succinct definitions of important terms—like precision, accuracy, Fourier analysis—and crisp, simple figures that typically emphasize a single point with great clarity. For undergraduate courses, the figures will be a very helpful teaching aid.

The many worked examples, which are separated from the main text by boxes, provide another strength for the book. In my opinion, however, the applied facet of the book should be expanded even further with more examples and insights. An enjoyable aspect of other data analysis books, such as *Numerical Recipes* by W. H. Press et al., published in 1994, is that they give personal insights into the advantages and disadvantages of various techniques. When does one use the mean versus the median or mode, and what are the implications? When and why do various estimators give biased or unbiased estimates?

Another concern about *Introduction to Geological Data Analysis* is that some critical topics such as propagation of errors, inverse theory, and spherical statistics are not even mentioned. On the other hand, the book does delve into time series analysis and multivariate methods, topics that have been ignored in other geological data analysis books. Other problems include the absence of equation numbers, which makes some worked examples difficult to follow, and references that are largely restricted to the end of the chapters and that are insufficient for the reader to thoroughly investigate the various topics. Most of these problems may be insignificant if the book is used in second- and third-year undergraduate classes. Alternatively, this book could be used in the introductory part of a higher-level course if supplemented with other more advanced books like *Numerical Recipes*, by Press, *Geophysical Data Analysis: Discrete Inverse Theory*, by W. Menke (1984), and *Data Reduction and Error Analysis for the Physical Sciences*, by P. R. Bevington (1969).

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Call For GSA Committee Service—1997

The GSA Committee on Committees wants your help. The committee is looking for potential candidates to serve on committees of the Society or as GSA representatives to other organizations. You can help by volunteering yourself or suggesting the names of others you think should be considered for any of the openings and submitting your nomination on the form on page 29. Younger members are especially encouraged to become involved in Society activities.

Listed are the number of vacancies and a brief summary of what each committee does and what qualifications are desirable. If you volunteer or make recommendations, please give serious consideration to the special qualifications for serving on a particular committee. *Please be sure that your candidates are Members or Fellows of the Society and that they meet fully the requested qualifications.*

Volunteering or Making a Recommendation

All nominations received at headquarters by **Friday, July 12, 1996,** on the official one-page form will be forwarded to the Committee on Committees. *Council requires that the form be complete.* Information requested on the form will assist the committee members with their recommendations for the 1997 committee vacancies. Please use one form per candidate (additional forms may be copied). The committee will present at least two nominations for each open position to the Council at its October 29, 1996, meeting in Denver, Colorado. Appointees will then be contacted and asked to serve, thus completing the process of bringing new expertise into Society affairs.

Committee on Committees

The 1996 committee consists of the following people: Chair **Elaine R. Padovani,** U.S. Geological Survey, 905 National Center, Reston, VA 22092, (703) 648-6638; **Ina B. Alterman,** National Academy of Sciences, 2101 Constitution Avenue, NW, Washington, DC 20418, (202) 334-2748; **Richard L. Brown,** Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6, Canada, (613) 520-2600, ext. 4396; **Craig McHugh Jarchow,** Amoco Corporation, P.O. Box 800, Denver, CO 80201-0800, (303) 830-5146; **Jill McCarthy,** U.S. Geological Survey, Mail Stop 999, 345 Middlefield Road, Menlo Park, CA 94025, (415) 354-3140; **Pradeep Talwani,** Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, (803) 777-6449.

The GSA Council acknowledges the many member-volunteers who, over the years, have stimulated growth and change through their involvement in the affairs of the Society.

Each year GSA asks for volunteers to serve on committees, and many highly qualified candidates express their willingness to serve. Not everyone can be appointed to the limited number of vacancies; however, members are reminded that there are also opportunities to serve in the activities and initiatives of the sections and divisions. Annually, the Council asks sections and divisions to convey the names of potential candidates for committee service to the Committee on Committees.

Continuing Education **(2 vacancies)**
Directs, advises, and monitors the Society's continuing education program, reviews and approves proposals, recommends and implements guideline changes, and monitors the scientific quality of courses offered.

