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INSIDE

Crater Lakes Reveal Volcanic Heat and Volatile Fluxes

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ABSTRACT

Aqueous lakes situated at the top of active but quiescent volcanoes serve as gas condensers and calorimeters that provide long-term integrated release rates of volatiles and heat during passive degassing of subsurface magma. Some crater lakes contain the most acid natural water on Earth (pH <0). Analysis of hydrogeology of the acid lake at Volcán Poás, Costa Rica, reveals volatile release rates into the hydrosphere of 0.78 Gg/yr fluorine, 15 Gg/yr chlorine, and 13 Gg/yr sulfur (1 Gg = 10^9 g) and a power output of 200 MW during passive degassing in 1988–1989. An equivalent flux of sulfur may be precipitating as chemical sediments in the crater lake. After magma intrusion or hydrofracturing events in the subsurface, these fluxes were observed to double (F, Cl) or even increase tenfold (S) for short periods of time. At Grímsvötn volcano, Iceland, the database for flooding from the lake suggests volatile release rates of 0.058 Gg/yr fluorine, 6.8 Gg/yr chlorine, 3.1 Gg/yr sulfur, and 39 Gg/yr carbon integrated over 15, 32, 32, and 15 yr, respectively, and 4000–5000 MW power output. Volatile flux ratios calculated over several years at Poás and over 15 yr at Grímsvötn are observed to be 0.87 and 0.71 (S/Cl) and 17 and 48 (S/F); the C/S flux ratio averaged 14 over 15 years at Grímsvötn. Power output for each volcano can also be used to calculate rate of magma cooling in the subsurface; the volatile release rate divided by the rate of magma cooling yields estimates for the decrease in volatile content of subsurface magma during cooling. For the shallowly buried calc-alkalic basalts and andesites at Poás, the magma lost 175 ppm F, 3400 ppm Cl, and 3000 ppm S; for the deeply buried basalts at Grímsvötn, the magma lost <1 ppm F, 75 ppm Cl, 34 ppm S, and 1600 ppm CO_2. Integrated estimates for release of F, Cl, and S at Poás are roughly within an order of magnitude of published estimates for most passively degassing volcanoes. However, F, Cl, S, and C fluxes at Grímsvötn are smaller than observed at noneruptive volcanoes. These low values suggest either that there are unaccounted-for sinks in the system or that other degassing estimates, based on short-term sampling, are overestimates. Only a few of the 80 or so crater lakes of the world have been analyzed; these lakes may reveal the long-term power and volatile release rates for these volcanoes.

Figure 2. Photograph looking north into the crater of Volcán Poás, Costa Rica. Visible are the Main Crater walls, the pyroclastic cone of 1953–1954 (center), and the greenish yellow waters of the crater lake, from which steam clouds emanate. The crater is about 800 m in diameter, and its floor lies at 2300 m above sea level.

INTRODUCTION

To assess the effects of anthropogenic input of critical components on the Earth system, we need to quantify the rates of natural release and cycling of these components into and within Earth's hydrosphere, biosphere, geosphere, and atmosphere. For example, to model the geochemical carbon cycle, we need to quantify degassing rates of CO_2 from volcanoes. Similarly, degassing rates of F, Cl, and S are needed to quantify the geochemical cycles of these elements. Most global volatile budgets rely on short-term measurements of volatile release at individual volcanoes, which are then extrapolated to longer time frames and multiplied by the number of passively degassing or actively erupting volcanoes (e.g., Stoiber et al., 1987). Gas emission rates and gas chemistry are measured by remote correlation spectrometry, direct fumarole sampling, treated filter analysis, sublimate analysis, MIRAN infrared spectrophotometry, Raman spectrometry, satellite remote sensing, incrustation sampling, ice-core-inclusion analysis, and melt-inclusion gas analysis. Most of these techniques do not provide long-term emission rates, unless permanent monitoring stations have been established. However, for at least 12% of the 714 Holocene-age or younger volcanoes listed in the *Catalog of Active Volcanoes of the World,* aqueous lakes in the crater condense volcanic volatiles. These lakes also change in volume and temperature, reflecting the power output of the volcano. Acting as condensers and calorimeters, these crater lakes thus integrate the long-term volatile and heat output of some active volcanoes.

Almost 40 crater lakes are reported to have above-ambient temperatures and to contain acidic, sulfur-rich water. Some of these lakes maintain the lowest pH of any natural waters on Earth (pH <0). A few of these lakes have been sampled and analyzed: e.g., El Chichón, Mexico; Kusatsu-Shirane, Japan; Mt. Ruapehu, New Zealand; Volcán Poás, Costa Rica; Rincón de la Vieja, Costa Rica. Other crater lakes contain neutral-pH water that represents condensed volcanic gases diluted by meteoric influx. The pH of the lake water is determined by the rates of the natural titration reaction: acid volcanic gas + water + acid-neutralizing silicate rock. In many cases, these closed-basin lakes concentrate dissolved solutes until chemical sediments (e.g., gypsum) precipitate.

Estimation of the heat, mass, and/or solute budgets of a few crater lakes has revealed mechanisms of fluid flow and heat exchange above shallow magma chambers (Shepard and Sigurdsson, 1978; Björnsson, 1988; Hurst et al., 1991; Brown et al., 1989; Brantley et al., 1992; Rowe et al., 1992a). We summarize the implications of the heat and mass balance studies at two volcanoes: Volcán Poás, a convergent-plate volcano in Costa Rica, and Grímsvötn, a hot-spot volcano in Iceland.

VOLATILE AND HEAT BUDGETS

To estimate the volatile and heat budget of a volcanic crater lake, we define the outputs and inputs of the system (Fig. 1): R_e (evaporation), R_{out} (river or floodwater flow), R_s (bottom seepage), R_{in} (low-temperature influx), R_{gv} (geothermal influx as vapor), R_{gw} (geothermal influx as water). The flux, R_{in}, can be composed dominantly of rain (R_r) as in Volcán

Crater Lakes *continued on p. 176*

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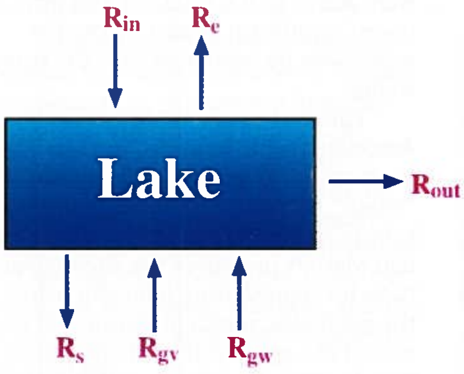

Figure 1. A box model for crater lakes summarizing the water fluxes: R_{in} (low-temperature meteoric input), R_{gv} and R_{gw} (geothermal input as vapor and liquid water, respectively), R_e (evaporative loss), R_s (seepage loss), and R_{out} (outflow as rivers or floodwaters).

Editor's Note:

Each year the David and Lucile Packard Foundation awards 20 Fellowships for Science and Engineering in a national competition to promising young scientists and engineers working in fields that receive relatively less popular attention than high-energy physics, space, and medicine. Each Packard Fellowship provides \$100,000 per year for five years to the Fellow's institution, \$90,000 of which is for use of the Fellow to support his/her research work. These young researchers are truly among the "best and brightest" in the United States. The science article in this issue is one of several in which Packard Fellows in earth science report on research in their field.

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Penrose Conference Report

Applications of Strain: From Microstructures to Orogenic Belts

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Scott R. Paterson, Department of Geological Sciences, University of Southern California, Los Angeles, CA 90089–0740

A Penrose Conference on Applications of Strain: From Microstructures to Orogenic Belts was held September 9–13, 1992, near Halifax, Nova Scotia. There were 71 participants, including five from Canada and 15 from Europe and Japan. They represented a broad range of backgrounds, from academic to industry, and spanning such disciplines as structural geology, geodynamical modeling, seismology, and petrology. The conference also benefited from the assistance and active involvement of its 15 student participants.

The conference program included three days of meetings and two days of field trips. The field trips, led by Jack Henderson, Mariette Henderson, and Tom Wright, focused on the deformational history of the lower Paleozoic Meguma Group, which is beautifully exposed along the Atlantic coast of Nova Scotia. The Meguma contains a variety of mesoscale structures, but even more important is the presence of useful strain markers, such as worm burrows, sand volcanoes, dewatering tubes, quartz veins, fiber overgrowths, and bedding and cleavage geometry. The field trip leaders defended their interpretation that deformation of the Meguma Group and formation of a well-developed pressure-solution cleavage was associated with large volume strains. They argued that the volume strain reflected both a loss of porosity and a loss of mass. This interpretation, that low-temperature deformation might be attended by wholesale loss of mass at a regional scale, remained a contentious and controversial issue throughout the conference.

An important objective of the conference was to ensure that a significant amount of time was devoted to informal presentations and discussions. As such, we limited the number of oral presentations to three to four per session. The rest of the time was devoted to a discussion period and poster presentations. Each discussion period also included unscheduled "comment" presentations, where an idea was briefly described using no more than two to three slides and five minutes. About 20 people made comment presentations. This format provided an important degree of flexibility that helped to ensure that discussions were not too highly structured or influenced by the oral presentations. About two hours of each session were devoted to poster sessions, which provided another format for informal discussion and exchange.

Much of the success of the conference stemmed from the informal exchanges outside of the oral presentations, but it is difficult to provide a useful account of those activities. Thus, in this report we have chosen to highlight the oral presentations because they help to illustrate the topics that were covered.

The first session was entitled "New Methods, Computer-Aided Analysis, and Primary Fabrics." Declan De Paor provided a computer-illustrated demonstration of the various tools that he employs in strain analysis, with an emphasis on a graphical approach. Two particularly interesting topics were the analysis of steady and accelerating flow under conditions of general shear and the use of Bézier curves to model heterogeneous deformation and displacement. Norman Fry presented a cautionary review of the density methods for strain analysis and discussed possible extensions of his Fry method. John Stamatakos reviewed the current status of magnetic anisotropy measurements as an indirect but quick method for measuring strain in bulk samples.

In the second session, "Strain, Vorticity, and Microfabric Development," Win Means presented a lucid discussion of continuum mechanics concepts as applied to microfabric analysis. This helped to establish a common conceptual basis for subsequent discussions about κ_N, the kinematic vorticity number, which represents an instantaneous measurement of the degree of noncoaxiality of the flow at a point. (In a less formal fashion, it can be viewed as a relative measure of the simple shearing component of the deformation.) Means emphasized the importance of selecting an appropriate reference frame. Microfabrics are best analyzed using an internal reference frame that considers the deformation of the material at a point relative to the instantaneous local stretching axes. This approach acknowledges the fact that the microfabric evolves as a result of local stretching, without direct reference to an external or geographic reference frame. Simon Wallis discussed how rotated porphyroblasts can be used to reconstruct the pattern and character of general shear in an orogenic wedge, the objective being to determine how tectonic processes might contribute to unroofing of the metamorphic interior of the wedge. Norm Gray introduced a new method for analyzing inclusion trails in rolled garnets. The method uses the geometry of the inclusion trails together with the Jeffery equations, which describe the rotation of a rigid inclusion embedded in viscously flowing matrix, to invert for the strain and vorticity history of the matrix around the garnet.

In the third session, "Volume Strain, Fluid Flow, and Mass Transfer," Ron Vernon's comprehensive review helped to put the various types of evidence, such as geometric strain measurements, textural observations, and chemical measurements of differentiation and mass loss, into an appropriate perspective. Charles Onasch presented a detailed analysis of volume strain in quartz arenites from the Appalachians. He showed interesting evidence that microveins within individual detrital grains could account for a local intragranular volume increase of 5% to 17%, whereas interpenetration at grain boundaries indicated 0% to 30% volume loss. Jay Ague provided a general review of the chemical approach to measuring volume strain. Given an appropriate immobile or conserved element, the chemical method can be used to measure *relative* changes in mass. However, the method is insensitive to volume strains caused by changes in porosity or average grain density, which makes it difficult to compare the results of the chemical method with those determined from geometric methods. Ague also stressed that an essential requirement for the chemical method is that the protolith have a well-defined composition with relatively little variation across the study area.

The fourth session, "Macroscale Structures," focused on how observations at a local scale might be integrated to the scale of the outcrop and larger. Cees Passchier's talk on the development of structures under conditions of general ductile shear highlighted the importance of κ_N as a general descriptor for steady two-dimensional deformation, but it also showed the difficulty of using this descriptor in geological studies where the deformation might have been unsteady and/or three dimensional. Terry Engelder presented the results of an integrated strain study of Appalachian siltstones, for which it is possible to compare various strain and stress methods, including magnetic susceptibility, chlorite fabric, Fry center-to-center, and deformed fossils. David Anastasio reviewed a study of folding mechanisms in the Lost River Range, Idaho, that used fiber overgrowths on pyrites as a record of incremental strains. Christian Teyssier reviewed the use of strain measurements for the study of emplacement mechanisms for granites. He emphasized the role of particle interactions and concluded that this mechanism should reduce the degree of preferred shape orientation.

In the fifth session, "Orogen-Scale Structures," John Ramsay discussed the difficulties of relating outcrop-scale strain measurements to the orogen-scale displacement field. He argued that strain data must be interpreted in the context of strain compatibility and that this type of analysis usually revealed the need for volume strain, at least at a local scale. Arnaud Pecher reviewed the structural evolution of the Himalaya, and in particular noted the difficulties in using the strain compatibility requirement in real geologic settings, mainly because of the poorly resolved contribution of faulting to the overall deformation. Martin Burkhard used the results of strain studies in the Helvetic Alps to show that the nappes had been affected by a two-phase history involving transport-parallel extension during nappe emplacement and orogen-parallel extension after emplacement. His talk highlighted the problems associated with explaining orogen-parallel extension. Gautam Mitra reviewed the current status of strain studies across the Idaho-Utah-Wyoming thrust belt, emphasizing implications for balancing cross sections and for mechanical models. He showed that cleavage fabrics generally predated thrust faulting, indicating that ductile strain mechanisms were active in the foreland and produced significant strains before the rocks were incorporated into the thrust wedge.

The sixth session, "Brittle Strain Associated with Faulting," focused on methods for estimating the amount of "strain" that discrete brittle faults contribute to the overall deformation. Randall Marrett presented the theoretical basis for representing fault slip using the geometric moment tensor and discussed the applicability of empirically based scaling laws for describing slip and size distributions for fault populations. He showed how the two

continued on p. 175

GSA Names Honorary Fellows and Awardees

Society awards for 1993 will be presented to the following individuals at the Boston Annual Meeting. The newly elected Honorary Fellows are also announced.

New Honorary Fellows

Sir George Malcolm Brown
Rosedene, Shipton Road
Milton-under-Wychwood
Oxfordshire, England OX7 6JT

Professor Victor A. Ramos
Diaz Velez 820 La Lucila
Buenos Aires 1636, Argentina

Dr. Kristján Saemundsson
National Energy Authority of Iceland
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Medal and Award Recipients—1993

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Alfred G. Fischer
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University of Southern California
University Park
Los Angeles, California 90089-0741

Day Medal
Hugh P. Taylor, Jr.
Division of Geological and Planetary Sciences
California Institute of Technology
Pasadena, California 91125

Donath Medal (Young Scientist Award)
Michael C. Gurnis
Department of Geological Sciences
University of Michigan
Ann Arbor, Michigan 48109-1063

GSA Distinguished Service Award
Michel T. Halbouty
M. T. Halbouty Energy Company
The Halbouty Center
5100 Westheimer Road
Houston, Texas 77056

George R. (Rip) Rapp, Jr., Archaeological Geology Award
Donald Lee Johnson
Department of Geography
University of Illinois
607 South Matthews Street
Urbana, Illinois 61801

Gilbert H. Cady Award (Coal Geology Division)
Marlies Teichmüller
Geologisches Landesamt Nordrhein-Westfalen
de Greiff Str. 195
47083 Krefeld
Germany

E. B. Burwell, Jr., Award (Engineering Geology Division)
Richard W. Galster
P.O. Box 908
Edmonds, Washington 98020

George P. Woollard Award (Geophysics Division)
Ronald M. Clowes
Department of Geological Sciences
University of British Columbia
6339 Stores Road
Vancouver, B.C., Canada V6T 1Z4

History of Geology Award
Martin Guntau
Thomas-Müntzer-Platz 30
B-O-2500 Rostock 1
Germany

O. E. Meinzer Award (Hydrogeology Division)
L. Neil Plummer
U.S. Geological Survey
Water Resources Division
431 National Center
Reston, Virginia 22092

G. K. Gilbert Award (Planetary Geology Division)
Michael H. Carr
U.S. Geological Survey
345 Middlefield Road, MS-946
Menlo Park, California 94025

Kirk Bryan Award (Quaternary Geology and Geomorphology Division)
William B. Bull
Department of Geosciences
University of Arizona
Tucson, Arizona 85721

Structural Geology and Tectonics Division Career Contribution Award
Benjamin M. Page
Department of Geology
Stanford University
Stanford, California 94305-2115

Penrose Conference *continued*

approaches can be combined to provide a measure of the bulk strain due to slip on a network of faults. Trenton Cladouhos showed how the geometric moment tensor could be extended to provide an approximate estimate of brittle strain for large-slip faults, giving examples from the San Andreas fault and the Andean thrust belt. Chris Scholz examined some of the physical processes that might be responsible for the observed scaling relation for faults. He then summarized the results of some recent studies on the relation of fault size to net slip which indicate that slip on small faults probably accounts for a much smaller proportion than previously thought of the total brittle strain within a network of active faults.

The objective of the seventh and last session, "Use of Strain in Computational Models," was to see how strain data might be combined with geodynamic modeling. Sean Willett presented the results of finite-element modeling of large deformation in a contractional Coulomb wedge, with a special emphasis on how instantaneous strain, K_N, and finite strain varied within a deforming wedge. Julia Morgan presented the results of a numerical study in which the finite strain in deformed sedimentary strata from the toe of the Nankai accretionary wedge was determined using changes in bedding thickness and porosity, as observed in a multichannel seismic reflection profile. Ian Duncan reviewed the advantages and problems associated with use of the finite-element method for deformational modeling.

The conference provided an important opportunity to assess the current state of strain-analysis research. Four topics generated considerable interest and debate: (1) the concept of general shear and the use of κ_N as a generalized descriptor of internal vorticity in deforming rocks; (2) the magnitude of volume strain, and in particular mass loss, in deformed rocks; (3) the determination of brittle strain—i.e., the bulk strain due to faulting—and how it compares with strain accumulated by ductile processes; and (4) the potential to incorporate strain data in geodynamical models. We view these developments as an indication that strain analysis is taking on a greater importance, in both structural geology and other fields such as petrology (mass transfer and volume strain), geodynamical modeling, and seismology.

Acknowledgments

We thank the conference participants, whose enthusiasm and stamina through a very tightly scheduled meeting made the experience stimulating and rewarding for us; Lois Elms for her assistance in organizing the conference; and the National Science Foundation for providing partial support for student participants and foreign keynote speakers. ■

Penrose Conference Participants

Jay Ague
David Anastasio
Edward Beutner
Frank Bilotti
Mark Brandon
Roland Bürgmann
Martin Burkhard
Karen Carter
Trenton Cladouhos
Brooks Clark
Kevin Corbett
Brent Couzens
Darrel Cowan
Jean Crespi
Sandy Cruden
Declan De Paor
Ian Duncan
Terry Engelder
Eric Erslev
Jeffrey Feehan
David Ferrill
Donald Fisher
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Pierre-Yves Robin
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Christian Teyssier
Basil Tikoff
Ken Tillman
Othmar Tobisch
Ron Vernon
Simon Wallis
David Ward
John Weber
Ruud Weijermars
Sean Willett
Michael Williams
Steven Wojtal
Nick Woodward
Tom Wright

Penrose Conference Scheduled

Fractured Unlithified Aquitards: Origins and Transport Processes

June 15–20, 1994

A Geological Society of America Penrose Conference, Fractured Unlithified Aquitards: Origins and Transport Processes, will be held June 15–20, 1994, in Racine, Wisconsin. Cosponsors are the Waterloo Centre for Groundwater Research (an Ontario Centre for Excellence), the Department of Geology and Geophysics at the University of Wisconsin, Madison, and the Wisconsin Geological and Natural History Survey.

Clay-rich unlithified aquitards compose much of the surface or near-surface sediment of the northern glaciated regions of the world. Although in many areas they govern rates of flow to and water chemistry in underlying aquifers and provide a measure of protection from contaminant spills and leaks, few studies have been done on solute transport in aquitards. Evidence suggests that while the migration of ground-water constituents is controlled by molecular diffusion in some aquitards, in others migration is controlled by advection in vertical fractures. Why some aquitards are fractured and others are not and the depth to which open fractures occur are much-debated issues among scientists working in the field.

Because the field of hydrogeology has traditionally focused on aquifers, many of the conceptual models developed in the study of aquifers are being challenged in the study of clay aquitards. One of the keys to solute transport in clayey aquitards is the behavior of naturally occurring ground-water tracers such as environmental isotopes, major ions, and gases. The use of these tracers requires detailed analyses of aquitard lithology, mineralogy, and time and mode of deposition in order to understand tracer cycling.

The goal of this conference is to bring together researchers from various areas of specialization such as Quaternary geology, aquifer-aquitard hydraulics, soil mechanics, geochemistry, isotope geochemistry, isotope hydrology, and clay mineralogy. In classroom, field, and informal settings, we will discuss and debate data, concepts, hypotheses, and dilemmas pertaining to unlithified clay-rich aquitards.

Participation in the conference will be limited to 120 persons. Attendance for graduate students and non–North American participants may be subsidized. Scientists in these categories are encouraged to apply. The registration fee will be approximately $600 and will include field trip expenses, all meals, and lodging. Formal invitations will be mailed by mid-January 1994.

Application Deadline: December 1, 1993. Applications should be sent to John A. Cherry.

Co-conveners:
John A. Cherry, Waterloo Centre for Groundwater Research, University of Waterloo, Ontario N2L 3GI, Canada, (519) 888-4516, fax 519-746-5644
David M. Mickelson, Department of Geology & Geophysics, University of Wisconsin–Madison, 1215 W. Dayton St., Madison, WI 53706-1692, (608) 262-7863, fax 608-262-0693
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Crater Lakes *continued from p. 173*

Poás, or dominantly of meltwater from ice (R_i) as in Grímsvötn.

Water mass balance is simply the balance between mass inputs, $R_{in} + R_{gv} + R_{gw}$, and outputs, $R_e + R_s + R_{out}$. Heat balance is simply the balance between heat inputs, $R_{gv}L_v + (R_{gv} + R_{gw})(h_h - h_l)$ and outputs, $R_eL_e + R_iL_i + R_{in}(h_l - h_{in}) + R_sh_l + R_{out}h_l$. Here, L_v is the latent heat of condensation at the temperature (T_h) at which the geothermal vapor enters the lake; L_e is the latent heat of evaporation at lake temperature (T_l); L_i is the latent heat of melting of ice; h_h is the specific enthalpy of water at T_h; h_l is the specific enthalpy of water at T_l; and h_{in} is the specific enthalpy of water at the temperature at which rain or meltwater enters the lake. We can also write a mass balance on a dissolved solute of concentration c which is non-volatile and does not dissolve or precipitate in the lake. Solute mass balance equates the solute inputs due to low-temperature water ($c_{in}R_{in}$), geothermal vapor ($c_{gv}R_{gv}$), and geothermal water ($c_{gw}R_{gw}$), to the solute outputs due to evaporation (c_eR_e), seepage (c_sR_s), and river or flood output ($c_{out}R_{out}$).

Slightly modifying the approach of Björnsson (1988), we define the ratio of geothermal input to meteoric input as $k = (R_{gv} + R_{gw})/R_{in}$. Noting that seepage or river output is chemically identical to lakewater, $c_{out} = c_s = c_l$, we can solve the heat and mass balance equations and constrain k by noting that either R_{gv} or R_{gw} can equal zero:

$$\frac{K_2 - K_1h_l}{h_h - 2h_l + L_v} < k < \frac{K_2 - K_1h_l}{h_h - 2h_l}.$$

In this equation, $K_1 = (R_e + R_{out})/R_{in} - 1$ and $K_2 = (R_eL_e + R_iL_i + (h_l - h_{in})R_{in} + R_{out}h_l)/R_{in}$. This value of k can also be used to calculate the ratio of geothermal influx to total water influx: $k/(1 + k)$. A further constraint can be placed on k by estimating c_{gw}, the concentration of solute in the liquid component of geothermal influx (see Björnsson, 1988).

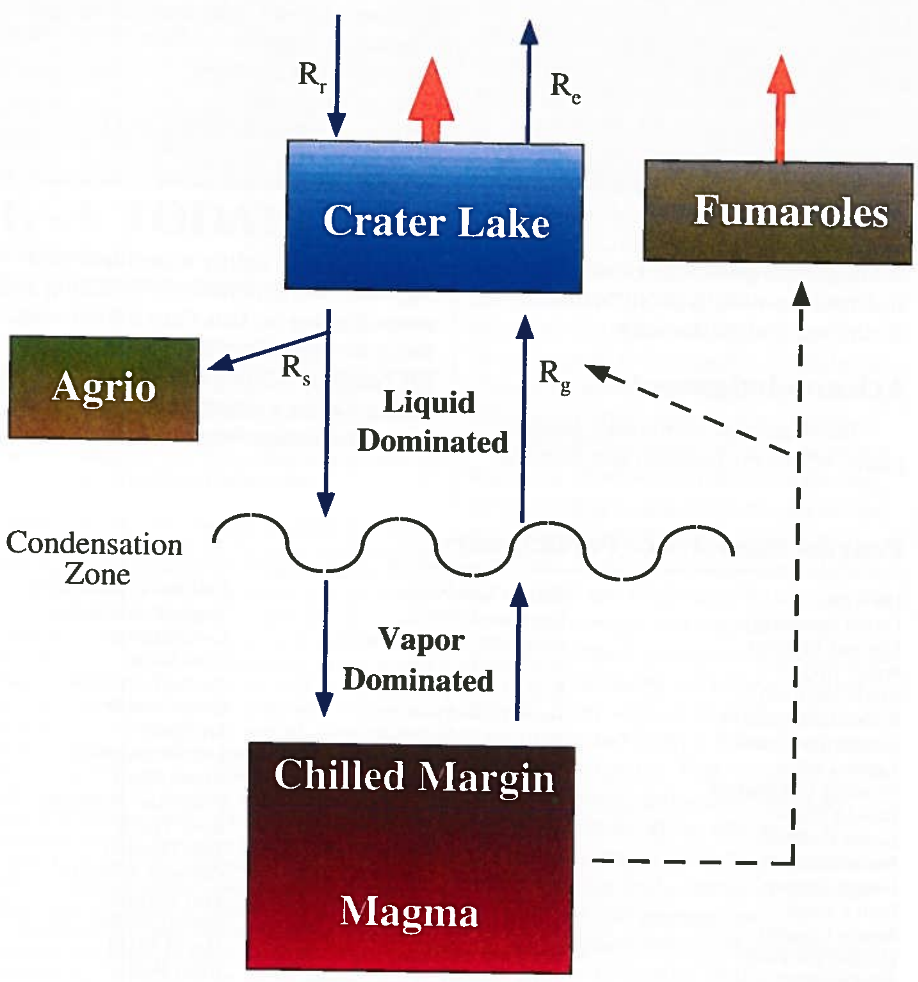

Figure 3. Box model for the summit hydrology of Volcán Poás. Inputs to the crater lake are rainfall (R_r) and geothermal fluid (R_g); outputs from the lake are evaporation (R_e) and seepage (R_s). Downward-seeping brine is heated until it rises again as geothermal influx to the lake, or escapes the summit system by flowing northwest to the Agrio River system. The simplest model that explains water mass, solute mass, and heat balance of the crater lake hypothesizes two convection cells in the volcano: an upper, liquid-dominated cell that is manifested at the surface as the lake, and a lower, vapor-dominated cell. High-temperature vapor escapes directly to the atmosphere as fumaroles emanating from the cinder cone in the Main Crater.

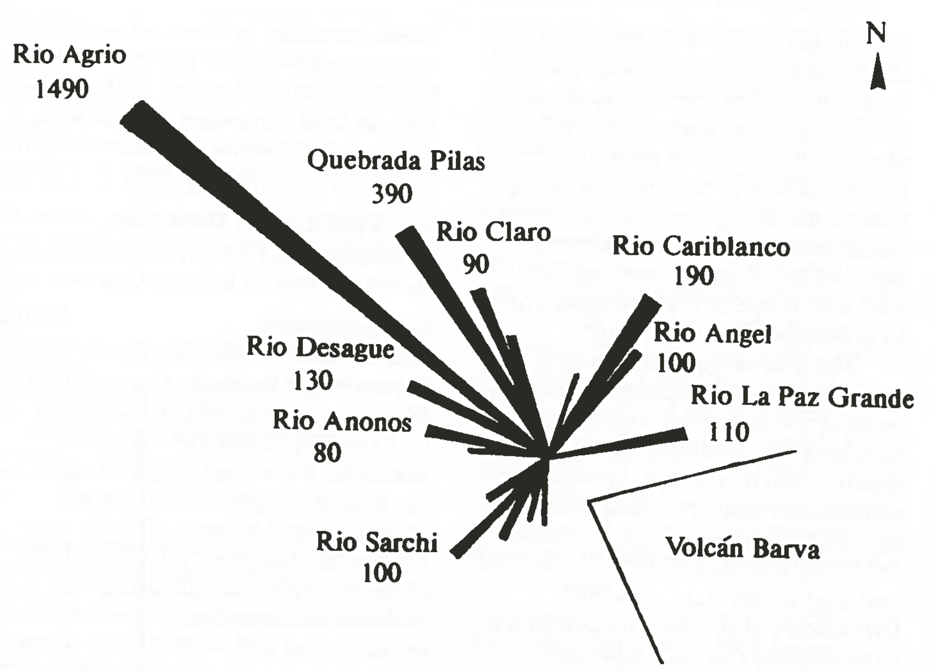

Figure 4. Schematic diagram illustrating the relative contribution of chemical weathering in rivers as a function of position around Volcán Poás. Triangular rays are scaled to indicate solute fluxes (metric tons of rock per year per km² of drainage basin) for each river as labeled. A second volcano, Volcán Barva, abuts Poás to the southwest.

HEAT AND WATER BUDGET OF VOLCÁN POÁS

Volcán Poás, along with adjacent volcanic centers, forms the Cordillera Central of Costa Rica. The northern half of the main crater is occupied by a pit crater, which contains an acidic lake (Fig. 2); the southern edge of the lake consists of a 30-m-high pyroclastic cone that formed during the last phreatomagmatic eruption (1953–1954) and which represents the locus of subaerial fumarolic activity. The lake varied between 38 and 91 °C and between pH values of –0.9 to 0.5 between 1978 and 1991. Gravity measurements suggest that the top of the cooling magma body lies at a depth of ~500 m (Rymer and Brown, 1987).

Inputs and outputs of the summit hydrothermal system, including ground-water seepage to the watershed of the Agrio River to the northwest, are summarized in Figure 3. Rowe et al. (1992a) analyzed all available data over the period 1978–1990 and concluded that the baseline power output of the volcano was 200 MW, with fluctuations to 800 MW. Using appropriate values summarized by Rowe et al. (1992a) for Poás for the period March 22, 1978, to January 1, 1980, we calculate that k must lie between 0.77 (all vapor geothermal influx) and 8.5 (all liquid geothermal influx). Noting that lake and rain water at Poás contained 1400 ppm and 4 ppm Na, respectively, geothermal fluid must have had a concentration of dissolved Na at least 4% higher than the lake water. Rowe et al. (1992a) concluded that the lake thus represents the upper manifestation of a liquid-dominated convection cell (Fig. 3) and that virtually no vapor enters the lake: $k = 8.45$. Calculations for other periods of lake stability during the past decade yielded similar conclusions. A value of $k = 8.45$ suggests that 90% of the lake's water mass is geothermal input.

HEAT AND WATER BUDGET OF GRÍMSVÖTN VOLCANO

Grímsvötn, the most active volcano in Iceland (more than 50 eruptions over the past 1100 yr), is located in the interior of the Vatnajökull ice cap. Grímsvötn consists of evolved quartz-normative tholeiites, and it hosts a dilute, neutral-pH crater lake. The bottom of the lake is at 1050 m above sea level, and pressure at the lake bottom varies from about 3 MPa when the top of the lake surface is 1330–1350 m above sea level, to 4 MPa when the top of the lake reaches 1425 to 1450 m (Björnsson, 1988). At this critical level, the water lifts the 7-km-wide ice barrier lying in the saddlepoint at the south-eastern edge of the caldera, and lake water floods for 50 km beneath the ice (probably through tunnels), and continues over 30 km of the Icelandic coast to the sea. These periodic floods, termed jökulhlaup, drain water from the bottom of the lake at maximum discharge rates since 1938 of 1000–8000 m³/s (Björnsson, 1988). Jökulhlaup are closely monitored; discharge, river chemistry, and ice cap elevation data are available back to 1954. Since 1974, jökulhlaup water samples were collected from the river Skeidará about 8 km from where the jökulhlaup water emerges from beneath the glacier.

Using these data, Björnsson (1988) estimated the rate of ice melting into the lake (R_i) at 400 Tg/yr (1 Tg = 10^{12} g), and the rate of ablation at the surface of the glacier (R_a) at 80 Tg/yr water. Total water input, R_{in}, thus averages 480 Tg/yr. Assuming that the lake temperature (T_l) averages 0.1 °C, the melting temperature (T_o) is 0 °C, and the temperature at which the geothermal fluid enters the lake (T_h) is 235 °C (boiling temperature at 3 MPa), Björnsson (1988) concluded that the power output of the volcano has decreased from about 5000 to 4000 MW since 1860.

Between jökulhlaup, we can follow Björnsson (1988) and solve for k: $0.10 < k < 0.28$. Assuming that silica is a conservative component introduced to the lake only by geothermal input, we can use our observed value for the lake, $c_l = 68$ ppm (see data below), and again following Björnsson and Kristmannsdóttir (1984), we note that the upper limit for silica concentration in Icelandic geothermal waters is 700 ppm, which, assuming mass balance on silica, puts a lower constraint on k: 0.18. The liquid fraction of the geothermal influx must therefore be greater than 65%. These calculations, first completed by Björnsson and Kristmannsdóttir (1984) reveal that the lake at Grómsvötn, like Poás, is primarily receiving liquid geothermal input. The ratio of geothermal to total water input is less than 22%, explaining the wide difference in chemistry between Grímsvötn and Poás.

VOLATILE BUDGET OF VOLCÁN POÁS

Rowe et al. (1992a) summarized several periods of relative constancy in Poás crater lake volume and chemistry. During these periods, the only volatile losses from the system consisted of ground-water losses from the liquid-dominated convection cell at the top of the volcano, the cinder-cone fumarole flux, and volatilization from the

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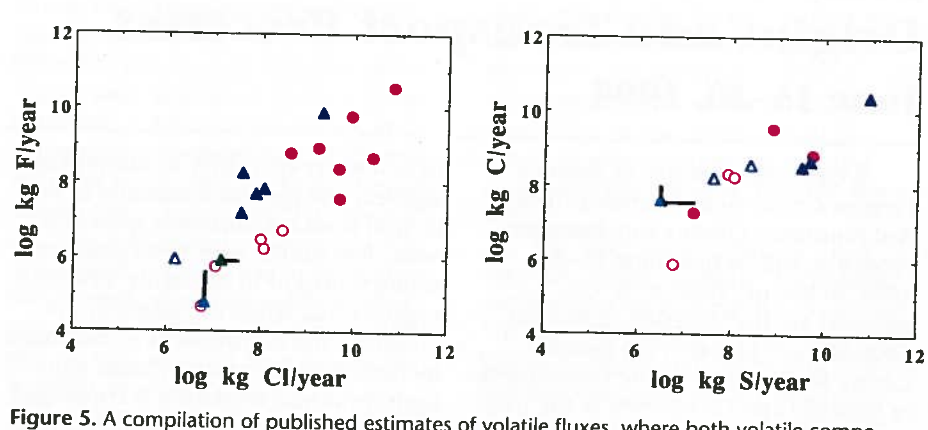

Figure 5. A compilation of published estimates of volatile fluxes, where both volatile components (C and S or Cl and F) are available, for erupting (solid symbols) and nonerupting (open symbols) volcanoes. Volatile release rates for Poás and Grímsvötn are indicated in green and aqua (no estimate for C release was made at Poás). Circles refer to volcanoes at convergent plates (Agung, Augustine, Etna, Katmai, Masaya, Merapi, Poás, Satsuma Iwojima, St. Helens, Tambora, Tarawera, Vulcano, White Island); triangles refer to intraplate or hot-spot volcanoes (Erebus, Grímsvötn, Kilauea, Öræfajökull); and the triangle indicating the largest C and S release refers to the estimate for the global mid-ocean ridge system. Literature references are in Ágústsdóttir (1993).

lake (Fig. 3). Quantification of these fluxes reveals overall volatile flux from the volcano. No attempt was made to assess CO_2 flux.

Numerical modeling of the summit ground-water system indicates that seepage from the crater lake, constrained by a high water table associated with older volcanic cones to the north and south, flows dominantly to the Rio Agrio watershed to the northwest (Sanford et al., 1993). Rowe et al. (1993) have shown that acid seepage causes dissolution around the volcano to be asymmetric (Fig. 4); dissolution along the northwest flank aquifer is approximately 6.7 Gg/yr (Rowe et al., 1992b). Observed fluxes of the conservative elements F, Cl, and S in waters exiting the Rio Agrio watershed during 1988–1989 were 0.69, 14, and 11 Gg/yr, respectively, and the residence time of fluids in the aquifer is estimated to be between 3 and 17 yr (Rowe et al., 1993).

The fluxes through the dome fumaroles fluctuated greatly: during the high-temperature period of 1981–1984, observed F, Cl, and S fluxes were 0.72, 22, and 110 Gg/yr, respectively; fluxes during low-temperature periods (e.g., 1985–1989) were on the order of 0.036, 0.22, and 0.36 Gg/yr (Rowe et al., 1992a; see also Casadevall et al., 1984). Rowe et al. (1992a) argued that these heat and volatile bursts were caused by hydrofracturing of the cooled magma carapace, or by influx of magma in the subsurface.

Analysis of lake chemistry reveals that some HCl gas escapes from the lake, especially when the lake temperature increases. Calculated chloride concentrations in the vapor phase during high-temperature periods were mirrored by observed chloride concentrations in acid rain falling downwind (Rowe et al., 1992b). On the other hand, the concentration of sulfate in acid rain collected during periods of low fumarole emission was generally low, and significant volatilization of HF from the lake was also not observed (Rowe et al., 1992b).

To quantify the loss of components such as Cl by volatilization from the lake during moderate-temperature periods (e.g., 1978–1988), we can calculate the flux of these components in flank rivers affected by acid rain (Anonos, Desague, Gata, Claro, Pozo Azul, Angel; see Fig. 4). By first correcting these compositions by subtracting concentrations of a nonacidified river (Gorrión), and then multiplying corrected concentrations by flow rates measured in 1988 and 1990, we calculate fluxes of 0.058, 1.0, and 1.8 Gg/yr F, Cl, and S, respectively (Rowe et al., 1993).

Summing these fluxes out of the volcano (fluxes through Agrio + fumaroles + lake volatilization), we estimate that steady-state passive degassing at Poás releases 0.78 Gg F, 15 Gg Cl, and 13 Gg S per year into the surrounding atmosphere and hydrosphere (Fig. 5). After magma intrusion or hydrofracturing events in the subsurface, these fluxes were observed to double (F, Cl) or increase tenfold (S) for short periods of time.

One sulfur sink we have neglected is precipitation of sulfur and gypsum in the lake bottom. Lake sediment averaged 4.7 wt% native S and 33 wt% $CaSO_4$ (Rowe, 1992), and its volume was 2.4×10^6 m^3, if we assume a cylinder of sediment with area 6×10^4 m^2 and height 40 m. A sediment density of 1500 kg/m^3 suggests that 0.45 Tg of sulfur accumulated over a period of 27 years, representing a rate of sulfur precipitation of 17 Gg/yr, roughly equivalent to the flux out of the Agrio watershed.

VOLATILE BUDGET OF GRÍMSVÖTN VOLCANO

In collaboration with the Icelandic Glaciological Society, in June 1991 we drilled through the Grímsvötn ice cap and collected lake-water samples at various depths at two different boreholes. Water chemistry and temperature varied with depth (Ágústsdóttir, 1993), but the deepest samples contained 15.7, 0.22, 68, 12.7, and 811 ppm Cl, F, SiO_2, total S, and total carbonate as CO_2, respectively. Lake temperature averaged 0.15 °C. Samples of the jökulhlaup that occurred 5 months after the ice-drilling expedition revealed concentrations of 14.9, 0.14, 67.9, 11.0, and 492 ppm of Cl, F, SiO_2, total S, and total carbonate, respectively.

To estimate the volatile release rates of Grímsvötn over the period 1948–1991, we used river concentration data and jökulhlaup discharge rates for eight jökulhlaup (Ágústsdóttir et al., 1992). Assuming the crater lake was at steady state, we estimated the volatile release rates, $M_j c_i/\Delta t$ where M_j is the mass of jökulhlaup water, c_i is the concentration of volatile component in jökulhlaup water, and Δt is the time between floods. We also calculated release rates integrated over the entire length of time for which data are available: 0.058 Gg/yr fluorine (15 yr), 6.8 Gg/yr chlorine (32 yr), 3.1 Gg/yr sulfur (32 yr), and 39 Gg/yr carbon (15 yr) (Fig. 5).

The calculation rests on the assumptions that (1) the lake chemistry maintains steady state, (2) there are no other outlets for volatiles from the volcano, (3) all dissolved volatiles in lake water are volcanic in origin, and (4) no significant loss or dilution of volatiles occurs during transport to the river sampling point.