Committee members should be familiar with continuing education programs or have adult education teaching experience.

Day Medal **(2 vacancies)**
Selects candidates for the Arthur L. Day Medal. Committee members should have knowledge of those who have made "distinct contributions to geologic knowledge through the application of physics and chemistry to the solution of geologic problems."

Education **(2 vacancies—1 member-at-large; 1 elementary teacher)**
Stimulates interest in the importance and acquisition of basic knowledge in the earth sciences at all levels of education.

Committee members work with other interested scientific organizations and science teachers' groups to develop precollege earth-science education objectives and initiatives. The committee also promotes the importance of earth-science education to the general public.

Geology and Public Policy **(3 vacancies)**
Translates knowledge of the earth sciences into forms most useful for public discussion and decision making.

Committee members should have experience in public-policy issues involving the science of geology. They should also be able to develop, disseminate, and translate information from the geological sciences into useful forms for the general public and for the Society membership; they should be familiar with appropriate techniques for the dissemination of information.

Honorary Fellows **(2 vacancies)**
Selects candidates for Honorary Fellows, usually non–North Americans.

Committee members should have knowledge of geologists throughout the world who have distinguished themselves through their contributions to the science.

Membership **(2 vacancies)**
Evaluates membership benefits and develops recommendations that address the changing needs of the membership and attract new members.

Committee members must be GSA Fellows and must be able to attend one meeting a year. Previous experience in benefit, recruitment, and retention programs is desired.

Minorities and Women in the Geosciences **(2 vacancies)**
Stimulates recruitment and promotes positive career development of minorities and women in the geoscience professions.

Committee members should be familiar with minority and female education and employment issues and have expertise and leadership in such areas as human resources and education. Membership shall include representation of minorities and women and representatives from government, industry, and academia.

Nominations **(5 vacancies; one to be a member from Canada or Mexico)**
Recommends to the Council nominees for the positions of GSA officers and councilors.

Committee members should be familiar with a broad range of well-known and highly respected geological scientists.

Penrose Conferences **(1 vacancy)**
Reviews and approves Penrose Conference proposals; recommends and implements guidelines for the success of the conferences.

Committee members must either be past conveners or have attended two or more Penrose Conferences.

Penrose Medal **(2 vacancies)**
Selects candidates for the Penrose Medal.

Committee members should be familiar with outstanding achievements in the geological community that are worthy of consideration for the honor. Emphasis is placed on "eminent research in pure geology which marks a major advance in the science of geology."

Publications **(1 vacancy)**
Makes recommendations to the Council concerning Society publications.

Committee members should be familiar with a wide range of scientific publications and especially GSA publications. Should also have some knowledge of publication processes and costs and should have concern for the quality of content and presentation of GSA publications.

Research Grants **(3 vacancies)**
Evaluates research grant applications and selects grant recipients.

Committee members must be able to attend the spring meeting and should have experience in directing research projects and in evaluating research grant applications.

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NOMINATION FOR GSA COMMITTEES FOR 1997

(One form per candidate, please. Additional forms may be copied.)

(Please print)

Name of candidate ______________________________

Address ______________________________

____

Phone (   ) ______________________________

COMMITTEE(S) BEING ☐ VOLUNTEERED or ☐ NOMINATED FOR (please check):

Committee(s):

Comment on special qualifications:

☐ GSA Fellow   Section affiliation:

☐ GSA Member   Division affiliation(s):

Brief summary of education:

Brief summary of work experience (include scientific discipline, principal employer—e.g., mining industry, academic, USGS, etc.):

If you are VOLUNTEERING to serve GSA, please give the names of 2 references (please print):

Name: ______________________________

Phone: (   ) ______________________________

Name: ______________________________

Phone: (   ) ______________________________

If you are NOMINATING SOMEONE other than yourself to serve GSA, please give your name, address, and phone number (please print):

Name: ______________________________

Address: ______________________________

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Phone: (   ) ______________________________

DEADLINE: Please return this form to GSA Headquarters, Executive Director's Office, P.O. Box 9140, Boulder, CO 80301, Attn: Dianne Bernier, **by Friday, July 12, 1996.** *Form must be complete to be considered.*