The assumption of steady state is confirmed by the observation that volatile budgets calculated for each jökulhlaup—the volatile budgets calculated over the ~5 yr between each jökulhlaup—are all within a factor of 2, with a slight trend of decreasing release rate with time, in agreement with the interpretation of Björnsson (1988) that the power output has decreased. If volatiles collected between jökulhlaup were not flushed with each event, the concentration in the lake and apparent release rates would increase.

Furthermore, some of the variability in release rates is explained by eruptive activity. The average ratio of release of F vs. Cl for floods not associated with eruptions is 0.013 ±0.004, whereas the average of the same ratio for the two jökulhlaup associated with eruptions (1953 and 1983) is 0.04. Similarly, the ratios of release rates of S and Cl for noneruptive vs. eruptive periods is 0.53 and 1.4, respectively.

Fumaroles on the nunataks at Grímsfjall mountain (the southern caldera rim) constitute a volatile leak. However, gas collected over several hours at four fumaroles revealed insignificant F, Cl, S, and C release rates (Ágústsdóttir, 1993).

Because the lake is undersaturated with respect to all oxidized gas phases at depth, minimal degassing of these components is expected. However, some degassing of H_2S occurs at the edge of the ice cap, where lake water is ephemerally exposed (area of ice hole in summer 1991 was only 20 m^2); H_2S degassing is presumably also accompanied by CO_2 degassing.

Calculations of chemical speciation in the lake water suggest that no precipitation of volatile-containing minerals is likely to occur, with the exception of alunite [$KAl_3(SO_4)_2(OH)_6$]. However, no alunite was discovered in sediments.

We have also assumed that contributions from snow melt and dissolution of bedrock or sediment are minimal. The concentrations of dissolved volatiles in glacial snow from Vatnajökull are well below 1 ppm. Correction of the volatile fluxes for calculated contribution from dissolution of basalt decreases the fluxes only slightly (Ágústsdóttir, 1993).

We expect little degassing to occur during the several-hour transport through ice tunnels 50 km to the edge of the glacier, but some degassing must occur in the 8 km between ice and sampling sites, especially for CO_2 and H_2S. We can compare concentrations of the relevant components in lake water sampled in June 1991 and jökulhlaup river water sampled in November 1991 (Ágústsdóttir, 1993). Because lake chemistry varied as a function of depth and distance to Grímsfjall, it is impossible to predict average lake concentration—or predicted jökulhlaup concentration if no degassing occurred—from just three sampling localities. For three components—fluoride, sulfur, and total carbonate as CO_2—the observed jökulhlaup concentrations (0.14, 11.0, and 492 ppm, respectively) were less than the observed highest concentrations in the lake water (1.05, 35, and 1109 ppm, respectively). All other components (except Ca) were observed to be identical between jökulhlaup and most concentrated lake waters. This suggests that, in the *worst* case, errors could be as large as a factor of 7.5, 4.9, and 2.2 for F, S, and C fluxes, respectively (Fig. 5).

VOLATILE RELEASE VS. POWER OUTPUT

Björnsson (1988) calculated the rate of magma cooling in the subsurface at Grímsvötn by calculating the heat released per kilogram of cooled magma: the specific heat of crystallization (419 kJ/kg) plus the specific heat capacity (1.046 kJ•kg^{-1}•°C^{-1}) multiplied by the drop in temperature (1300 to 200 °C). The power output of the volcano divided by the heat release per kilogram of magma reveals the rate of magma cooling in the subsurface: at Grímsvötn, 4500 MW power requires 9×10^{10} kg/yr. Using the same thermodynamic constants for Poás magma cooling, but assuming a lower temperature cooling range (1150 to 200 °C), we estimate that 200 MW power requires 4.4×10^9 kg/yr.

Assuming these magma cooling rates, we can also calculate the volatile content released from the magma during degassing. We assume that the depth of magma intrusion controls the extent of degassing, but that cooling of magma and associated cracking and water infiltration allows release of gas to the surface. At Grímsvötn, <1 ppm F, 75 ppm Cl, 34 ppm S, and 1600 ppm CO_2 must be released to account for the observed fluxes. At Poás, 180 ppm F, 3400 ppm Cl, and 2950 ppm S must be lost.

At Grímsvötn, we can assume that initial volatile contents of the tholeiitic basalts are approximately equal to that of Kilauean basalts: 350 ppm F, 87 ppm Cl, 1000 ppm S, and 3000–6000 ppm CO_2, (Gerlach and Graeber, 1985; Moore and Calk, 1991). Comparison of calculated and expected compositions suggests that emission of F and S is strongly suppressed at Grímsvötn, while a significant proportion of Cl and CO_2 is released.

Comparison of volatile release at Poás to that expected for andesitic magmas (Anderson, 1974) indicates suppression of F release, but significant Cl and S release. These observations can be qualitatively explained by the observation that S exsolution from magma is much more depth-dependent than exsolution of CO_2 (Gerlach, 1986). Anderson (1974) has also argued that Cl is much more efficiently transferred to surface reservoirs than is S. Enhanced release of volatiles at Poás is expected, given the shallower depth of magma intrusion (~500 m) compared to that of Grímsvötn (probably greater than 2 km).

Crater Lakes *continued on p. 178*

Crater Lakes *continued from p. 177*

COMPARISON TO ESTIMATES IN THE LITERATURE

Release rates of F, Cl, and S at Poás are approximately within an order of magnitude of estimates for most passively degassing volcanoes, especially if the accumulation of sulfur sediments in the lake is included (Fig. 5). Including the maximum error estimates based on lake- vs. jökulhlaup-water concentrations, the F, S, and C flux at Grímsvötn is within about an order of magnitude of other fluxes. Although we saw no evidence of the existence of alunite in sediments, S loss as alunite is theoretically predicted, and it may also help explain the low S flux. However, the C flux, although within a factor of 10 of other estimates, is lower than all but one of the seven subaerial volcanoes summarized by Gerlach (1991). This, combined with the low value for Cl (and possibly F and S) release at Grímsvötn may indicate that our estimates are minima, or that published fluxes for other volcanoes are overestimates based on spot measurements limited by logistics and weather. Sampling bias may also emphasize volcanoes with large volatile release rates.

CONCLUSIONS

At 200 MW, Volcán Poás is comparable to a moderately small coal-fired power plant in the United States; at 4000–5000 MW, Grímsvötn is much larger than the average coal-burning power plant (1000 MW). However, we note that only 102 volcanoes were known to be degassing in 1981–1982 (Stoiber et al., 1987), and if the power output for these volcanoes is between 200 and 5000 MW (see also Glaze et al., 1989), we calculate a rough global power output between 2×10^4 and 5×10^5 MW for nonerupting volcanoes. This global power output is small compared to the overall heat flow of Earth (4×10^7 MW) or commercial power consumption by humankind worldwide (1×10^7 MW, according to the Worldwatch Institute).

At 13 Gg/yr S release, Poás is comparable to a 200 MW coal-fired power plant burning coal that has 2 wt% S. The local effects of this volcanic S release were documented by Brantley et al. (1992). Storage of S at the top of this volcano could have important implications if a large-scale explosive eruption released the S. Globally, release of S to the atmosphere from passively degassing volcanoes amounts to about 3.4 Tg/yr (Stoiber et al., 1987). This is a very small flux compared with the total anthropogenic emission (about 100 Tg S/yr).

Ratios of S/Cl and S/F release integrated over several years at Poás (0.87 and 17), and integrated over 15 yr at Grímsvötn (0.71 and 48), are within the range 0.5 to 50 estimated by Symonds et al. (1988) for most active volcanoes. Symonds et al. (1988) used such ratios to calculate global release rates of F and Cl based on an assumed global release of 3.4 Tg S/yr. Our long-term integrated ratios may be especially useful in predicting global volatile release rates by this method; however, more long-term estimates of volatile ratios are needed. The two long-term estimates summarized here would suggest global passive release rates of approximately 0.07 to 0.2 Tg/yr F and 3.9 to 4.8 Tg/yr Cl, comparable to the anthropogenic fluxes due to coal-burning and industrial production of halocarbons: 0.44 Tg/yr F and 4.0 Tg/yr Cl (Symonds et al., 1988).

The ratio of C/S release at Grímsvötn is quite large, presumably because of the depth of the magma body. If the average global C/S ratio lies between the estimated minimum of 2.3 (Gerlach, 1991) and the value at Grímsvötn (14), then the global CO_2 flux would lie between 7.8 and 44 Tg/yr C, much smaller than the global anthropogenic flux (approximately 6000 Tg/yr C). However, more such long-term estimates, based on crater lakes or spectrophotometric monitoring, are needed to determine more accurately the global flux of all the volatile elements.

ACKNOWLEDGMENTS

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REFERENCES CITED

Ágústsdóttir, A., 1993, Heat and volatile fluxes integrated over four decades at Grímsvötn volcano, Iceland [M.S. thesis]: University Park, Pennsylvania State University.

Ágústsdóttir, A., Brantley, S. L., Gudmundsson, M. T., and Björnsson, H., 1992, Volatile release rates from the Grímsvötn volcano, Iceland, *in* Kharaka, Y., and Maest, A. S. eds., Proceedings of the 7th International Conference on Water-Rock Interaction: Rotterdam, Balkema, p. 465–468.

Anderson, A. T., 1974, Chlorine, sulfur, and water in magmas and oceans: Geological Society of America Bulletin, v. 85, p. 1485–1492.

Björnsson, H., 1988, Hydrology of ice caps in volcanic regions: Reykjavík, Iceland, University of Iceland, Societas Scientarium Islandica.

Björnsson, H., and Kristmannsdóttir, H., 1984, The Grímsvötn geothermal area, Vatnajökull, Iceland: Jökull, v. 34, p. 25–50.

Brantley, S. L., Rowe, G. L., Konikow, L. F., and Sanford, W. E., 1992, Toxic waters of Poás Volcano: National Geographic Research and Exploration, v. 8, p. 328–337.

Brown, G. C., Rymer, H., Dowden, J., Kapadia, P., Stevenson, D., Barquero, J., and Morales, L. D., 1989, Energy budget analysis for Poás crater lake: Implications for predicting volcanic activity: Nature, v. 339, p. 370–373.

Casadevall, T. J., Rose, W. I., Jr., Fuller, W. H., Hart, M. A., Moyers, J. L., Woods, D. C., Chuan, R. L., and Friend, J.P., 1984, Sulfur dioxide from Poás, Arenal, and Colima volcanoes, Costa Rica and Mexico: Journal of Geophysical Research, v. 89, p. 9633–9641.

Gerlach, T. M., 1986, Exsolution of H_2O, CO_2, and S during eruptive episodes at Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 91, p. 12,177–12,185.

Gerlach, T. M., 1991, Present-day CO_2 emissions from volcanoes: Eos (Transactions, American Geophysical Union), v. 72, p. 249–255.

Gerlach, T. M. and Graeber, E. J., 1985, Volatile budget of Kilauea volcano: Nature, v. 313, p. 273–277.

Hurst, A. W., Bibby, H. M., Scott, B. J., and McGuinness, M. J., 1991, The heat source of Ruapehu Crater Lake, New Zealand: Journal of Volcanology and Geothermal Research, v. 46, p. 1–20.

Moore, J. G. and Calk, L. C., 1991, Degassing and differentiation in subglacial volcanoes, Iceland: Journal of Volcanology and Geothermal Research, v. 46, p. 157–180.

Rowe, G. L., 1992, The acid crater lake system of Poás Volcano, Costa Rica: Geochemistry, hydrology, and physical characteristics [Ph.D. thesis]: University Park, Pennsylvania State University, 309 p.

Rowe, G. L., Brantley, S. L., Fernandez, M., Fernandez, J. F., Borgia, A., and Barquero, J., 1992a, Fluid-volcano interaction in an active stratovolcano: The crater lake system of Poás volcano, Costa Rica: Journal of Volcanology and Geothermal Research, v. 49, p. 23–51.

Rowe, G. L., Ohsawa, S., Takano, B., Brantley, S. L., Fernandez, J. F., and Barquero, J., 1992b, Using crater lake chemistry to predict volcanic activity at Poás Volcano, Costa Rica: Bulletin of Volcanology, v. 54, p. 494–503.

Rowe, G. L., Brantley, S. L., Fernandez, J. F., and Borgia, A., 1993, The chemical and hydrologic structure of Poás Volcano, Costa Rica: Journal of Volcanology and Geothermal Research (in press).

Rymer, H., and Brown, G. C., 1987, Causes of microgravity changes at Poás Volcano, Costa Rica: An active but non-erupting system: Bulletin of Volcanology, v. 49, p. 389–398.

Sanford, W. E., Konikow, L. F., Rowe, G. L., and Brantley, S. L., 1993, Ground-water transport of crater-lake brine at Poás Volcano, Costa Rica: Journal of Volcanology and Geothermal Research (in press).

Shepard, J. B. and Sigurdsson, H., 1978, The Soufrière crater lake as a calorimeter: Nature, v. 271, p. 344–345.

Stoiber, R. E., Williams, S. N., and Huebert, B., 1987, Annual contribution of sulfur dioxide to the atmosphere by volcanoes: Journal of Volcanology and Geothermal Research, v. 33, p. 1–8.

Symonds, R. B., Rose, W. I., and Reed, M. H., 1988, Contribution of Cl- and F-bearing gases to the atmosphere by volcanoes: Nature, v. 334, p. 415–418.

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GSA Officer and Councilor Nominees for 1994

Council announces the following officer and councilor candidates. Biographical information on all candidates will be mailed with the ballot to all voting members in August.

For Councilor (1994–1995) and President (1994)
William R. Dickinson; Tucson, Arizona

For Councilor and Vice-President (1994)
David A. Stephenson; Scottsdale, Arizona

For Councilor and Treasurer (1994)
David E. Dunn; Richardson, Texas

For Councilor (1994–1996)—Position 1
Charles G. Groat; Baton Rouge, Louisiana
John A. Cherry; Waterloo, Ontario, Canada

For Councilor (1994–1996)—Position 2
Grant Garven; Baltimore, Maryland
Leigh H. Royden; Cambridge, Massachusetts

For Councilor (1994–1996)—Position 3
Keros Cartwright; Champaign, Illinois
C. Blaine Cecil; Leesburg, Virginia

For Councilor (1994–1996)—Position 4
George H. Davis; Tucson, Arizona
H. Catherine W. Skinner; New Haven, Connecticut

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. Each Forum presentation consists of an informative, neutral introduction to the month's topic followed by two or more opposing views concerning the Forum topic. 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.

ISSUE: Ground-water Cleanup vs. Ground-water Protection—Where Should the $$$ Go?

This Forum, which is a condensation of the IEE Annual Environmental Forum at the 1992 GSA Annual Meeting, will be presented in two parts. Part 1, in this month's issue, presents the viewpoints of two environmental scientists and an economist regarding inadequacies in this nation's hazardous waste management program, real vs. perceived health risks, and the economic value of ground-water protection, respectively. Part 2, which will be published in the September issue of *GSA Today*, will discuss roles of local government, the environmental engineer, and the geoscientist in ground-water cleanup and prevention.

PERSPECTIVE 1: Ground-water Pollution Prevention—Putting Our Money Where Our Mouth Is

Linda E. Greer,
Natural Resources Defense Council

The United States has two laws that govern the management of hazardous waste. The more famous and well funded law is Superfund, which was established in 1980 in the wake of the discovery of Love Canal. In 1986, the law was expanded to provide a fund of $8.5 billion over five years to address the contamination caused by abandoned or inactive hazardous waste dumps. Over 1200 dump sites are in the Superfund program, which is notorious for the fact that many sites remain unremediated a decade after having been identified as a national priority for cleanup. The second, less famous law is the Resource Conservation and Recovery Act (RCRA), which was established in 1976 to control the management of hazardous waste as it is generated, to its point of ultimate disposal—or from "cradle to grave." RCRA defines wastes that are hazardous, tracks the waste to ensure that it is disposed of in licensed facilities, provides treatment requirements prior to the land disposal of wastes, requires cleanup where contamination occurs at licensed facilities, and provides for proper closure of facilities at the end of their active life.

Despite all its bad publicity, Superfund is critically important to this nation's ground-water resources, in that it provides the only real tool to effect cleanup of hazardous constituents that threaten drinking-water supplies and other important environmental resources in our country. Fully one-third of the nation's 1200 priority dump sites have contaminated existing drinking-water wells; in some instances, the wells that have been closed or restricted are public wells that served tens of thousands of citizens in both small and large communities. Nothing but Superfund is around to stop the sources of contamination to these wells.

Here I address an even more important concern for the long-term environmental health of this nation: despite the existence of RCRA, our nation is doing pitifully little to prevent the creation of Superfund sites of the future. I speak about the inadequacies of our nation's hazardous waste management program under RCRA, with the hope of convincing you that much, much more must be done in this overlooked program to ensure that we do not continue to create Superfund dump sites indefinitely into the future.

It is not obvious to everyone why it is necessarily smart to emphasize pollution prevention over pollution control or cleanup. Some in the Bush administration, for example, felt that pollution prevention could be justified only where it is less costly than the alternatives. But if we have learned nothing else in the past 12 years of working on hazardous waste in this country, we have at least learned this—that dump-site cleanup is much more technologically complex and expensive than we ever contemplated. Recently published information about the inability of ground-water pump and treat systems to fully remediate contaminated aquifers under certain conditions only underscores this point. Clearly, then, preventing the creation of dump sites whose contamination we cannot fully control deserves our utmost attention.

So, what's the problem with RCRA? Why is it failing us in this important work? In a nutshell, the problem is not depth, it is breadth. Where RCRA regulates, it regulates comprehensively—by means of the 1984 amendments to the law that required, among other things, treatment of hazardous waste prior to land disposal. *The problem is that RCRA does not regulate a large number of important toxic waste streams.*

To understand the remarkable gaps in the coverage of RCRA, some background is required. First, the only industrial wastes with meaningful federal control in this country are those which fall under the Subtitle C definitions of RCRA hazardous waste. All other waste is covered under Subtitle D, whose requirements are virtually nonexistent. Second, the RCRA definition of Subtitle C hazardous waste is peppered with statutory loopholes, and there is substantial reason to believe that "loophole" waste is causing problems, as I discuss below. And, third, RCRA regulations defining Subtitle C waste are extremely narrow and miss many

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LETTER TO THE EDITOR

Englishly Speaking

Today, many scientific journals are published in English. Many non-native English-speaking (NNES) scientists publish articles and books in English in order to reach a larger number of readers. In some non–English-speaking countries, scientific journals publish at least a summary in English even when the rest of the article is in the native language. By now, without hesitation, we acknowledge that English has become the universal language of science. But most will agree that the ubiquity of English is not because English is more precise, lyrical, or easier to speak than other languages. Most NNES scientists have undoubtedly had the experience of not being understood when pronouncing a word in English, merely because they placed an accent on a different syllable than the expected one. What an embarrassing situation it was when I was trying to explain the mechanics´ instead of mechan´ics of salt diapirs to a colleague, a native speaker of English who did not have a clue as to what I was talking about. English is not an easy language to learn, especially because British and American English are very different in colo(u)r, pronunciation, idioms, and sometimes in spelling. Visiting the United States for the first time, one of my male British colleagues asked the lady who ran a motel where he was staying: "could you knock me up in the morning, please?" The American lady, who had almost fainted, replied "I beg your pardon, certainly not!"

I am not trying to make native English-speaking (NES) scientists feel pity for us NNES scientists who, in many cases, learned(t), or are still trying to learn, English as adults, nor do I believe that we NNES scientists should be given a "milder" review or a better opportunity to publish our results. But I want to urge NES scientists to be more considerate when reviewing a manuscript written by an NNES scientist by not harshly attacking the writer's usage of English. Scientists who are native speakers of English have the advantage of their language ability over NNES scientists. In many cases, a command of the language makes expressing the thoughts considerably easier.

Recently, a manuscript written by a colleague and me was given what I believe was an unfair review by an NES scientist. The manuscript was reviewed by a North American referee who, in a letter to the editor, had clearly written that "The paper is about salt diapirs, a subject with which I have almost no experience, so my opinions should be regarded with that in mind." This reviewer, unfortunately, had not returned the manuscript to the editor to be sent to another scientist more familiar with the subject. Instead, s/he had made unsound judgments about the substantive content without scientific backup. Later, when I found out that one of his/her major criticisms was focused on the grammatical style, syntax, and punctuation of the manuscript, my perception of the comments was altered altogether. This reviewer had commented on "clumsy usage of parentheses for references" in the manuscript, and had overreacted to there being "at least three omissions of articles such as 'a' or 'the' and some European spellings (e.g., colour, Palaeozoic) that should be addressed." S/he had also admitted that "some of these shortcomings are naturally attributable to at least one of the authors working in a second language," indicated awareness that one of the authors was an NNES.

We should expect all articles published in English to be written in understandable English. Reviewers' tasks are not easy, but reviewers are effective only when they spend sufficient time on the review and when they decline to review a manuscript that is not in their field of expertise. When scientists send their manuscripts to a journal, they expect a substantial evaluation of the scientific results from the reviewers rather than a harsh criticism of editorial details. Stylistic comments on manuscripts do not contribute to better presentation of scientific work and are very discouraging. It is, after all, the editor's responsibility to see to it that the journal's style, citations, headings, etc., are followed. Although manuscripts should be written in a clear and understandable language, editorial comments by a reviewer should be incidental to the review. Critique and evaluation of the substance and presentation of the material are the crucial tasks of the reviewers.

I believe that most NNES scientists show their manuscripts to English-speaking reviewers (usually colleagues) before submitting them for publication. In some countries, manuscripts are translated into English by people who may not have had scientific training. These literal translations may result in complicated and unfamiliar uses in English. I recommend that NNES scientists show their manuscripts whenever possible to NES scientists who are also familiar with the content of the manuscript.

With the ending of the Cold War and the opening up of the former Eastern bloc countries, many scientists have more access to western English journals and are free to send their results to these journals for publication. Some of these scientists, due to lack of contact with English as a result of their former governments' previous policies, have a limited knowledge of the English language. English-language journals likely will receive more manuscripts from NNES scientist than before. I challenge reviewers in general and NES reviewers in particular to review manuscripts by using standards that would naturally reject those of low scientific quality, but which do not judge the scientific quality by the quality of English. Journal editors and reviewers must not discourage NNES scientists from sending their future contributions to the globally disseminated English-language journals, because the substance of these contributions may very well be profound.

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important industrial segments. As some of you might know, the only two ways that industrial waste can be classified as RCRA hazardous are (1) to be listed by name, a vehicle with severe limitations, and (2) to flunk a characteristic laboratory test such as the toxicity characteristic leaching procedure (TCLP), which also suffers from severe limitations.

By weight, the universe of unregulated waste dwarfs that in Subtitle C. According to the just-released Congressional Office of Technology Assessment report *Managing Industrial Wastes,* between 11 and 12 billion tons of industrial waste are generated in this country, in contrast with only 700 million tons of waste under Subtitle C. (It should be noted that the estimate of 700 million tons for Subtitle C waste does not include additional wastes brought into the system by a recently expanded toxicity characteristic. This expansion might double the amount of industrial waste that would be identified as hazardous, but the vast majority of industrial waste would still be unregulated.) OTA concludes that potential environmental and human health risks associated with unregulated industrial wastes might be significant for several reasons, including relatively few controls at industrial waste management facilities, the broad range of toxic constituents in these wastes, and the large volumes involved.

Several interesting facts should be pointed out about the nation's waste universe. First, despite everything stated about the problems of municipal waste disposal and the need for recycling various components of trash, municipal waste contributes a very small amount—only about 1.5%. Second, two industries notorious for the contamination they have caused in certain areas of this country—mining, and oil and gas production—generate large quantities of wastes that are unregulated in Subtitle C of RCRA. Each of these industries has a specific statutory exemption from regulation under RCRA. Perhaps the most surprising, however, is the large proportion of waste generated in this country that is "not otherwise classified." Over 50% of our nation's waste is classified as "miscellaneous industrial nonhazardous," and is almost completely unregulated at the federal level. What is in this miscellaneous industrial waste category? Does it have the potential to contaminate our environment at levels that pose risk to human health and the environment?

The Natural Resources Defense Council (NRDC) has recently developed some information that, although not conclusive, strongly suggests that an important universe of dangerous materials exists without meaningful RCRA coverage. Various industries were arrayed on the basis of the total number of pounds of toxic substances released to underground injection wells, to on-site land disposal, or to off-site disposal. Additional NRDC analysis considered the total number of pounds of specific federal Toxic Release Inventory (TRI) chemicals to these media, as well. TRI requires that emissions to the environment be reported in terms of pounds of *toxic constituent* and not total pounds of waste. Therefore, TRI numbers do not reflect, for example, pounds of water in contaminated wastewater, or pounds of inert materials in sludge. In contrast, RCRA requires reporting of waste on the basis of pounds of total waste.

Consider the pesticide industry, one of our nation's largest generators of toxic substances, according to the federal TRI. This industry reported nearly 20 million (of the more than 900 million) pounds of toxic constituents released to waste disposal facilities such as underground injection wells, on-site or off-site landfills, and incinerators in 1989 (hereinafter referred to as "TRI waste releases"). Of these 20 million pounds of waste releases from the pesticide industry, 1.6 million pounds were chlorophenols and 1.6 million pounds were formaldehyde, to name just two of the 82 important hazardous chemicals reported to have been released.

One would think that the RCRA program would be heavily regulating this type of industry. Yet, data from EPA indicate that RCRA barely regulates the pesticide industry at all. Only two of the 30 most important herbicides in the country have wastes associated with their production in RCRA Subtitle C at this time—and not even the top two herbicides. Wastes associated with the production of such chemicals as atrazine, alachlor, paraquat, and other herbicides are completely unregulated in RCRA. In fact, NRDC analysis shows that only about 15% of the quantity of herbicides used in the country have been regulated with regard to either the disposal of off-spec pesticide products or wastes generated with the production of these important toxic compounds. Given that pesticides are chemicals actually designed to be toxic (at least to some organisms), the fact that far less than a quarter of these compounds have been regulated, or even reviewed for the quantity and toxicity of their wastes, should be cause for great concern.

Similar indications of serious gaps in Subtitle C coverage exist for other important industries as well. For example, one of the most important parts of the synthetic organic chemical industry is the sector that manufactures compounds called "cyclic organic crudes." TRI data indicate that the cyclic organic crudes industry ranks in the top ten of hundreds of industries that report their toxic waste constituents. On the basis of 1989 estimates, the latest data available, the industry releases 40 million pounds of toxic constituents each year. However, RCRA data indicate that the program currently regulates only two major and three minor wastes in this industry, overlooking wastes from such manufacturing processes as the production of ethylbenzene, naphthalene, nitrophenol, styrene, xylene, and toluene.

The problems identified with the two industrial sectors discussed above are only the tip of the iceberg. Seven of the top 20 most important TRI waste-producing industries have *no* RCRA waste listings at all. What does this mean? It means that, to date, EPA has overlooked a large percentage of important industries in developing its Subtitle C program, and that much potentially dangerous waste might be unregulated today.

The situation does not improve when one analyzes the potential

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effectiveness of the RCRA toxicity characteristic test (TCLP) in netting unlisted hazardous wastes into the RCRA Subtitle C regulatory program. As mentioned above, the only two ways that industrial waste can be classified as RCRA hazardous are to be a waste stream listed by name, a vehicle with the limitations just described, or to flunk a toxicity characteristic test.

In its ability to bring important industrial wastes into the Subtitle C program, the TCLP suffers from limitations of at least the magnitude described above for listing industrial wastes. The TCLP concerns itself with only 39 toxic compounds—chemicals, toxic metals, and a handful of organic substances. The inadequacy of a list of only 39 compounds for classifying waste as hazardous becomes obvious when one considers that, elsewhere in Subtitle C, a facility can be out of compliance with the RCRA ground-water protection standard on the basis of the presence of any of 260 contaminants (40CFR264, App. IX). Thus, RCRA concerns itself with the impact of 260 chemicals if they enter the environment from waste of any sort, yet only regulates "up front" waste that contains one or more of 39 chemicals.

The inadequacy of the coverage of the TCLP to net our important industrial waste is clear upon even a cursory review of the toxic chemicals from the top 20 TRI waste-generating industries. Few of the chemicals reported from these industries are among the 39 RCRA regulated toxicity constituents, with the exception of the chemicals reported from the steel industry. No industry other than the steel industry reports more than 30% of its pounds of toxic substances as deriving from the TCLP list.

What does this mean to us? It means that only in the case of one industrial sector are the inadequate Subtitle C listings possibly compensated for by the RCRA Subtitle C toxicity characteristic. These data are a clear indication of the poor coverage of the RCRA Subtitle C program, further indication of the importance of expanding Subtitle C, and further indication of the need to develop meaningful regulation of industrial waste.

It should be noted that the NRDC analysis of the coverage of RCRA is, by necessity, limited. Because EPA has no reporting or testing requirements for industrial waste not currently regulated in the Subtitle C system, NRDC had very little basic information on the composition of unregulated materials. The analysis, then, while highly suggestive, is not conclusive. However, at a minimum, it is clear that industrial waste testing requirements are needed that provide answers to questions raised by the analysis. Moreover, the analysis clearly shows that, whereas it might be true that there are varying degrees of hazard in the industrial waste generated in America today, it is a myth that all truly hazardous wastes are currently regulated. Furthermore, wastes currently unregulated are not restricted to those "at the margin," in terms of either toxicity or volume, but rather might comprise wastes from important industrial sectors, should the indications from TRI data prove correct.

When people think about the problems associated with hazardous waste, they generally think about the problems with Superfund. They should also be thinking about the other law that governs management of hazardous waste—RCRA. RCRA provides us with a vehicle to stop the ongoing creation of hazardous waste dumps that cannot be cleaned up without vast expenditures of time and money. But the scope of the program needs to be greatly expanded to ensure that all wastes that pose a hazard when mismanaged are regulated up front in a protective manner. Costs of managing these wastes correctly in the first place become insignificant when compared with the costs of remediating the contamination they cause years hence. Moreover, we get the benefit of a safe and healthy environment for our future generations.

PERSPECTIVE 2: Health Risks of Contaminated Ground Water: Real or Imaginary?

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In keeping with the subject of this forum, I offer the following quote: "The time interval between initial waste disposal and appearance of polluted water in wells may be so great as to permit irreparable damage to underground supplies. The results of groundwater pollution might be very long lasting—sometimes to the extent of affecting future generations. Some wastes are so potent that very small concentrations produce severe injury. If corrective measures are deferred until proof of actual damage is at hand, so much pollution is likely to have taken place that restoration of purity will be difficult, costly, and slow, if possible at all."

Who said this, and when? The answer is not the Sierra Club, nor the Environmental Defense Fund, nor the Natural Resources Defense Council, and it wasn't written this year, or even last year. Rather, it was written by a task force of the American Water Works Association in 1952—over 40 years ago. What this suggests to me is that a fundamental change has occurred in the relationship between the technical community and the public over these past 40 years. In the first 20 years of this period, between roughly 1950 and 1970, the technical community couldn't get the public to pay attention to ground-water pollution. It might be more accurate to say that it could not get the public's institutions—Congress and the regulatory agencies—to pay attention. Over the next 20 years, from 1970 to the present, the changing public perception has driven the technical community to its limits.

Today, the technical community can't seem to assure the public that we know how to protect them. Like George Bush's plea that the economy "ain't so bad," the plea of scientists like Bruce Ames that a little bit of carcinogen in water "ain't so bad" seems to be falling on deaf ears. Congress certainly isn't listening to Bruce Ames. In 1986 Congress amended the Safe Drinking Water Act, mandating that 83 organic chemicals be regulated under the Act by 1989, and that 25 more chemicals be added to that list every year thereafter.

In view of these historical developments, I focus here on two broad questions. First, do ground-water contamination problems represent a *real* or an *imaginary* health threat? Second, if the health threats are real, are the approaches being used today to set health-protection goals reasonable?

To answer the first question, consider chemical carcinogens. After all, it's the potential carcinogenic effects of these chemicals that almost always drive cleanup decisions at contamination sites. An extraordinary range in toxicity, or carcinogenic potency, exists for chemical carcinogens as a whole. In fact, from the least potent carcinogen that scientists have investigated in the laboratory, which is probably saccharine, to two of the most potent, dioxin and aflatoxin, the potency range is about a millionfold. So, when one combines that fact with the knowledge that contaminant concentrations in ground water can vary by a thousandfold or even a millionfold, perhaps it is not surprising that very real public health risks can exist. To determine the significance of these risks, one must consider both the *potencies* and the *concentrations* of the chemicals in ground water.

The polluted private wells discovered in a rural area in Hardeman County, Tennessee, provide an illustration. In this particular case, chlorinated solvents—those ubiquitous chemicals such as carbon tetrachloride and chloroform that are present almost everywhere we find ground-water contamination—seeped out of a dump site, now a Superfund site, and into private wells. Local residents were consuming contaminated water from the private wells for six or seven years before the potential risks of the situation were recognized and the residents were placed on a community water supply.

A comparison of the exposure that resulted in tumors in 40% of the laboratory animals studied to the human exposure in Hardeman County (Fig. 1) suggests that the cancer risk was quite significant. One needn't extrapolate from high-dose to low-dose events to conclude that adults consuming water from the contaminated wells might have been exposed to an extraordinary amount of chemical that is known to cause cancer in laboratory animals.

The Hardeman case is clearly an extreme example of the public health risk posed by contaminated ground water; water with more than 20,000 parts per billion of carbon tetrachloride was actually consumed by individuals before public health officials took action to reduce exposures. On the other end of the spectrum are thousands of areas with ground-water contamination where chemical concentrations are only in the range of tens or hundreds of parts per billion. In many known episodes, exposures to such relatively low levels of chemicals in ground water have occurred for several years before public health officials responded to the contamination.

Although they may not be aware of it, most people in this country are exposed to chlorinated chemicals day in and day out as a result of the widespread use of chlorine to disinfect public drinking-water supplies. Disinfection of drinking-water supplies with chlorine produces a number of low-molecular-weight chlorinated and other halogenated compounds, very similar, and in some cases identical, to the synthetic industrial chemicals that we often find contaminating ground-water supplies. Many so-called trihalomethane compounds (such as chloroform) are also formed; the EPA now regulates many of these chemicals. The concentrations of chlorination by-products in typical drinking water range in the low to high hundreds of parts per billion. This range is similar to the range of chlorinated organic chemical concentrations that we find contaminating ground water in many, many areas of this country as a result of past industrial operations or waste disposal practices.

An epidemiological study conducted at the National Cancer Institute (NCI) compared the cancer risks associated with the consumption of chlorinated water to the cancer risks of

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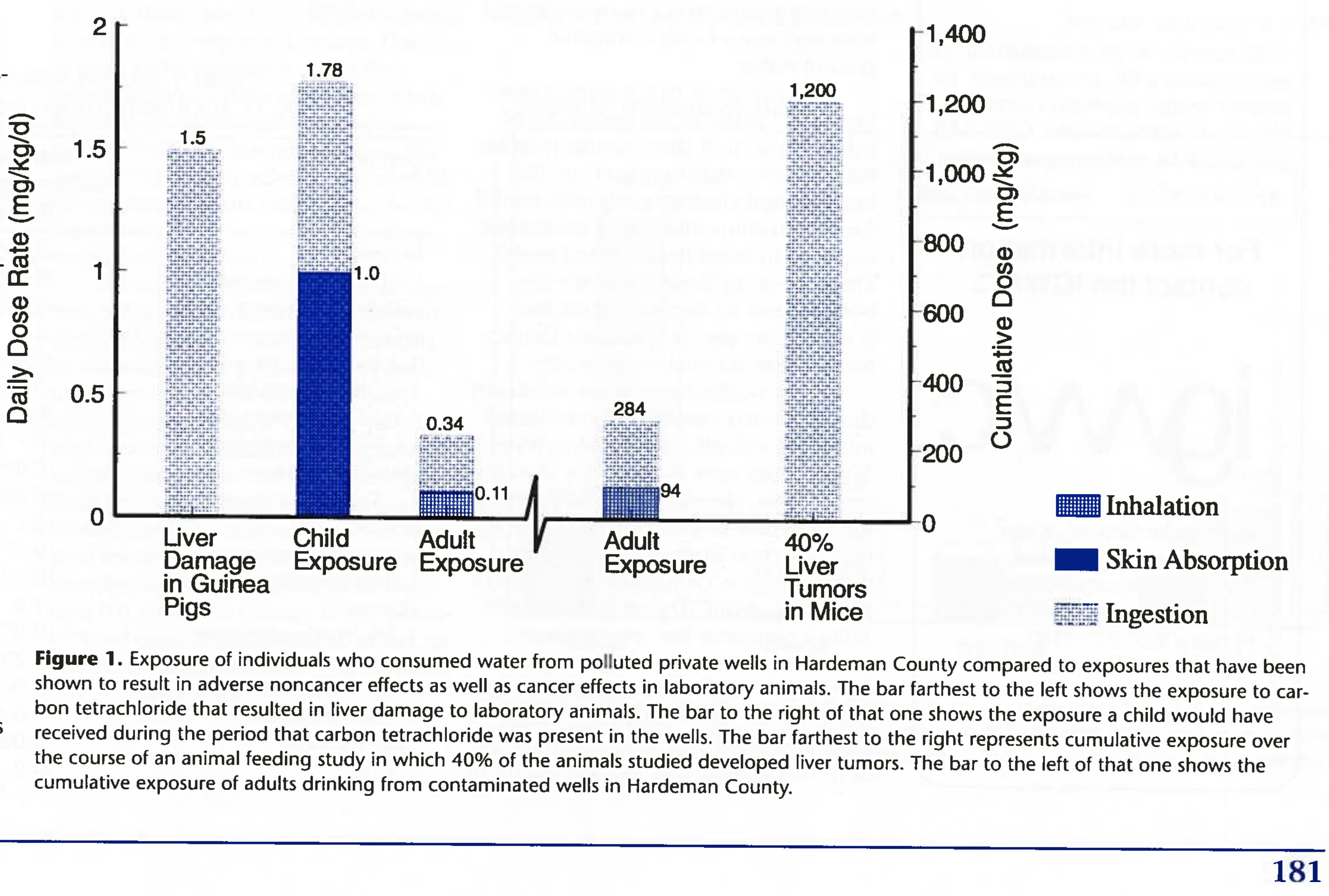

Figure 1. Exposure of individuals who consumed water from polluted private wells in Hardeman County compared to exposures that have been shown to result in adverse noncancer effects as well as cancer effects in laboratory animals. The bar farthest to the left shows the exposure to carbon tetrachloride that resulted in liver damage to laboratory animals. The bar to the right of that one shows the exposure a child would have received during the period that carbon tetrachloride was present in the wells. The bar farthest to the right represents cumulative exposure over the course of an animal feeding study in which 40% of the animals studied developed liver tumors. The bar to the left of that one shows the cumulative exposure of adults drinking from contaminated wells in Hardeman County.

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consuming water that is not chlorinated (Fig. 2). The comparison is expressed as an "odds" ratio; a ratio greater than one suggests an increased risk of bladder cancer.

Studies of the risks of exposure to contaminated ground water have been all too few because they're expensive, time-consuming, and difficult to conduct, and have many confounding variables. However, a few studies have been done in locations around the United States, with the aim of determining whether contaminated ground water represents an appreciable risk when chemicals are present in the concentration range of tens to a few hundreds of parts per billion. These investigations have been designed to be similar to the NCI chlorination by-products study described above.

One of these ground-water investigations was conducted in Woburn, Massachusetts, by a study team out of Harvard University. This team studied the infamous G&H wells that were contaminated by disposal activities at at least two industrial locations. The contaminant concentrations spanned the range of a few hundred parts per billion of low-molecular-weight chlorinated compounds, such as tetrachloroethylene and chloroform, and the degradation by-products of these compounds. The results of the Woburn study indicated an increase in perinatal deaths (within the last three months of pregnancy or the first seven days after birth) in families receiving contaminated water. This determination was based on evaluation of 4403 pregnancies from 1970 to 1979, and showed a death rate of 77 per 1000, compared to 7.2 per 1000 expected. The relative risks of various types of birth defects were also compared for 3814 births. The groups for both studies were women who received less than 20% or more than 20% of their drinking water from contaminated wells. Relative risks were found to be elevated for eye and ear birth defects—4 per 150 children compared to 0.9 expected. For birth defects generally considered to be associated with environmental exposures, including defects of the central nervous system, the relative risk factor was also elevated. A leukemia cluster also correlated with the use of the contaminated well water.

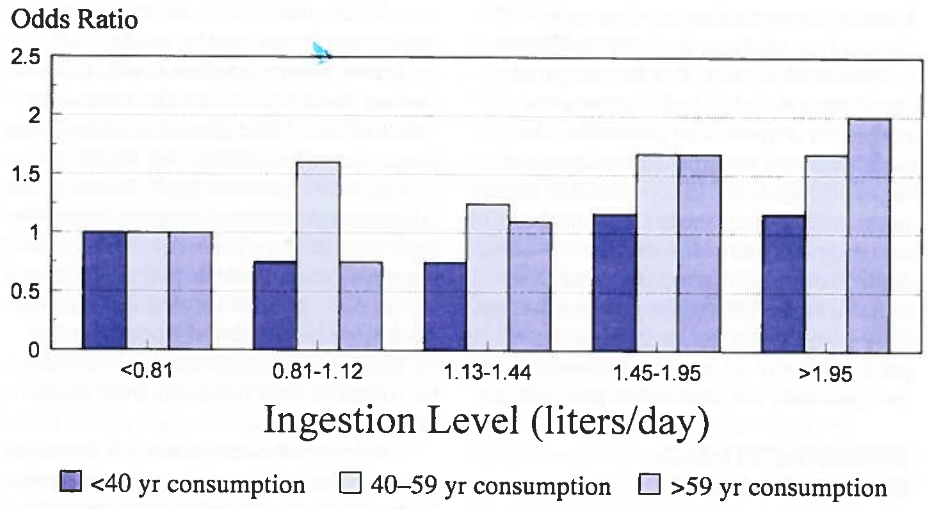

Figure 2. Graph summarizing study of bladder cancer risk and drinking of chlorinated water. The bars are grouped according to the quantity of water consumed per day in a case-control epidemiological study. The risk of developing bladder cancer increases as the consumption of chlorinated water increases. As one would expect, the risk also increases as the duration of exposure increases. Therefore, as indicated by the bar at the far right, the greatest cancer risk is posed by a lifetime (> 59 years) of consumption of two liters or more of chlorinated water per day.