GSA ANNUAL MEETINGS

1996

Denver, Colorado
October 28–31
Colorado Convention Center
Marriott City Center

General Chairs:
Gregory S. Holden *and* ***Kenneth E. Kolm,***
Colorado School of Mines

Technical Program Chairs:
John D. Humphrey *and* ***John E. Warme,***
Colorado School of Mines, Dept. of Geology & Geological Engineering, Golden, CO 80401, (303) 273-3819, fax 303-273-3859
E-mail: jhumphre@mines.edu

Field Trip Chairs:
Charles L. Pillmore, *(303) 236-1240 and*
Ren A. Thompson, *(303) 236-0929*
U.S. Geological Survey, MS 913, P.O. Box 25046, Denver Federal Center, Denver, CO 80225

Call for Papers and First Announcement appears in the April issue of *GSA Today.* Registration and housing information will appear in the June issue.

1997

Salt Lake City, Utah
October 20–23
Salt Palace Convention Center
Little America

General Chair: ***M. Lee Allison,*** *Utah Geological Survey*

Technical Program Chair: ***John Bartley,*** *University of Utah*

Call for Field Trip Proposals: We are interested in proposals for single-day and multi-day field trips beginning or ending in Salt Lake City, and dealing with all aspects of the geosciences. Please contact the field trip chairs listed below.

Paul Link
Department of Geology
Idaho State University
Pocatello, ID 83209-8072
(208) 236-3365
fax 208-236-4414
E-mail: linkpaul@isu.edu

Bart Kowallis
Department of Geology
Brigham Young University
Provo, UT 84602-4646
(801) 378-3918
fax 801-378-2265
E-mail: bjk@geology.byu.edu

Field trip guides will be published jointly by Brigham Young University Geology Studies and the Utah Geological Survey. Review drafts of field guides will be due March 15, 1997.

GSA SECTION MEETINGS — 1997

NORTHEASTERN SECTION, *March 17–19.* Sheraton Valley Forge Hotel, Philadelphia, Pennsylvania.

ROCKY MOUNTAIN AND SOUTH-CENTRAL SECTIONS, *March 20–21.* University of Texas at El Paso, El Paso, Texas.

SOUTHEASTERN SECTION, March 27–28. Auburn University, Auburn, Alabama.

NORTH-CENTRAL SECTION, *May 1–2.* University of Wisconsin Conference Center, Madison, Wisconsin.

CORDILLERAN SECTION, *May 21–23.* University of Hawaii, Oahu, Hawaii.

CALL FOR CONTINUING EDUCATION COURSE PROPOSALS

Proposals Due by December 1

The GSA Committee on Continuing Education 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 1997 Salt Lake City Annual Meeting or the 1998 Toronto Annual Meeting.

Proposals must be received by December 1, 1996. Selection of courses for 1997 will be made by February 1, 1997. For those planning ahead, we will also consider courses for 1998 at that time.

For proposal guidelines or information, contact:
Edna Collis, Continuing Education Coordinator, GSA headquarters,
1-800-472-1988, ext. 134. E-mail: ecollis@geosociety.org

FOR INFORMATION ON ANY GSA MEETING CALL THE GSA MEETINGS DEPARTMENT
1-800-472-1988 or (303) 447-2020, ext. 133
or E-mail: meetings@geosociety.org or see GSA's world wide web page at http://www.geosociety.org

Committee Service *continued from p. 28*

Treatise on Invertebrate Paleontology **(1 vacancy)**
Advises the Treatise editor in all phases of Treatise policy, including planning of new volumes as well as revisions; also gives advice on special editorial matters such as acceptance or rejection of contributed manuscripts.

Committee members should be familiar with and have a broad understanding of paleontology.

Young Scientist Award (Donath Medal) **(2 vacancies)**
Selects candidates for the Donath Medal.

Committee to have members covering a broad range of disciplines, i.e., geophysics, economic geology, stratigraphy.

Committee members should have knowledge of young scientists with "outstanding achievement(s) in contributing to geologic knowledge through original research which marks a major advance in the earth sciences."

Joint Technical Program Committee
GSA Representatives-at-Large **(2 vacancies)**
Supervises the review of abstracts for papers to be presented at the GSA annual meeting.

Representatives-at-large should be specialists in marine geology and petroleum geology, and must be able to attend a meeting in August. These subdisciplines are not represented by any of the associated societies or GSA divisions.

GSA Representative to the North American Commission on Stratigraphic Nomenclature **(1 vacancy)**
Must be familiar with and have expertise in stratigraphic nomenclature.

GSA Representative to the American Association for the Advancement of Science (AAAS) **(2 vacancies)**
Section E, Geology and Geography, and Section W, Atmospheric and Hydrospheric Sciences
Must be members of AAAS who will be attending the AAAS meetings under other auspices: Term February 23, 1997, to February 23, 2000. ■

CLASSIFIED ADVERTISING

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

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Positions Open

HYDROGEOSCIENCE, VIRGINIA TECH

The Department of Geological Sciences at Virginia Polytechnic Institute and State University (Virginia Tech) continues to seek rolling applications to hire faculty as part of restructuring using opportunities created by retirements. At this time we are inviting applications for a second tenure-track faculty position in Hydrogeoscience (first hydroposition filled in 1995-96). The position is at the Assistant Professor level only and the department intends to fill the position in the 1996-97 academic year. Candidates with a strong quantitative background in fluid flow/transport in subsurface porous/fractured media including multi-phase flow are encouraged to apply. A Ph.D. is expected at the time of appointment. Review of applications will begin July 1, 1996 and continue until the position is filled.

The present faculty, 19 full-time tenured and 2 part-time, have diverse strengths and represent economic geology, earthquake seismology, exploration geophysics, geochemistry, hydrogeosciences, mineralogy, paleontology, petrology, sedimentology, structural geology, and tectonics. For detailed information applicants are encouraged to visit the departmental home page at http://www.geol.vt.edu. The department offers B.S., M.S., and Ph.D. degrees in geological and geophysical sciences. Faculty are expected to teach introductory level undergraduate geoscience courses and undergraduate/graduate level courses in their areas of expertise. They are also expected to direct M.S. and Ph.D. candidates while developing and maintaining externally funded research programs. New faculty will play a central role in collaborating with complementary department/university programs and developing applied programs to prepare students for future job markets. Candidates must be able to demonstrate expertise in quantitative applications in the geosciences.

Interested applicants should send a letter of interest, curriculum vitae, transcripts, names of three references, a statement of anticipated research and teaching interests, along with a short essay explaining were the applicant would like to see him/ herself within the geosciences in the 21st century. Applicants should send their application package to Cahit Coruh, Chairman, Department of Geological Sciences, Virginia Tech, 4044 Derring Hall, Blacksburg, VA 24061-0420; Phone: 540-231-6894; TDD: 540-231-3749; fax: 540-231-3386; E-mail: coruh@vt.edu

Virginia Tech has a strong commitment to the principle of diversity and, in that spirit, seeks a broad spectrum of candidates including women, minorities, and people with disabilities. Individuals with disabilities desiring accommodations in the application process should notify Cahit Çoruh at the above address. Virginia Tech is an equal opportunity/affirmative action employer.

UNIVERSITY OF ILLINOIS URBANA–CHAMPAIGN MINERALOGY/PLANETARY GEOLOGY

The Department of Geology seeks to fill a position of Visiting Assistant Professor or Visiting Lecturer. The successful candidate is expected to teach courses in mineralogy and introductory courses in planetary geology, physical geology, and environmental geology. Experience in these or closely related branches of geology is highly desirable. Candidates with a Ph.D. or equivalent in geoscience are preferred, but applications from candidates who have not yet finished the dissertation will be considered. Applicants should be able to demonstrate promise of being excellent instructors with superior interpersonal skills.

The term of the appointment will be for one year with the possibility of renewal for additional years. This is a non-tenure track position. The starting date of the appointment will be August 21, 1996.