Although the accumulated evidence does suggest that a significant risk might exist, or that at least some risk (significance being a subjective determination) exists, certain results of the Woburn study, like the results of the chlorinated water study, are not conclusive. The epidemiological community will not agree that this proves there is a clear and unambiguous risk to the public health. The Woburn study was very controversial, as were others such as the ones in Gray, Maine, and at a number of other locations around the country. Yet, the results of these studies do represent warning signals that, in fact, real health risks can be associated with exposures to contaminated ground water.

This brings us to the second question that I posed at the beginning of this discussion: If these health risks are real (I believe that they are), are the health-based cleanup goals reasonable? Are the cleanup strategies a reasonable response to these health-based goals? The answers to these questions are both *yes* and *no*, depending on location, and on specific decisions that are being made at contaminated sites.

These health-based goals are mostly drinking water standards promulgated under the Federal Safe Drinking Water Act or under state statutes. For chemical carcinogens, the standards are generally the analytical detection limit (the practical detection limit or quantitation limit), which is typically in the range of about 2 to about 10 parts per billion. Table 1 compares the drinking-water standards and the quantitation limits for several common contaminants. As suggested by this comparison, these goals are established more on the basis of technical feasibility and the ability to monitor chemical concentrations in water than by health-effects studies.

Statutes such as the Safe Drinking Water Act and, to some extent, Superfund and the Resource Conservation and Recovery Act (RCRA), use these drinking-water standards or try to strike a balance between the risk that contaminated water represents and the cost and technological feasibility of cleaning up ground water. The National Contingency Plan (NCP) is an example of how the health goals are supposed to be established, and the trade-off between feasibility and cost. The NCP is a rule that was promulgated under Superfund and the Clean Water Act. It provides practical, common-sense procedures for approaching ground-water contamination problems and releases of hazardous substances.

The nine criteria that one is supposed to balance in order to arrive at a decision about cleanup at a Superfund site are as follows.

Threshold Criteria
1. Overall protection of human health and the environment
2. Compliance with applicable or relevant and appropriate requirements (ARARs)

Primary Balancing Criteria
3. Long-term effectiveness and permanence
4. Reduction of contaminant toxicity, mobility, or volume
5. Short-term effectiveness
6. Implementability
7. Cost

Modifying Criteria
8. State acceptance
9. Community acceptance

The first two criteria, so-called threshold criteria, are related to risks and the use of risk assessment at sites, and to compliance with applicable or relevant and appropriate requirements (ARARs). ARARs for ground water include any possibly applicable standards, such as the drinking-water standards, that might be used as ground-water cleanup goals and standards. We've had considerable difficulty over the years in striking a balance between our health goals (threshold criteria) and cost, implementability, long-term effectiveness, and some of the other balancing criteria that are supposed to be taken into account. We've been very slow as a country, and perhaps as a profession, to recognize that many ground-water contamination problems cannot be cleaned up to current health goals using existing technology. For example, the presence of dense, nonaqueous phase liquids (DNAPLs) might make cleanup to ARARs technically unfeasible.

The EPA is beginning to recognize this, and to date it has issued three policy statements that represent a common-sense approach to this problem. In essence, the EPA states that, if we determine that it is not technologically feasible to achieve cleanup goals at a site, then we abandon the goals in favor of options like containment and institutional controls to protect the public by preventing use of the ground water. Sad to say, in many instances that's what we're having to do. But, unfortunately, we've been very slow to recognize these technical infeasibilities at many sites. As a result, we have spent countless dollars, both in transaction costs and in capital, operation, and maintenance costs, attempting to achieve something that is simply not possible with existing technology.

The use of risk assessment methods might help us define and meet the threshold criterion of overall protection of human health and the environment under the NCP. In practice, a fair degree of latitude exists for defining when such protection is achieved. For chemical carcinogens, there's a hundredfold degree of latitude; that is, the NCP says that we can clean up a site such that, afterwards, we can have excess cancer risks between 1 in 10,000 and 1 in 1 million, a fairly broad range that allows for a lot of discretion. Yet, we've used risk assessment methods

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TABLE 1. FEDERAL DRINKING STANDARDS AND PRACTICAL QUANTITATION LIMITS FOR VOLATILE ORGANICS

Compound	Maximum contaminant level (mg/L)	Practical quantitation limit (mg/L)
Benzene	0.005	0.005
Carbon tetrachloride	0.005	0.005
p-Dichlorobenzene	0.075	0.005
o-Dichlorobenzene	0.6	0.005
1,2-Dichloroethene	0.005	0.005
1,1-Dichloroethylene	0.007	0.005
c-1,2-Dichloroethylene	0.07	0.005
t-1,2-Dichloroethylene	0.1	0.005
Dichloromethane	0.005	0.005
1,2-Dichloropropane	0.005	0.005
Ethylbenzene	0.7	0.005
Monochlorobenzene	0.1	0.005
Tetrachloroethylene	0.005	0.005
Toluene	1.0	0.005
1,2,4-Trichlorobenzene	0.07	0.005
1,1,1-Trichloroethane	0.20	0.005
1,1,2-Trichloroethane	0.005	0.005
Trichloroethylene	0.005	0.005
Vinyl chloride	0.002	0.01
Xylenes	10.0	0.005

that in many cases border on the absurd. To give one example (I've seen this at many, many sites), potential risks associated with a site have been estimated using the highest concentration of each contaminant detected in a monitoring well anywhere on the site, regardless of whether these maximum concentrations were at different wells for different chemicals. Using this method to construct the hypothetical risks that might exist in the future requires the assumption that, somehow, a future resident near the site or at the site could sink a number of wells, interconnect them and therefore be exposed to all these chemicals simultaneously.

Over the past ten years, however, those of us in this business have observed that the approaches for addressing ground-water contamination are changing, and that new guidance has come out of EPA that relates to both the problems of technical infeasibility and the question of risk assessment methodologies. These developments are beginning to put this problem in perspective, leading to greater cost-effectiveness and economic efficiency when deciding "How clean is clean?" at a site.

There is a basis for concern about the health effects of ground-water contamination. The health-based goals that we are now using, the drinking water standards, are generally reasonable. The way they are being applied, however, has led to problems, in the sense that more health protection is being attempted at certain sites than the health goals would suggest. Thus, it's not so much that the health goals we've established are inadequate; rather, it is the implementation that has fallen far short.

PERSPECTIVE 3: The Economic Value of Ground-Water Protection: What Are the Benefits, and How Do They Compare to the Costs?

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Ground-water contamination is one of many problems these days that calls for integration of skills from different disciplines. One needs hydrogeologists, toxicologists, policy analysts, even economists (as I am). Because many instances involve litigation, one needs attorneys, and so forth. So ground-water contamination, like many environmentally related areas, provides an opportunity for people to work across disciplines and learn how these disciplines fit together.

Why protect ground water? Well, we have some notion that the benefits of doing so outweigh the costs. Certainly there is legislation, such as RCRA and Superfund, and a lot of public interest in seeing ground water protected or past problems remediated at particular sites. But do we have any evidence as to what the benefits are and how they compare to the costs? To engage in that sort of discussion we need to think about what types of benefits exist for protecting or cleaning up ground water. We also need to think about what uncertainties exist, with respect to benefits and ground-water contamination in general, and how the uncertainties impact the issue of benefits vs. costs. Finally, we need to consider whether the benefits information or benefit cost analysis should influence policy, or how it should do so. My view is that benefit cost analysis is a useful guide to policy—but it's a tool, not a rule. Benefit cost analysis has many inherent uncertainties in the same way that the underlying risk assessment and underlying hydrogeology have many uncertainties embodied in their respective aspects. When one incorporates these in benefit cost analysis, it will only compound the uncertainties and propagate the errors. In any policy context, one needs to view it in that light.

What are the benefits of ground-water protection? Benefits that people often speak of first are the avoided damages and the avoided remediation costs. This is essentially the prevention vs. cure argument. In addition, there are premiums, as economists call them, for avoiding uncertainty. It's a recognized psychological and economic fact that people are willing to pay something, like an insurance premium, to reduce uncertainty, and there are many uncertainties related to ground-water contamination. Finally, there also are benefits not associated with the direct use, or even potential use, of the resource. These are called non-use values or intrinsic values, such as existence and bequest values, and they refer to a resource that existed naturally in a certain state with certain qualities and in a certain quantity. People might be willing to pay to have it preserved, or returned to that state if it has been altered. They might pay to protect the resource for future generations.

As I illustrate below, prevention is not always cost effective relative to remediation. Although "an ounce of prevention is worth a pound of cure" is a catchy phrase, it's not always clear that that's true for ground water. What are the expected damages for a site that might contribute to ground-water contamination? When we speak of damages caused by ground-water contamination, we must consider human health risks as well as corrective-action costs.

The expected damages are related to the probability, p, that contaminants will be released from that site and to the probability, q, of detection if a release should occur, as expressed by the following equation:

$$\text{Expected damages} = p\,[\,q\,C_R + (1 - q)\,C_H\,],$$

where C_R represents the costs of remedial response and C_H represents the costs of related health risks. We don't know for certain that there will be a release, so it's a probabilistic event. If the release is detected before it hits somebody's drinking-water well, there would normally be some sort of remedial response. Or, one might choose to leave it alone, and that can be included as one of the response options. The $(1 - q)$ term is the probability that the release won't be detected before it hits the well, in which case health-risk-related costs, C_H, are posed. Thus, the expected damages reflect the probabilities of release of the contaminants and detection-weighted costs of any contamination incident.

Given this expected damages context, what are the benefits of different policies that influence the probability of a release or the probability of detection? For the probability of release, adding more stringent liner requirements at a waste facility, for instance, would change the expected damages because of the change in the probability that a release might occur. Similarly, for a monitoring-oriented policy, the benefits would be the change in damages (D) given the change in the probability of detecting the release earlier, or the contamination earlier. The benefits can be expressed as:

$$\text{Benefits} = dD/dp \;\text{ or }\; dD/dq\,.$$

Several years ago, when I was working at EPA, everyone was talking about prevention vs. cure. Nobody had looked into what the benefits of ground-water protection were, so I embarked on an investigation to see whether there were data out there. For the examples I give here, it's important to recognize that the outcomes are very site specific and that I'm not trying to infer that they represent vast national trends.

One can see from Figure 1 that, for three of the four case study sites, the costs of fixing the problem after the fact are lower than the costs of trying to prevent it. At one site (Nashua), there is a balance between the costs of prevention and the costs of remediation. The prevention costs all assume that whatever was costed out would definitely work, and would reduce the probability of release to zero. If, in fact, some probability of release still existed, even with preventive actions, certain remediation costs would also have to be incurred.

To provide some sense of where these numbers come from, Table 1 (see p. 184) gives a breakdown of costs for the Miami site. For prevention, we evaluated improved landfill management over the course of the operation of a very large municipal landfill. We did not even apply advanced RCRA-type standards, but just considered such changes as their not having dug the cells into the ground-water table, having put better covers on with greater frequency during the course of operation, and similar measures. The changes did not represent a high-tech solution, and there was therefore a high probability that releases and contamination would still occur. Nevertheless, the preventive costs, in present value, would have been about $67 million.

For remediation, several options can be considered. Option 2, which involves putting a final cap on the landfill, containing the plume through counterpumping, treating the plume, and then reinjecting it in the ground water, would cost close to $63 million. So, that would represent a tossup between possibly avoiding the problem and fixing it after the fact. Other types of remediation provide opportunities for significant cost savings. For example, options 3 and 4 are similar to 2 except that the plume is not treated for reinjection in the ground water under those options. In option 4 the plume is directly reinjected into a lower saltwater aquifer, which saves a considerable amount of money. Option 4 would cost only $17 million per year. Obviously, debates about how well confined the lower aquifer is and what the residual risks are would take place. Nevertheless, this shows that several options are available to deal with the contamination of this site, and most are less expensive than trying to prevent it.

One of the other sites we looked at was an industrial facility and an associ-

Forum *continued on p. 184*

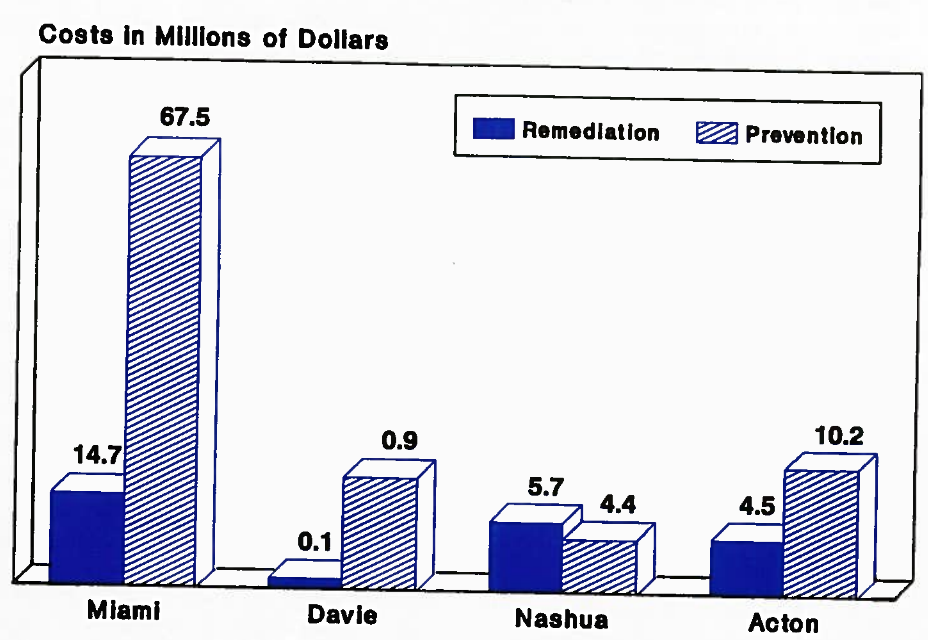

Figure 1. Costs of prevention and remediation at four case study sites. The black bars represent what it costs to fix the problem once the contamination has occurred. These are known contamination incidents. The striped bars represent the costs of actions that might have prevented the contamination in the first place.

Forum *continued from p. 183*

ated public well field in Massachusetts (Table 2). The facility had a lagoon with some liquid and some sludge. Closing the site, moving the sludge, and putting caps on (option 3) would cost almost twice as much as treating the drinking water at the well site and dealing with the source of the problem by shutting the plant, removing liquids in the lagoon, and appropriate disposal offsite (option 2). Moreover, option 3 would provide lower health protection. This option is more of a typical Superfund remedy, and does not involve treating the drinking water. The study results are shown graphically in Figure 2 to illustrate more clearly a cost-effective strategy. Figure 2 clearly shows that treating the drinking water —which includes certain source controls at the industrial facility—is not only the least costly, but also the most cost effective in terms of protecting human health. A more traditional remedy under Superfund would be closing the site, most likely including plume removal, which costs considerably more and is far less cost effective from a public health standpoint.

TABLE 1. COSTS OF PREVENTION AND REMEDIATION FOR MIAMI SPRINGS WELLFIELD–58TH STREET LANDFILL

Management strategies	Costs* (millions)
Prevention of contamination†	
1. Improved landfill management	$ 67.5
Remediation of contamination	
2. Stop source (final cover at landfill), contain plume (counterpump), treat plume, and reinject	$ 62.8
3. Stop source, contain plume, and treat plume for surface disposal	$ 38.1
4. Stop source, contain plume (counterpump), and deepwell inject contaminant plume	$ 16.6
5. Stop source and treat drinking water	$119.0
6. Treat drinking water	$ 95.0
7. Move wellfield (close current wells, develop new wellfield)	$ 48.0

Note: Source is Sobotka and Co., Inc., 1983.
* Present value. Discounted at 2% real rate, over a 30-year time horizon.
† Hypothetical, hindsight option.

TABLE 2. COSTS OF PREVENTION AND REMEDIATION FOR ASSABET WELLFIELD–ACTON

Management strategies	Costs* (millions)	Cancers avoided	Cost per cancer avoided
Prevention of contamination			
1. RCRA 264 rules (double liners, monitoring, etc.)†	$10.2	1.31	7.8
Remediation of contamination§			
2. Treatment of drinking water (includes plant closing and removal of liquids in lagoon)	$ 4.5	0.86	5.2
3. Closure of site (includes plant closings, liquids removal, solidification and removal of sludge, caps)	$ 8.5	0.22	38.6
4. Drinking-water treatment and site closure (2 and 3 combined), plus plume removal	$10.6	0.86	12.3

Note: Derived from an analysis by Industrial Economics, Inc., October 1985.
* Present value. Discounted at 5% real rate.
† Hypothetical, hindsight option.
§ Costs of remediation do not include $3.1 million spent on aquifer studies. Nearly 95% of these costs were for studies purchased by the site owner or operator and may be indirectly associated with litigation.

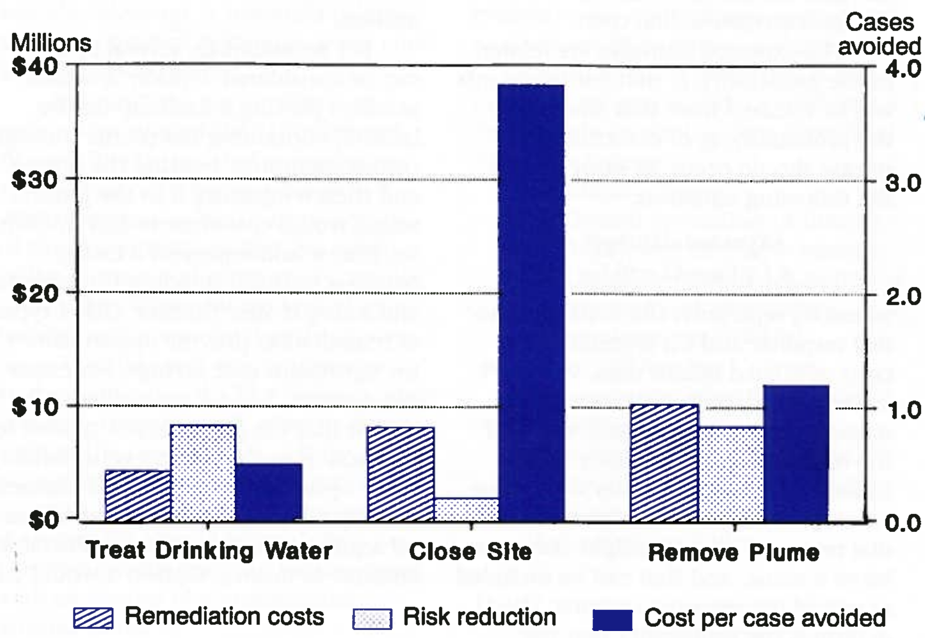

Figure 2. Cost-effective remediation strategy. The "cost per case avoided" is the dollar cost to avoid each statistical excess cancer case.

So, the cost of prevention is not necessarily less than the cost of the cure. Yet, the public has considerable interest in and has expressed public values regarding protection of ground water. What are we missing here? What are we not counting that's really important? One potentially important factor we're not considering is the uncertainty inherent in the process. Uncertainty might rationalize higher benefits of protection. People dislike uncertainty or risk, and they're willing to pay for policies that reduce their exposure to uncertainty. For example, option values might be added to the prevention vs. cure debate. Option value is an economic concept related to uncertainty regarding the demand for (or supply of) a scarce resource. We're not sure about future water supply or what future demands will be, and we're willing to pay a premium to have clean water there in the future.

Another uncertainty issue involves risks to health and to income. Income here refers to basic pocketbook issues. For example, if you're willing to pay for monitoring at your drinking water well, you are actually protecting your health. You hope to detect a contaminant before you ingest it, and the risk you're exposed to is therefore to your wallet. If you find a problem, it will be not a health problem, but a financial problem to remedy the site. Alternatively, for a containment policy that doesn't have a detection or monitoring component, you're leaving people open to a health risk. So, risk-related or risk-aversion premiums to protect incomes and health might come into play. That's one way to think about the differences between policies for monitoring and detection vs. those that affect the likelihood of contamination or involve corrective action.