Applicants should send a curriculum vita, list of publications, statement of research interests, and the names of three refererences to: Professor R. James Kirkpatrick, Department of Geology, University of Illinois, 1301 W. Green Street, Urbana, IL 61801; (217) 333-1018; fax 217-244-4996. Preference will be given to applications received before May 21, 1996.

The University of Illinois is an equal opportunity/affirmative action employer. Women and minorities are encouraged to apply.

Services & Supplies

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

Opportunities for Students

*Do you have an opportunity for a student? Your first 25 lines are **FREE**!. Contact the GSA Advertising Department. Copy is due by the first of the month, one month prior to issue.*

CALENDAR

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

1996 Penrose Conferences

October

October 8–14, **Exhumation Processes: Normal Faulting, Ductile Flow, and Erosion,** Island of Crete. Information: Uwe Ring, Institut für Geowissenschaften, Universität Mainz, Becherweg 21, D-55099 Mainz, Germany, 49-6131-392164, fax 49-6131-394769, E-mail: ring@ mzdmza.zdv.uni-mainz.de.

1996 Meetings

July

July 22–26, **Society for Industrial and Applied Mathematics Annual Meeting,** Kansas City, Missouri. Information: SIAM Conference Coordinator, 3600 University City Science Center, Philadelphia, PA 19104-2688, (215) 382-9800, fax 215-386-7999, E-mail: meetings@siam.org.

July 28–31, **American Association of Petroleum Geologists Rocky Mountain Section Meeting,** Billings, Montana. Information: L. D. Vern Hunter, 2903 Parkhill Dr., Billings, MT 59102, (406) 656-5197.

August

August 23–29, **Geomorphic and Climatic Significance of Rock Glaciers (Chapman Conference),** Northwest Field Station near Cody, Wyoming. Information: Doug Clark, Geological Sciences, Box 351310, University of Washington, Seattle, WA 98195, (206) 543-6229, E-mail: doug@rad.geology.washington.edu; Eric Steig, INSTAAR, University of Colorado, Boulder, CO 80309-0450, (303) 492-5792, E-mail: steig@stripe.colorado.edu; or AGU Meetings Department, Rock Glaciers Conference, 2000 Florida Ave. NW, Washington, DC 20009, (202) 462-6900, or 1-800-966-2481, fax: 202-328-0566, E-mail: meetinginfo@ kosmos.agu.org. *(Abstract deadline: May 17, 1996.)*

September

September 13–18, **Alluvial Basins, Giens, France.** Information: Josip Hendekovic, European Science Foundation, 1 Quai Lezay-Mamésia, 67080 Strasbourg Cedex, France, phone (33) 88 76 71 35, fax 33 88 36 69 87, E-mail: euresco@esf.org, WWW: http://www.esf.org/euresco.

September 16–20, **7th International Symposium on Deep Seismic Profiling of the Continents,** Asilomar, California. Information: Simon Klemperer, Dept. of Geophysics, Stanford University, Stanford, CA 94305-2215, (415) 723-8214, fax 415-725-7344, E-mail: klemp@ pangea.stanford.edu.

October

October 21–24, **Magnetization of Oceanic Crust,** Orcas Island, Washington. Information: H. P. Johnson, Oceanography, Box 357940, University of Washington, Seattle, WA 98195, (206) 543-8474, E-mail: johnson@ ocean.washington.edu.

November

November 4–7, **Global Networks for Environmental Information,** Lake Buena Vista, Florida. Information: ERIM/Eco-Informa, P.O. Box 134001, Ann Arbor, MI 48113-4001, (313) 994-1200, ext. 3234, fax 313-994-5123, E-mail: wallman@ erim.org, WWW: http://www.erim.org/ CONF/ conf.html.

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

Geological Society of America

Annual Meeting and Exposition

Denver, Colorado • October 28–31, 1996

Call for Papers April *GSA Today*

Abstracts Due July 9

Preregistration Due September 20

EARTH SYSTEM SUMMIT

Denver

Registration and Housing Information
June *GSA Today*

Program Schedule
September *GSA Today* and the Web

For Information:

GSA Meetings Department
P.O. Box 9140
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