This raises the issue of the moral and ethical aspects of making policy in the face of uncertainty. A moralist I've worked with, who teaches philosophy, points out that when considerable uncertainty exists regarding the protection of human health, standard public policy in a society like ours would be to err on the side of conservatism. One can see this in the dose-response paradigm: we use upper confidence limits when we extrapolate dose-response functions; and we use a linear, no-threshold model for carcinogens—even though that's becoming less and less supported by scientific evidence. So, the ethical or moral type of issue in dealing with uncertainty, by being conservative and perhaps overly protective, might provide one set of reasons for rationalizing ground-water protection.

Another aspect that's relevant concerns the fact that uncertainties inherent in ground-water contamination, and in protection efforts, greatly exceed the uncertainties associated with other environmental media. For many environmental issues, concern is with dose-response uncertainties. For ground water, these are compounded with large uncertainties about exposure, so there is considerable potential for error propagation. Uncertainties in exposure assessment for ground water can be related to source, pathway, and use.

Comparison between a ground-water contamination incident and, say, discharge from a pipe or point source at an industrial facility reveals some interesting differences about what we know and don't know, and the risks that are posed. For surface water discharge, we know where the pipe comes out of the factory. We know what's going to be coming out the end of that pipe, and we can easily monitor the permit limits. We know where the effluent is going—it's going into the river. We know where that river flows. We know it goes downstream; we can monitor it easily at various places downstream to see whether it's biodegrading or getting diluted. We know whether anyone is drinking from it downstream. In brief, it's fairly straightforward to link the source of the potential contamination, its loadings to the environment, its ultimate transport and fate, and the potential for exposure. In contrast, for ground-water contamination there are several uncertainties related to the source of the contamination. We don't know for sure that a given facility is going to release anything to the environment, or, if it does, when the release will occur. We don't know what contaminants will be released, and we don't know how much contaminant will be released. So, we're starting with a lot of uncertainty that we normally don't have with typical stack and pipe emissions.

Many factors create uncertainties in fate and transport. We don't know whether contaminant will flow toward a drinking-water well or toward an area that is not used for drinking water. Various processes might change contaminant characteristics during transport. We don't know when contaminants might reach the well, what contaminants might reach it, or what concentration will reach the well.

Even if one gets beyond the source- and the pathway-related uncertainties, use-related uncertainties are possible. Is drinking-water treatment that will take care of the problem in whole or in part already in place? Are people exposed, or potentially exposed—possibly sensitive populations? Will they detect it because of their normal practices? How long might they be exposed before they find out about it? Uncertainties present in a ground-water contamination case that one doesn't see in many other environmental issues are summarized below.

Source-related Uncertainties
- Will contaminants be released to the environment? (Probability of release due to failure of containment system)
- When will release occur, and for how long? (Timing and duration of containment failure)
- What contaminants will be released? (Chemical constituents on-site)
- How much will be released? (Constituent mass loadings)

Pathway-related Uncertainties
- Will contaminant reach a drinking water well? (Flow direction and proximity of source to well)
- When will contaminants reach the well? (Time of travel and duration of exposure)
- What contaminants will reach the well? (Environmental fate of contituents)
- How much contamination will reach the well? (Constituent concentration at the well)

Use-related Uncertainties
- Will the well be used for drinking water? By whom? (Exposure route, and number and sensitivity of exposed population)
- How long will users rely on the well for drinking water? (Duration and continuity of exposure)
- What monitoring is practiced to detect contaminants? (Potential to avert exposure)
- What dilution and/or treatment occurs prior to consumption? (Reduced exposure levels due to drawdown, blending, and/or contaminant removal)

If uncertainty is the basis for saying that maybe the benefits of prevention and remediation are worth the costs, then we need to consider whether the public's perceived benefits differ from so-called real benefits or risk reductions. For that, we will consider some evidence on *perceived* vs. *real* or so-called actual risks. This also raises an interesting issue in public choice. In a democratic society the people govern.

Forum *continued on p. 193*

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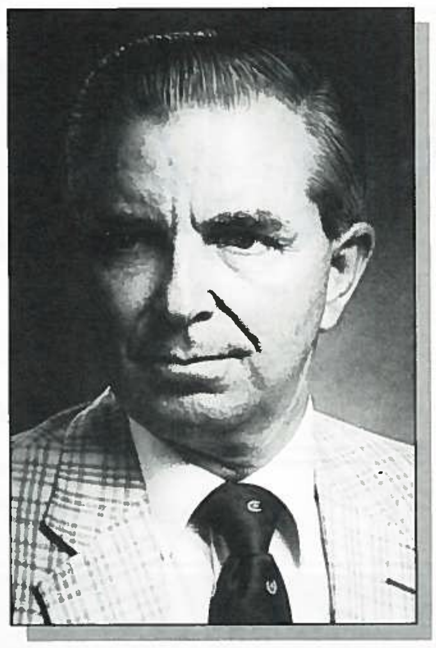

CHAIRMAN'S MESSAGE

Last year I reported that new programs were going to command the Foundation's attention in these early years of GSA's second century. DNAG closed the first 100-year chapter, and SAGE and IEE are opening the second. With respect to center stage, the "E's" have it — Earth, education, and environment.

SAGE has quickly become an important part of GSA's work in advancing the science of geology. Under the dynamic leadership of Dr. Ed Geary, the SAGE program is becoming known throughout earth science education. This expanding activity has resulted in a significant challenge to the Foundation. Where can the funds be found to finance partnering, teacher training, workshops, and a myriad of other undertakings?

The Institute for Environmental Education has presented the Trustees with a similar charge. The first annual IEE environmental forum was held in Cincinnati in October. From all accounts the speakers and topics were extremely well recieved. Perhaps the proof of the pudding was a continuing discussion among attendees well past the 5:30 p.m. session closing time. IEE Executive Director and Foundation Trustee Dr. Fred Donath has been advancing the Institute along a number of fronts in addition to the annual forums. Developing activities include other conferences and workshops, a visiting geoscientist program, and the design of a public outreach program. The expansion of the Institute at this time defines a further need for program funding.

New programs are not the whole story. Student research grants continue to be an important contribution that GSA makes every year to the well-being and advancement of our science. We have had the benefit of an NSF grant for the past three years which has stimulated interest in the program and allowed GSA to make more grants of larger size. Nevertheless, student research grants would benefit from a lot more money, either in the form of endowment income or program funds.

Publications such as the very popular *Geology* are a key service to the scientific world, but few readers could stand the true cost of producing and publishing. Financial support from the Penrose endowment brings GSA's publications within the reach of our universe of buyers.

Meetings, field trips, and symposia such as the Penrose conferences provide important platforms for scientific communication among geologists and with other disciplines and the public. The GSA Congressional Science Fellow program, now in its seventh year, has successfully brought scientific information and expertise into the depths of Congress, enabling legislators to make better national science policy. On net balance, these programs are not financially self-supporting and require supplemental monies from GSA.

The growth of the Society's activities has brought with it an increase in staff, the people who do the work. This in turn has meant that more space is needed for the workers, and in recent years employees have spilled out of the Boulder headquarters into adjacent buildings. That condition will soon be remedied, with the start of a 13,200 square foot addition to 3300 Penrose Place. While the costs of construction are being covered through the issuance of tax-free bonds at a very attractive interest rate, the Foundation intends to reduce and eventually eliminate that debt through capital contributions to the building fund.

These activities on behalf of Earth, education, and the environment boil down to a significant need for new funds, both endowment and programmatic. GSA Council has directed the Foundation to obtain these funds, an undertaking of considerable magnitude, akin to the DNAG funding in the early 1980's, that will occupy the next several years and take up the time of an expanded Foundation staff. A fund raising effort of this magnitude requires extensive planning and preparation, and 1992 was a year occupied by this type of activity.

The Trustees of the GSA Foundation, nine in number, are one of the principal assets of GSA. These people are leaders in the science, in business, and in the community. Their enthusiasm, experience, and vision make it all work, and I extend my personal appreciation to them for the hours that they have volunteered on Foundation business and deliberations.

The Foundation staff has once again performed its functions of finding, receiving, holding, and disbursing money with routine efficiency. Bob Fuchs, Mike Wahl, and Donna Russell have conducted business as usual while planning for a greatly expanded fund-raising effort. In this regard, I am very happy to welcome Dorothy M. Palmer who joined the Foundation staff in January 1993 after many years as the senior administrator under the Executive Director. Dorothy's many years of experience and contact with the membership will be an invaluable asset to the Foundation in the important work that lies ahead.

Saving the best for last, it is a distinct pleasure for me to be able to thank all the members of GSA for the financial support they have provided through contributions and dues. We had a significant achievement in 1992. The total of 1,400 contributors was the highest in the Foundation's twelve-year history, and this augurs well for the success of our efforts to finance GSA's second century challenges in Earth, education, and the environment.

Charles J. Mankin
Chairman

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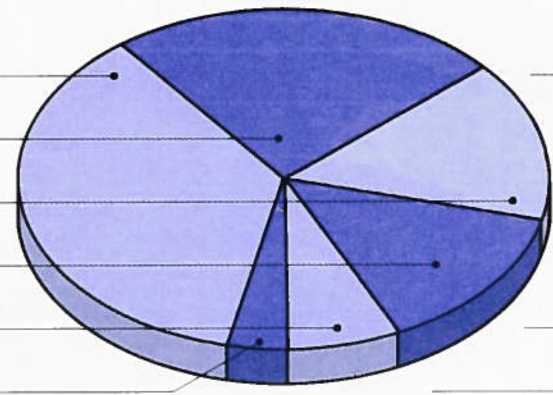
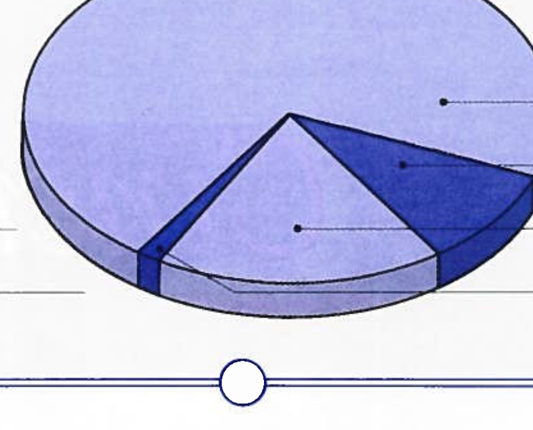


Contributions 1992
Total $172,082



Foundation Mission Statement

The GSA Foundation operates under the following mission statement:

The GSA Foundation exists to fund those research, publications, student support, public outreach, and other geoscientific programs of the Geological Society of America that the Society considers necessary to accomplish its purpose of the advancement of geology, the scientific growth and development of its members, and the application of geology to the wise use of Earth's resources and the stewardship of Earth's environment.

To accomplish this mission, the Foundation's long-term policy is to raise money from members, individuals, companies, and institutions. Funds received are invested for income, preservation of capital, and growth of principal. GSA program funding requirements are met out of income and such principal as is necessary. The Foundation's financial goal is to build a fund balance in the $5-10 million range.

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Senior Fellows Reception

This popular GSA annual meeting event was well-attended in Cincinnati. Each year the Foundation hosts a party that immediately follows the Board of Trustees meeting, for GSA's Senior Fellows, the Foundation's major contributors, GSA Council, and other special people. The affair provides a unique opportunity for GSA's longest-standing members to remember the past, discuss the present, and look forward to the Society's future.

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PRESIDENT'S MESSAGE

The Foundation's purpose is to fund GSA programs. From inception in 1980 until recently, most money spent by the Foundation was to pay the costs of DNAG. With the winding down of the DNAG publication project, a record high was realized in 1992 for payments in support of activities other than DNAG. The Foundation disbursed $153,703, which was a 53% increase over 1991, and a 570% increase over 1986. This money was used by GSA for student research grants, scholarships, awards, medals, travel grants, conferences, symposia, SAGE, and the Institute for Environmental Education.

The largest group of payments was made from the 28th IGC Fund, totaling $47,742. This money was in the form of travel grants to 23 U.S. resident geologists under the age of 40 who attended the 29th International Geological Congress in Kyoto, Japan.

The Pooled Income Fund began in January 1992 with a gift from Carol McGill. Her gift also established the Carol G. and John T. McGill Fund for research grants in Engineering Geology. New participants and additional gifts during the year increased the PIF to over $100,000. The Pooled Income Fund is one of several types of planned or deferred gifts used by the Foundation to meet the personal retirement and estate planning of members and donors. Contributors retain a life income interest while the Foundation holds the remainder interest, which eventually becomes part of the Foundation's endowment upon the death of the donor. Pooled Income Fund recipients were paid a cash return of 7.0% in 1992. The Fund's total return was 8.1%.

In addition to the McGill Fund, other funds were established in 1992. The Arthur D. Howard Fund for research grants in Quaternary geology and geomorphology was the result of a bequest. The newly formed GSA International Division set up an award fund. The Rip Rapp Archaeological Geology Award Fund was begun with an initial contribution from George "Rip" Rapp. The first contributions to the Second Century Fund for Earth — Education — Environment were recorded. Also, a contribution to the Pooled Income Fund by Trustee William B. Heroy, Jr. will eventually become the corpus of the Heroy Fund for Research Grants.

The Foundation's fund balance, the principal measure of the net worth of a non-profit organization, was $1,365,966 at the end of 1992. This was a decrease of 6.7%, attributed largely to two factors, a decrease in the value of the DNAG inventory and a change in accounting policy. Sales of DNAG products and the writedown of items remaining in inventory, in line with GSA fiscal policy, were the reasons for the reduction in the balance sheet value of DNAG to $441,409 from $618,418 one year earlier. In 1992 the Foundation Trustees approved a change in valuation of investments to the lower of cost or market, which conforms to GSA's policy. This switch to a more conservative policy created a downward adjustment of $98,134. If year end market values had been used, the fund balance would have declined 3.1% during 1992.

As a result of the completion of large corporate pledges to DNAG, contributions to the Foundation declined 8.6% from the prior year. Counter to the dollar trend, however, was the number of contributors, which rose significantly to 1,397, the highest annual number in the Foundation's history. This was an increase of 15.8% over the previous year and represents 8% of GSA membership.

A number of major financial challenges face GSA and the Foundation. The new SAGE and IEE programs and the growth of existing activities such as research grants are important to GSA's mission to support geology. This program growth brings with it the need to enlarge GSA's headquarters building. As the fund-raising arm of the Geological Society of America, the Foundation is preparing the groundwork that will result in an increase in both endowment and program funds. The strong demonstrated support of GSA's membership during 1992 provides a high degree of confidence that the challenges before us can be met.

Robert L. Fuchs
President

Trustees Meeting

At GSA's annual meeting each year, the Foundation Trustees meet to elect officers, appoint new Trustees, review the progress of the Foundation, and plan for the future. Foundation officers and some GSA staff attend the meeting, thereby providing a forum for the coordination of GSA programs, and Foundation financing activities.

Trustees

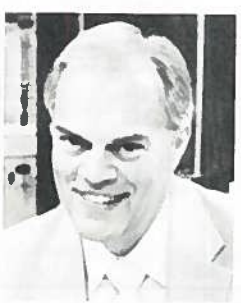
CHAIRMAN

Charles J. Mankin, *director of the Oklahoma Geological Survey, received his B.S., M.A., and Ph.D. in geology from the University of Texas. He served as President of the American Institute of Professional Geologists, the American Geological Institute, the Association of American State Geologists and the Mid-Continent Section of the Society of Economic Paleontologists and Mineralogists. A Fellow of GSA, he has served on the GSA Council and Executive Committee.*

VICE-CHAIRMAN

William B. Heroy, Jr. *earned a geology degree from Dartmouth and his Ph.D. from Princeton. His professional career included serving as a geologist at Texaco, as geologist, vice-president, and president of Geotech, and as a group executive of Teledyne. He was vice-treasurer and professor at Southern Methodist University and is now Professor Emeritus. He belongs to SEG and AAPG (Treasurer) and is an Honorary Life Member of both the Dallas Geological and Geophysical Societies. A Fellow of GSA, he has been a councilor, treasurer, and has served on numerous committees.*

Paul A. Bailly *is chairman of Castle Group, Inc., a company managing two venture capital partnerships focused on precious metals mines at the development stage. He received a Geological Engineering Degree from Nancy University, France and his Ph.D. in Economic Geology from Stanford University. A Fellow of GSA, he was President in 1983. He was President of the Society of Economic Geologists in 1981, and received the Jackling Award of the Society of Mining Engineers in 1979. He received the Mineral Economics Award of the American Institute of Mining and Metallurgical Engineers in 1993. He is a Director of the Mineral Information Institute, and of five mining companies.*



Fred A. Donath *a consultant located in San Clemente, California, received his Ph.D. from Stanford University. His professional career has included positions as Corporate Vice-President for R&D in the Earth Technology Corporation, Head of Geology at the University of Illinois and Professor of Geology at Columbia University. He has published extensively on experimental studies of various geologic phenomena and on dynamic structural geology. He is a Fellow of the Geological Society of America and served as Acting Editor for the Society during 1964. Donath currently serves as the Executive Director for GSA's Institute for Environmental Education.*

Peter T. Flawn *received a B.A. Degree from Oberlin College and a M.S. and Ph.D. from Yale University. Flawn was Director of the Bureau of Economic Geology, a faculty member and president of the University of Texas. He is a member of the National Academy of Engineering, an honorary member of AASG and AAPG, and past-president of AGI. He received the Wilbur Lucius Cross Medal from Yale University and the Ben H. Parker Medal from AGI.*
A Fellow of the Geological Society of America, Flawn was Councilor from 1972-74 and President in 1978.

Philip E. LaMoreaux *is Senior Hydrogeologist of P. E. LaMoreaux & Associates, Inc. He is a past president of the American Geological Institute, the American Association of State Geologists, and the International Association of Hydrogeologists. He received his B.A. from Denison University and his M.A. from the University of Alabama, both in geology. He was a geologist, USGS, Chief Ground Water Branch until May 1961, State Geologist of Alabama through 1976. He also served as Director of the Environmental Institute for Waste Management Studies, University of Alabama through January, 1989, and was elected to the National Academy of Engineering. A Fellow and former councilor of GSA, he is the author of many professional publications.*

Haydn H. Murray *received his B.S., M.S., and Ph.D. degrees in geology from the University of Illinois. He taught geology at Indiana University from 1951 to 1957 and was also a clay mineralogist with the Indiana Geological Survey. He worked at the Georgia Kaolin Company for 16 years and in 1973 returned to Indiana University as chairman of the geology department where he continues today as professor of geology. He is a distinguished member of the Clay Minerals Society (CMS) and SME, and a Fellow of MSA, ACS, and the Technology Association of the Pulp and Paper Industry. He is a past president of CMS, SME, and AIPG. Murray has been involved in GSA activities for more than 40 years. He is a Fellow of the Society and has served on the Council from 1982 through 1984. He is the recipient of the Hal Williams Hardinge Award in industrial minerals from the American Institute of Mining Engineering.*

Phil Oxley *is Exploration Advisor to the Board for Graham Resources, Inc., located in Covington, Louisiana. He received his B.A. from Denison and his M.A. and Ph.D. from Columbia University. Oxley worked for several U.S. oil companies until 1971 when he joined Tenneco Oil Exploration and Production in Houston, Texas. Following his retirement as President of Tenneco in 1989 he joined the faculty at the University of Colorado in Boulder, Colorado. He is a Fellow of GSA, a Certified Petroleum Geologist, and belongs to AAPG and Sigma Xi. Oxley has been a frequent speaker on geology, exploration, and energy in the U.S. and Europe.*

Brian J. Skinner *was born and raised in Australia. He has a Ph.D. from Harvard and is now a professor at Yale University working on the geochemistry of mineral deposits. He is editor of Economic Geology, chairman of the Board of Overseers of the American Journal of Science, chairman of the U.S. National Committee on Geology, and was formerly chairman of the Board on Earth Sciences and Resources (NAS/NRC). A Fellow of the Society, he was President in 1985 and chairman of the Committee on the Path to 2000.*

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Financial Report • GSA Foundation 1992

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INDEPENDENT AUDITORS' REPORT

We have audited the accompanying balance sheet of The Geological Society of America Foundation as of December 31, 1992, and the related statements of operations and fund balances and cash flows for the year then ended. These financial statements are the responsibility of the Foundation's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of The Geological Society of America Foundation as of December 31, 1992 and the results of its operations and its cash flows for the year then ended in conformity with generally accepted accounting principles.

As discussed in Note 2 to the financial statements, the Foundation changed its method of accounting for investments to lower of cost or market. Prior to the current year, the Foundation had accounted for investments at fair market value.

Strait, Kushinsky and Company P.C.

Colorado Springs, Colorado
March 17, 1993

BALANCE SHEETS • DECEMBER 31, 1992

			Restricted		Totals December 31	
	Operating	Unrestricted	Pooled Income Fund	Donor Restricted	1992	1991
Assets						
Cash and cash equivalents	$14,078	$ 7,632	$ —	$ 29,819	**$ 51,529**	$ 48,866
Contributions receivable *Note 1*	—	1,125	—	914	**2,039**	916
Accounts receivable *Note 1*	—	—	—	—	—	1,876
Due from Geological Society of America *Note 4*	—	2,967	—	4,607	**7,574**	16,831
Accrued interest receivable and other assets—	—	—	335	—	**335**	5,768
Due from other funds	10,159	—	—	—	**10,159**	3,621
Investment securities *Note 2*	950	28,933	106,440	1,408,575	**1,544,898**	1,447,471
DNAG publications inventory *Note 3*	—	—	—	441,409	**441,409**	618,418
Furniture and equipment, net of accumulated depreciation of $38,375 *Note 1*	5,523	—	—	—	**5,523**	5,434
Other	—	—	—	1,140	**1,140**	—
TOTAL ASSETS	$30,710	$40,657	$106,775	$1,886,464	**$2,064,606**	$2,149,201
Liabilities						
Deferred support *Note 1*	$ —	$ —	$105,974	$ —	**$ 105,974**	$ —
Accounts payable	714	—	801	7	**1,522**	7,764
Due to Geological Society of America *Note 4*	1,195	—	—	579,790	**580,985**	673,540
Due to other funds	—	483	—	9,676	**10,159**	3,621
	1,909	483	106,775	589,473	**698,640**	684,925
FUND BALANCES *Note 1*						
Unrestricted	28,801	40,174	—	—	**68,975**	144,524
Restricted	—	—	—	1,275,786	**1,275,786**	1,297,670
Held in trust for others	—	—	—	21,205	**21,205**	22,082
	28,801	40,174	—	1,296,991	**1,365,966**	1,464,276
TOTAL LIABILITIES	$30,710	$40,657	$106,775	$1,886,464	**$2,064,606**	$2,149,201

See accompanying notes to financial statements.

OPERATIONS AND FUND BALANCES • DECEMBER 31, 1992

			Restricted		Totals December 31	
	Operating	Unrestricted	Pooled Income Fund	Donor Restricted	1992	1991
REVENUES						
Contributions	$ 1,140	$35,844	$ —	$ 134,823	**$ 171,807**	$ 188,017
DNAG Program	—	—	—	396,064	**396,064**	437,770
Interest and dividends	317	3,684	—	77,514	**81,515**	96,887
Other *Note 4*	173,234	—	—	—	**173,234**	116,224
	174,691	39,528	—	608,401	822,620	838,898
EXPENDITURES						
Operating expenses	209,791	533	—	11,465	**221,789**	148,730
DNAG Program	—	—	—	552,088	**552,088**	726,581
Grants — Geological Society of America programs	—	3,922	—	149,781	**153,703**	100,229
	209,791	4,455	—	713,334	**927,580**	975,540
EXCESS (DEFICIENCY) OF REVENUES OVER EXPENDITURES	(35,100)	35,073	—	(104,933)	**(104,960)**	(136,642)
INVESTMENT ACTIVITY						
Realized gain (loss) on investments	1	2,913	—	55,659	**58,573**	(315)
Unrealized gain (loss) on investments	—	—	—	—	—	105,982
CAPITAL ADDITIONS	—	—	—	46,211	**46,211**	143,051
EXCESS (DEFICIENCY) OF REVENUES OVER EXPENDITURES, INCLUDING INVESTMENT ACTIVITY AND CAPITAL ADDITIONS	(35,099)	37,986	—	(3,063)	**(176)**	112,076
ADJUSTMENT FOR THE CUMULATIVE EFFECT ON PRIOR YEARS OF ADOPTING LOWER OF COST OR MARKET ACCOUNTING *Note 2*	—	(8,651)	—	(89,483)	**(98,134)**	—
EXCESS (DEFICIENCY) OF REVENUES OVER EXPENDITURES, INCLUDING INVESTMENT ACTIVITY, CAPITAL ADDITIONS AND CHANGE IN ACCOUNTING PRINCIPLE	(35,099)	29,335	—	(92,546)	**(98,310)**	112,076
BEGINNING FUND BALANCE	8,226	136,298	—	1,319,752	**1,464,276**	1,352,200
TRANSFERS IN (OUT)	55,674	(125,459)	—	69,785	—	—
FUND BALANCE (DEFICIT) END OF YEAR	$28,801	$40,174	$ —	$1,296,991	**$1,365,966**	$1,464,276

See accompanying notes to financial statements.

CASH FLOWS FOR THE YEAR ENDED DECEMBER 31, 1992

	1992	1993
CASH FLOWS FROM OPERATING ACTIVITIES		
Excess (deficiency) of revenues over expenditures, including investment activity and capital additions	$(98,310)	$112,076
Adjustments to reconcile excess (deficiency) of revenues over expenditures to net cash provided by operating activities:		
Depreciation	4,091	4,651
Realized (gain) loss on investments	(58,573)	315
Unrealized loss on investments	—	(105,982)
Change in accounting principle	98,134	—
(Increase) Decrease in assets:		
Contributions receivable	(1,123)	4,737
Accounts receivable	1,876	(1,876)
Due from other funds	(6,538)	(2,540)
Due from Geological Society of America	9,257	(16,831)
Accrued interest receivable and other assets	5,433	(5,132)
DNAG publications inventory	177,009	189,482
Other	(1,140)	—
Decrease (Increase) in liabilities:		
Accounts payable	(6,242)	(131,895)
Due to other funds	6,538	2,540
Due to Geological Society of America	(92,555)	(81,349)
Deferred support	105,974	—
Net cash provided (used) by operating activities	143,831	(31,804)
CASH FLOWS FROM INVESTING ACTIVITIES		
Additions to furniture and equipment	(4,180)	(1,028)
Net change in investment cash	(124,738)	183,738
Purchase of investments	(1,620,505)	(1,056,626)
Proceeds from maturities and sale of investments	1,608,255	838,660
Net cash used by investing activities	(141,168)	(35,256)
NET CHANGE IN CASH	2,663	(67,060)
CASH AND CASH EQUIVALENTS, BEGINNING OF YEAR	48,866	115,926
CASH AND CASH EQUIVALENTS, END OF YEAR	$51,529	$48,866

See accompanying notes to financial statements.

NOTES TO FINANCIAL STATEMENTS • DECEMBER 31, 1992

Note 1
Summary of Significant Accounting Policies

Foundation Operations

The Geological Society of America Foundation (the Foundation) was founded in 1980 to promote the science of geology. A primary objective of the Foundation is to provide funds for the Decade of North American Geology Program (the DNAG Program), which was established to publish a series of geological references in celebration of the 100-year anniversary of the Geological Society of America (the Society) in 1988.

Fund Accounting

To ensure observance of any limitations or restrictions placed on the use of resources, the accounts of the Foundation are maintained in accordance with the principles of fund accounting. The resources are classified for accounting and reporting purposes into funds established according to their nature and purpose. Interfund borrowings are in the combined totals presented in the financial statements.

Operating fund. The operating fund contains those net resources used in the current operations of the Foundation. Operating revenue is available to meet any Foundation expenditures.

Unrestricted fund. The Foundation board has full authority to use donated unrestricted funds for operational purposes.

Restricted fund. Restricted funds represent funds restricted by the donor, grantor or other outside party for particular purposes.

Pooled Life Income funds. Included in the restricted funds are life income funds representing gifts to the Foundation subject to life income interests to the donors and/or named beneficiaries. Upon satisfaction of the particular agreement, the principal balance of the respective fund is transferred to the fund designated by the donor.

Assets held in trust. The Foundation has an agreement with the Symposium of the Geology of Rocky Mountain Coal (the Symposium) whereby the Foundation will manage the assets of the Symposium. The Foundation receives a management fee equal to 1% per year of the market value of the funds. The agreement can be terminated by either party upon 90-day written notice.

Investments in Marketable Securities

Investments in marketable securities are carried at the lower of cost (first-in, first-out) or fair market value. *See Note 2.*

Tax Exempt Status

The Foundation qualifies as an exempt organization under Section 501(c)(3) of the Internal Revenue Code. Accordingly, no taxes are paid on the Foundation's revenue.

Fixed Assets

Fixed assets are depreciated over their estimated useful lives using the straight-line method as follows:

	Amount	Estimated Useful Lives
Computers	$20,395	5 years
Equipment	23,503	5 years
	43,898	
Less accumulated depreciation	38,375	
	$ 5,523	

The Foundation recognized $4,091 of depreciation expense for the year ended December 31, 1992 which is recorded in the operating expenses of the operating fund.

Allowance for Bad Debts

It is management's estimate that all material pledges and accounts receivable are collectible; therefore, no allowance has been established in the financial statements.

In-Kind Donations

In-kind donations are recorded at fair value at the date of gift.

Statement of Cash Flows

For purposes of reporting cash flows, cash and cash equivalents include cash on hand and due from banks.

Note 2
Investments

As of December 31, 1992, the Foundation adopted the lower of cost or market reporting for marketable securities. In prior years, investments were reported at fair market value. The Foundation felt that reporting at the lower of cost or market would provide consistency with the Geological Society of America (Note 4). The cumulative effect on years prior to 1992 was to reduce fund balances by $98,134.

Realized gains and losses are determined on the basis of average cost of securities sold. Unrealized losses are charged to fund balance. Income earned on investment securities is recorded in the fund to which it is restricted, or if unrestricted, as designated by the Council. Investments are comprised of the following at December 31, 1992:

	Cost	Market Value
Operating fund	$ 950	$ 950
Unrestricted fund	28,933	29,914
Restricted fund	1,515,015	1,566,438
	$1,544,898	$1,597,302
U.S. Government bonds	$ 112,913	$ 115,107
U.S. Agency bonds	136,937	137,661
Corporate bonds	243,718	244,315
International bonds	14,978	15,321
Mutual funds	869,766	918,312
Cash, held for investment purposes	165,636	165,636
Other	950	950
	$1,544,898	$1,597,302

Note 3
DNAG Publications Inventory

The publications inventory of the DNAG Program is recorded at the lower of cost first-in, first-out (FIFO) method or market and consists of the following at December 31, 1992:

	Amount
Finished publications	$577,535
Costs incurred for unfinished publications	142,666
	720,201
Estimated adjustment to market	(278,792)
	$441,409

Note 4
Related Party Transactions With Geological Society of America

The amount due from the Society of $7,574 is for various contributions and other items received by the Society for the benefit of the Foundation.

The amount due to the Society of $580,985 represents $578,917 of expenditures incurred by the Society for the DNAG Program in excess of designated contributions received from the Foundation and $2,068 due from other restricted funds for awards and other activities related to the Foundation's activities. Net proceeds the Foundation receives from the sale of DNAG publications are applied to this amount due.

Included in other revenue is $173,234 received from the Society to subsidize operating expenses of the Foundation.

The Foundation leases its office space from the Society under a month-to-month agreement. Total rent expense paid in 1992 was $3,600.

Note 5
Pension Plan

Employees of the Foundation participate in a discretionary pension plan covering substantially all employees. Contributions to the plan are made at the discretion of the Foundation's Board of Directors. The total amount contributed for December 31, 1992 was $2,386.

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WOMEN IN SCIENCE FUND

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Joanne Bourgeois
Helen L. Cannon
James Channing Cole*
Margaret Cooper
Claire B. Davidson
(in memory of
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Roger L. Duba
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**Second Century Club (Gifts of $100 or more)*

SIXTY YEARS OF RESEARCH GRANTS

1992 was the 60th anniversary of GSA's Research Grants program. The first grant was awarded from the Penrose endowment in 1933 to R.V. Anderson to study the geology of the coastal Atlas Mountains in western Algeria. Since then 5,086 students, professors, and researchers have received $4.6 million from the Society to study a myriad of earth science topics.

For 60 years the Penrose endowment has been at the financial heart of the research grants program until GEOSTAR was formed by the Foundation to help supplement Penrose money for research.

Because of GEOSTAR, the Foundation has increased its research grants funding since 1989, from $25,000 that year to a budgeted $45,000 in 1993, a rate of increase of 16% per year.

Gifts to GEOSTAR for endowment, and for annual program expenditure enable the Foundation to offset the decline in Penrose funds due to the needs of other GSA programs. The degree of offset is dependent upon the generosity of GSA members and the outside funding received from industry and friends of geology — THANK YOU.

Forum *continued from p. 184*

But if information asymmetries exist, who should govern here? For example, experts in toxicology and hydrogeology can say that little risk is posed by a site because of how it's designed, or, for contaminant releases, because they know where a release would go or what the contaminants would be. Yet, the people in the community can be frightened to death. Whose views should determine policy—the experts' or the public's?

Several years ago EPA began its Comparative Risk Project in an effort to rank risks. Table 3 compares how the public ranks risks with how EPA experts rank risk. One of the interesting things to note here is that the number one item on the list for the public is chemical waste disposal, which is what we're talking about when we talk about ground-water protection. But look where the EPA experts put it—at the bottom of their list. All the RCRA and Superfund and underground storage tank issues are at the bottom of the list by the EPA experts. What is the basis for that difference?

A paper by Krauss, Malforms, and Slovic on risk assessment conveys some information about why professionals, such as toxicologists, have different opinions than the typical lay person. Table 4 is extracted from their tables. It's fairly common for people to equate exposure with an adverse health effect. Indeed, 86% of the public agree with the first statement in Table 4. They believe that, if exposed, they're in line for an adverse health effect. Toxicologists disagree. They know that threshold concepts apply, and the majority feel differently about the link between exposure and ultimate risk. Responses to the next two statements follow the same pattern.

In response to the fourth statement, the toxicologists very strongly agree that the danger has been reduced because people's exposure has been reduced. The contaminant hasn't been eliminated, but the concentration has been reduced, and that reduces risk. In this instance, the public does perceive that there is an association between the level of exposure and the level of risk.

The next several statements listed in Table 4 address attitudes toward reducing risk, rather than dose-response functions. If we accept that it's unrealistic to expect to eliminate completely risks created by chemicals, we are stating that there is no such thing as a risk-free or zero-risk society, regarding chemicals. The toxicologists overwhelmingly agree with that statement. We can't live in a zero-risk society. A very strong majority of the public also agrees with the statement. Responses to the next statement reveal that toxicologists believe that it can be too expensive to deal with all chemical risks. Some have to be let go. The public, by essentially a 2:1 margin, however, is willing to pay *any* amount of money—i.e., they believe that society should be willing to invest any amount of money—to reduce a risk related to chemicals. We still don't understand the foundation for that willingness to pay. Is it because people are misinformed, or because they hold some deeply held views?

Toxicologists, overwhelmingly agree that a one in ten million risk from exposure to a particular chemical is too small to worry about. It's an order of magnitude smaller risk than the lowest of acceptable risks likely to be sought in the Superfund remedy, whose standards aim for 10^{-4} to 10^{-6}. The public agrees, but not nearly as strongly. That the differences can sometimes be very significant is evident by the response to the last question in Table 4.

The last category of potential benefits of ground-water protection that I'll mention are non-use or intrinsic benefits. For ground-water protection, these might be appreciable, though we have only limited empirical evidence so far. Non-use values include existence values, stewardship values, and bequest values. These reflect people's willingness to pay to protect ground water apart from any current or potential future use.

The economics profession is engaged in a debate about the conceptual relevance, and certainly the measurement, of these kinds of benefits of protection. The debate has been heightened by a new area in the law that's subject to considerable litigation. This involves Natural Resource Damage Assessments, which come to bear under Superfund law. They arise apart from remediation, where a natural resource has been damaged by an activity, in, say, a mining site or a hazardous waste facility. The trustees for that resource, whether it's a federal government, a state, or an Indian tribe, can make claims for damages. There's a growing caseload of these damage claims, some of them pertaining to ground water.

The economists who work for the potentially responsible parties argue that there are no such things as non-use values, and that even if one thinks there are, these can't be measured. And then there's good evidence from the other side that, to the contrary, these values probably are important and can be measured. This is a debate that's generating much more heat than light, and it is polarized by the litigation context in which it's occurring. This debate has reached the courts in a couple of ways. The Department of Interior is required under CERCLA to come out with regulations that govern how one does a Natural Resource Damage Assessment. Their first cut at the regulations downplayed the importance and legitimacy of non-use values. Several states, led by Ohio, took objection and sued Interior. In the court decision in the summer of 1989, the judge ruled that non-use values were potentially extremely important and had a legitimate place in these damage claims, and that an attempt should be made to measure them.

This recently came up again in a case that I've been involved with in Utah. The state of Utah made a claim for natural resource damages, related to ground-water contamination, against Kennecott for its operations in the Greater Salt Lake Valley. We had done a report that addressed different ways of valuing water, and bringing in different water or treating water. We also mentioned that we did not include potential non-use values and other kinds of values. The state reached a tentative settlement with Kennecott, but when it went to the judge for review and approval, the Sierra Club and one of the water conservancy districts intervened against the settlement. The judge reviewed all the materials and ruled that he could not allow this settlement. One of his two major reasons was that the ground-water evaluation did not consider non-use values, and he believed these could be important in the case. The non-use value issue is contentious, but it is getting more attention in the courts. The court rulings in these damage claim contexts indicate that they will have to be considered more seriously.

Only limited empirical evidence exists as to the possible level of non-use values for ground water. But recent work by Bill Schulze, an economist, working in concert with Gary McClelland, a psychologist, and several other researchers examines the existence and bequest value of protecting ground water. They estimate that bequest and existence values for ground water amount to about $3 per household per month. If one accepts that number and applies it to all households in the United States, that would amount to about $3.3 billion per year in non-use values for protecting ground water nationwide. In comparison, $3.3 billion is about 10% of what the EPA estimated would be spent on CERCLA- and RCRA-related activities in 1992. Although the significance of the

Forum *continued on p. 194*

TABLE 3. RISK PERCEPTIONS: PUBLIC VS. EXPERT VIEWS

How the public ranks selected environmental risks	How EPA experts rank environmental risks
High risk • (1) Chemical waste disposal • (2) Water pollution • (3) Chemical plant accidents • (4) Outdoor air pollution	**Overall high and medium risk** • "Criteria"air pollution (includes acid precipitation) • Stratospheric ozone depletion • Pesticide residues in or on foods • Runoff and air deposition of pesticides
Medium risk • (5) Oil tanker spills • (6) Exposure to pollutants on the job • (7) Eating pesticide-treated food • (8) Other pesticide risks • (9) Contaminated drinking water	**High health risk; low ecological and welfare risk** • Hazardous or toxic air pollutants • Indoor radon • Indoor air pollution other than radon • Drinking water as it arrives at the tap
Low risk • (10) Indoor air pollution • (11) Exposure to chemicals in consumer products • (12) Genetic engineering (biotechnology) • (13) Waste from strip mining • (14) Non-nuclear radiation • (15) "Greenhouse effect" (CO_2 and global warming)	**Low health risk; high ecological and welfare risk** • Global warming • Surface water pollution (point and nonpoint sources) • Aquatic habitat alteration (including estuaries and wetlands) and mining waste
	Overall medium and low risk (ground-water–related problems) • Hazardous waste sites—active (RCRA) • Hazardous waste sites—inactive (Superfund) • Other municipal and industrial waste sites • Underground storage tanks

Note: Original data drawn from 1984–1986 polls conducted by the Roper Organization, Inc. "Unfinished Business: a Comparative Assessment of Environmental Problems" (EPA 1987).

TABLE 4. RESPONSES OF TOXICOLOGISTS AND LAY PERSONS TO STATEMENTS ABOUT RISK-RELATED ATTITUDES

Statement	R*	Disagree (%)	Agree (%)
If you are exposed to a toxic chemical substance, then you are likely to suffer adverse health effects.	T	68	29
	P	12	86
There is no safe level of exposure to a cancer-causing agent.	T	75	19
	P	35	54
People are unnecessarily frightened about very small amounts of pesticides found in ground water and on fresh food.	T	29	67
	P	69	24
A chemical was found in a city's supply of drinking water in a concentration of 30 parts per million.... The water was filtered by a process that was able to reduce, but not eliminate, the chemical concentration in the water. Under most circumstances, this means that the danger associated with drinking the water has also been reduced.	T	8	88
	P	22	71
While we should always try to minimize the risk we take by using chemicals, it is unrealistic to expect that we can completely eliminate those risks.	T	2	98
	P	17	81
It can never be too expensive to reduce the risks associated with chemicals.	T	82	16
	P	31	62
A 1 in 10,000,000 lifetime risk of cancer from exposure to a particular chemical is too small a risk to worry about. (For perspective, the lifetime risk of dying in a car accident is 1 in 100.)	T	6	93
	P	30	59
Residents of a small community (30,000 people) observed that several malformed children had been born there during each of the past few years. The town is in a region where agricultural pesticides have been used during the past decade. It is very likely that these pesticides were the cause of the malformations.	T	82	6
	P	27	49

Note: Source is Kraus et al., *Risk Analysis,* v. 12, no. 2, 1992.
* Responders: toxicologists (T), public (P).

Forum *continued from p. 193*

non-use values is subject to debate, this exercise at least provides some insight as to the potential magnitude of non-use values for ground water.

Do the benefits of protection outweigh the costs? The prevention vs. cure argument is not completely convincing, given the empirical evidence. However, we need to keep in mind that any work done in this area would be very *site specific*. It's also very *activity specific*. We have looked mostly at municipal wastes and at some industrial waste activities. We haven't looked at areas not yet covered under RCRA, such as mining waste or oil and gas extraction. The benefits vs. costs ratio also depends on how far the parties are driven in their corrective action or mediation efforts. If they continue to be driven to, in some cases, remedies that make no sense, or that don't provide any particular resource or human health protection value, then maybe using those kinds of costs would shift the balance.

There are also benefits other than expected damages, however, and these are conceptually plausible and perhaps even likely. Some arise out of all the uncertainties that are inherent in ground-water contamination, and therefore give rise to various types of risk aversion premiums. And there are also non-use values that we're just beginning to evaluate.

Finally, in terms of the attitudes and beliefs held by the public about risks and contamination and the values of preventing ground-water contamination, two issues remain to be resolved. If the public is really misinformed, we have a dilemma as to whether we ignore the public and follow the experts, or blindly follow the public even though we know they're misinformed, or try some middle ground through education to see if that leads to a different expression of public values and attitudes. But if these values expressed by the public are real and do reflect true attitudes and values about protecting ground water, then we need to confirm that and articulate better what those values are, and what the motivations are, in order to use these factors in the policy debate. ■

New Initiative in Studies of Earth's Deep Interior

Thorne Lay
University of California, Santa Cruz

A multidisciplinary research community in the United States is undertaking a new coordinated effort to study the state and dynamics of Earth's deep mantle and core. At an open meeting held at MIT in September 1992, more than 120 earth scientists discussed this new program, which was an outgrowth of activity during the previous year by an ad hoc steering committee. The research program will be coordinated by a community-based scientific organization and supported through competitive research proposals submitted to the National Science Foundation, with the aim of facilitating cooperative research projects cutting across traditional disciplinary and institutional boundaries.

The new organization is the United States Studies of the Earth's Deep Interior (SEDI) Coordinating Committee. This committee will facilitate communication among the U.S. SEDI research community, federal funding agencies, the AGU Studies of the Earth's Interior (SEI) Committee, the Union SEDI Committee of the International Union of Geodesy and Geophysics (IUGG) and the general public. In addition, the Coordinating Committee will (1) organize and coordinate topical symposia and workshops addressing deep Earth problems; (2) promote consensus within the U.S. SEDI research community on important problems of highest priority for focused effort and assist in the resolution of controversies; (3) communicate this consensus to the larger scientific community and to government agencies; and (4) disseminate discoveries and other results of U.S. SEDI research activity as part of an educational outreach program. A modest administrative support budget has been provided to the SEDI Coordinating Committee from NSF funding of U.S. SEDI activities related to IUGG. At the MIT meeting, an initial one-year membership of the SEDI Coordinating Committee was approved, with the following committee members: Thomas Ahrens, Jeremy Bloxham, Donald DePaolo, Raymond Jeanloz, Thomas Jordan, Louise Kellogg, Thorne Lay, David Loper (secretary), Richard O'Connell (chair), and Alan Zindler. The charge for this initial committee was to complete the Science Plan described below and to convene a meeting for fall 1993, at which time formal elections of coordinating committee membership for longer rotating terms will be conducted.

The proposed NSF research program is called Cooperative Studies of the Earth's Deep Interior (CSEDI). The goal of CSEDI is to advance our understanding of how the Earth works: to determine how the dynamics of the deep interior control its structure and evolution on a planetary scale; to understand complex dynamical processes occurring in the deep interior such as the generation of the magnetic field; to discover features in Earth's interior and relate them to its geological history and present state; to quantify the chemical and physical state of the interior; to understand how Earth's chemical and volatile budgets have functioned and evolved over geologic time; and to understand the engine in Earth's deep interior that drives plate tectonics and other surface processes. NSF intends to provide support for competitive proposals in cooperative multidisciplinary studies, so that accelerated progress can be made on fundamental problems of Earth's deep interior. NSF grants will be made using the usual mechanisms of peer review and panel evaluations of proposals. The program will be open to all investigators who wish to submit proposals. Proposal ranking will take into consideration several criteria related to the multidisciplinary and/or multi-institutional aspects of the initiative, including: (1) proposals should demonstrate the possibility of making accelerated progress on major problems of global significance; (2) the proposed work should draw from, contribute to, or be aimed at establishing more than a narrow disciplinary perspective; and (3) the investigators should come from more than one research unit.

A Science Plan for the NSF CSEDI research program, written by the broad U.S. SEDI community and discussed at the MIT meeting, has been submitted to NSF and presented to NSF's Advisory Committee for Earth Sciences. NSF has planned a multi-year program with a budgetary increase to support the CSEDI effort, beginning in FY 1994. While NSF will now accept proposals in the CSEDI framework, the program and budget have not yet been approved, and the level of support for the program will depend on the level of future budgets. Copies of the NSF CSEDI Science Plan are available from T. H. Jordan, Dept. of Earth, Atmospheric and Planetary Sciences, MIT 54-920, Cambridge, MA 02139; phone (617) 253-3382; fax 617-253-7651; E-mail thj@quake.mit.edu. It is important that U.S. researchers involved in SEDI provide their addresses, including E-mail, to T. H. Jordan so that they will receive regular mailings of information from the SEDI Coordinating Committee. The committee is currently working to develop an expanded CSEDI program which will involve additional Federal Agencies such as NASA and DOE.

The next annual meeting of the U.S. SEDI community will be held in September 1993; details about the venue are available from any Coordinating Committee member. As part of its outreach program, the SEDI Coordinating Committee offers to communicate at large all information that is received on CSEDI-related activities, including important research developments, workshops, and CSEDI proposals to NSF. Information should be provided to R. J. O'Connell, Dept. of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138; phone (617) 495-2532; fax 617-495-8839; E-mail: oconnell@geophysics.harvard.edu. ■

Bravo Boston GSA Chorale

Tuesday, October 26, 7:00 to 10:00 p.m.;
Jordan Hall at New England Conservatory of Music
Cost: Concert only $18; Concert with Reception $28.

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

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

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

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

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

PRE-CONCERT WINE AND CHEESE AT THE COLONNADE

5:30 to 6:30 p.m.; Colonnade Hotel

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

Come to BOSTON

by James E. MacNeil

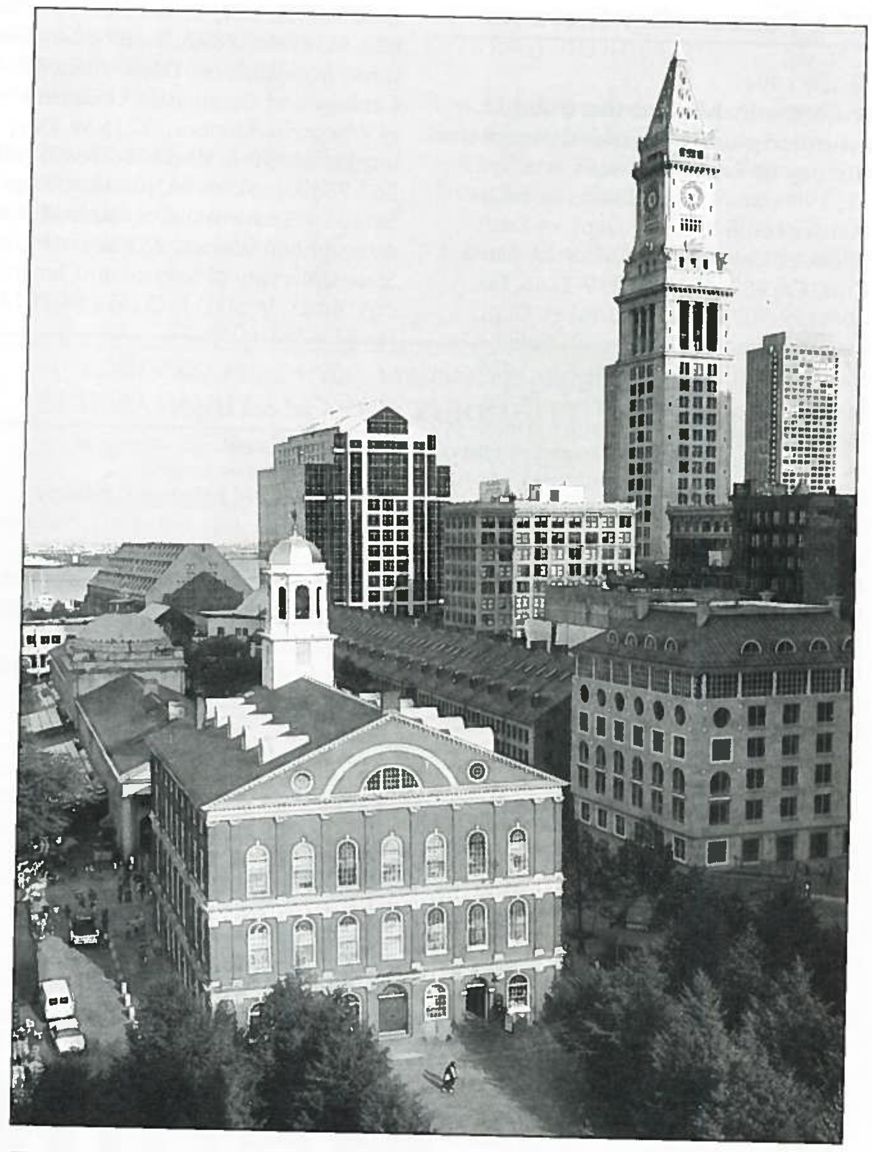
If you are not registering for one of the GSA Tours or want to sightsee on your own, we suggest you begin with an inexpensive trolley tour available from all hotels. The tour provides a quick overview of downtown and a brief history of key Boston events. During the tour, if you see something that interests you, hop off the trolley for a short visit. You can reboard anytime, free of charge.

Be sure not to miss Freedom Trail, a wonderful three-mile walking tour of sixteen historic colonial and revolutionary sites throughout Boston. An easy to follow red painted line on the sidewalk leads you to each place of interest. Maps are available from one of the many Boston visitors booths along the way. The National Park Service at 15 State Street sells a guide book. Allow at least a half day for this walking tour. The most popular Freedom Trail sites are:

- **Boston Common**—In colonial days, the Common was used for militia training and pasture land. It is bordered by downtown Boston and Beacon Hill, and is the oldest public park in this country. Across from the Common is the Public Gardens, site of numerous floral plantings and the Swan Boats, a Boston tradition not to be missed and a wonderful area for photographs.
- **State House**—The gold dome atop the State House is a well-known landmark. The building was designed by the 18th century architect Charles Bullfinch, and houses the Massachusetts government. Tours of the State House are available.
- **Park Street Church**—This white, steepled church sits at the corner of Park and Tremont Streets. It is nicknamed "Brimstone Corner" because gunpowder was stored there during the War of 1812.
- **Other sites on Freedom Trail are:** Granary Burying Ground, Kings Chapel, Site of First Public School, Ben Franklin Statue, Old Corner Bookstore, Old South Meeting House, Old State House, Site of Boston Massacre, Faneuil Hall—great place for lunch stop, Paul Revere House, Old North Church (Christ Church)—signal given for Paul Revere, Copps Hill Burying Ground, *U.S.S. Constitution* (Old Ironsides), Bunker Hill Monument—great view of city from top; an easy walk

If your schedule permits you might want to visit some of the museums and other special attractions. Boston's abundance of museums and attractions gives visitors a glimpse of the art, history, and technology that contributes to the city's prominence. Among the more popular attractions are:

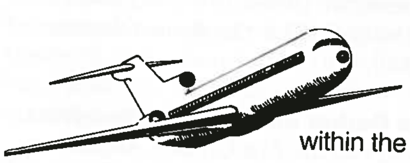
- **Boston Tea Party Ship**—the site of the Boston Tea Party.
- **New England Aquarium**—2000 aquatic creatures and 4-story glass ocean tank housing a coral reef display.
- **New England Sports Museum**
- **Prudential Skywalk**—offers the only 360-degree view of Boston from more than 700 feet up. Also houses the Top of the Hub restaurant, a great place for Sunday brunch.
- **John F. Kennedy Library**
- **Museum of Fine Arts**—collections and exhibits of the world's finest paintings and sculpture.
- **Museum of Science**—a well-known educational institution featuring live animal displays and physical science demonstrations, traveling exhibits, and the 360-degree Omni Max theater and planetarium.



Custom House Tower and Faneuil Hall. Photo courtesy of Boston Convention and Visitors Bureau, Inc.

- **Computer Museum at Museum Wharf**
- **John Hancock Observatory**—panoramic view of Boston and the harbor. Listen to the historical narration by Walter Whitehill, architectural historian, and see the exhibits "Boston 1775" and "Uncommonly Boston." There is an excellent photorama of the old and new Boston.

Walk the streets of the Back Bay for a view of how residential neighborhoods once were and have been reclaimed by yuppies and students. View the brownstone residences on Commonwealth Avenue and Marlboro Street. Venture over to Beacon Hill, especially at dusk before curtains are drawn, for a view of luxury living. The Cheers Bar, located in the Hampshire House at 84 Beacon Street, is worth looking in on. Right across from the Hampshire House is Boston Common and the Public Gardens. Be sure to go for a stroll in each during your time in Boston.



TECHNICAL PROGRAM CORRECTION:

Theme Session 35 (T35) was incorrectly advertised earlier as a POSTER ONLY session. Abstracts for this theme session will be accepted in oral OR poster mode.

STUDENT TRAVEL GRANTS

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

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

GSA Penrose Conferences

March 1994

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

June 1994

■ **Fractured Unlithified Aquitards: Origins and Transport Processes,** June 15–20, 1994, Racine, Wisconsin. Information: John A. Cherry, Waterloo Centre for Groundwater Research, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada, (519) 888-4516, ext. 2892, fax 519-746-5644; David M. Mickelson, Department of Geology and Geophysics, University of Wisconsin–Madison, 1215 W. Dayton St., Madison, WI 53706-1692, (608) 262-7863, fax 608-262-0693; William W. Simpkins, Department of Geological and Atmospheric Science, 253 Science I, Iowa State University of Science and Technology, Ames, IA 50011, (515) 294-7814, fax 515-294-6049.

1993 Meetings

July

International Mining Geology Conference, July 5–8, 1993, Kalgoorlie-Boulder, Australia. Information: The Chairman, International Mining Conference, c/o Kalgoorlie Consolidated Gold Mines Pty. Ltd., PMB 27, Kalgoorlie, 6430, Australia, phone 61-90-22 1229, fax 61-90-93 2315.

Fluvial Sedimentology 5th International Conference, July 5–9, 1993, Brisbane, Australia. Information: Continuing Professional Education, University of Queensland, St. Lucia, 4072, Australia, phone 61-7-365 7100, fax 61-7-365 7099, telex UNIVQLD AA40315.

Society for Industrial and Applied Mathematics, Annual Meeting, July 12–16, 1993, Philadelphia, Pennsylvania. 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.

AAPG Hedberg Research Conference—Unconformities and Porosity Development in Carbonate Strata, July 13–16, 1993, Vail, Colorado. Information: AAPG Continuing Education Department, P.O. Box 979, Tulsa, OK 74101, (918) 584-2555, fax 918-584-0469.

Geological and Landscape Conservation International Conference, July 17–24, 1993, Great Malvern, United Kingdom. Information: D. O'Halloran, JNCC, City Road, Peterborough, PE1 1JY, UK, phone 44-733-62626, fax 44-733-893 971.

10th International Clay Conference, July 18–23, 1993, Adelaide, Australia. Information: Conference Secretariat, Elliservice Convention Management, P.O. Box 753, Norwood, 5067, Australia, phone 61-8-332-4068, fax 61-8-364-1968.

August

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

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

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

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

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

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

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

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

September

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

October

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

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

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

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

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

Seismological Society of America, Eastern Section Meeting, October 13–15, 1993, Weston, Massachusetts. Information: John E. Ebel, Weston Observatory, Dept. of Geology & Geophysics, Boston College, 381 Concord Road, Weston, MA 02193-1340, (617) 899-0950, fax 617-552-8388, E-mail: EBEL@-BCVMS.BC.EDU. *(Abstract deadline: September 10, 1993.)*

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

New Developments in Geothermal Measurements in Boreholes, October 18–23, 1993, Klein Köris, Germany. Information: E. Hurtig, GFZ Potsdam,

Meetings *continued on p. 198*

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PRESENT EMPLOYER ____

TYPE OF POSITION DESIRED (Check as many boxes as apply.)

Interested in: ☐ Academic ☐ Government ☐ Industry ☐ Other

Specific interest: ☐ Administration ☐ Exploration/Production ☐ Field ☐ Research ☐ Teaching

Will accept employment in: ☐ U.S. only ☐ U.S. with foreign assignments ☐ Either

GIVE NUMBER OF YEARS EXPERIENCE FOR ANY OF THE FOLLOWING THAT ARE APPLICABLE

Administrative____ Exploration/Production____ Field____ Research____ Teaching____ Total geological experience____

KNOWLEDGE OF FOREIGN LANGUAGES: ☐ French ☐ German ☐ Russian ☐ Spanish ☐ Other____

ACADEMIC TRAINING

College or University	Degree (rec'd or expected)	Year	Major	Minor

Postgraduate work beyond highest degree in (field) ____ **Number of years** ____

SPECIALTY CODES Select those that best describe your ability. Use codes in bold face only when other breakdowns are inadequate.

100 Economic Geology
101 coal geology
102 geothermal, etc.
103 metallic deposits
104 nonmetallic deposits
105 mining geology
120 Engineering Geology
150 Environmental Geology
160 Public Education & Communication
200 General Geology
220 Geochemistry
221 organic
222 high temperature
223 low temperature
224 stable isotopes
225 geochronology
250 Geomorphology
300 Geophysics
301 seismic
302 gravity/magnetics
303 seismicity
304 paleomagnetism
320 Hydrogeology
321 hydrochemistry
322 ground water
323 surface water
330 Library
350 Mathematical Geology
351 computer science
352 statistical geology
400 Mineralogy
401 crystallography
402 clay mineralogy
410 Museum (curator)
420 Oceanography
421 marine geology
422 coastal geology
450 Paleontology
451 invertebrate
452 vertebrate
453 micropaleontology
454 paleobotany
455 paleoecology
500 Petroleum Geology
501 exploration
502 subsurface strat.
520 Petrology
521 igneous
522 metamorphic
523 sedimentary (clastic)
524 sedimentary (carb.)
525 experimental
550 Planetology
575 Quaternary Geology
600 Regional Geology
620 Remote Sensing
621 photogeology
622 photogrammetry
630 Science Editing
650 Sedimentology
651 sed. processes
652 sed. environments
720 Stratigraphy
750 Structural Geology
751 tectonics
752 tectonophysics
753 rock mechanics
800 Volcanology

Résumé must be attached, ***limited to two pages,*** typewritten on one side only, to be acceptable for reproduction to employers. Include your name, address, and phone number; concise details of work experience; and majors/minors on degrees. Fee: $30 if you are a Member or Student Associate of GSA in good standing (Member # ____), $60 if you are not a member of GSA. Payment in U.S. funds (check, money order, or charge information ***must accompany form***).

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☐ Check/Money Order ☐ MasterCard ☐ VISA ☐ American Express or Optima

Card Expires Mo/Yr ____ Card Number ____ **Signature** ____ Required for credit card payment Date ____

I agree to release GSA or their representatives from responsibility for errors that may occur in processing or distributing these data. I understand that GSA makes *no guarantee* of contact by an employer in this service. I agree to notify GSA Employment Service immediately of (1) change of address, (2) acceptance of a position.

Signature *(required)* ____ I will/will not attend the 19____ GSA Annual Meeting in ____

GSA Employment Service

Looking for a New Job?

Are you looking for a new position in the field of geology? The GSA Employment Service offers an economical way to find one. Potential employers use the service to find the qualified individuals they need.

You may register any time throughout the year. Your name will be provided to all participating employers who seek individuals with your qualifications. If possible, take advantage of GSA's Employment Interview Service, which is conducted each fall in conjunction with the Society's Annual Meeting. The service brings potential employers and employees together for face-to-face interviews. Mark your calendar for October 25–28 for the 1993 GSA Annual Meeting in Boston, Massachusetts.

To register, complete the application form on this page, prepare a one- to two-page résumé, and mail it with your payment to GSA headquarters. One-year listing for GSA Members and Student Associates in good standing: $30; nonmembers: $60.

NOTE TO APPLICANTS: If you plan to interview at the GSA Annual Meeting, GSA must receive your material no later than September 1, 1993. If we receive your materials by September 1, your record will be included in the information employers receive prior to the meeting. Submit your forms early to receive maximum exposure! Don't forget to indicate on your application form that you would like to interview in October. Good luck with your job search!

For additional information or submission of forms, please contact T. Michael Moreland, Manager, Membership Services, Geological Society of America, P.O. Box 9140, Boulder, CO 80301, (303) 447-2020.

◀ **APPLICANT FORM**

Meetings *continued from p. 197*

Talegrafenberg A45, 0-1561 Potsdam, Germany, phone 49-331-310-347, fax 49-331-310-610, E-mail: gth@gfz-potsdam.dbp.de.

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

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

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

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

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

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

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

November

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

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

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

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

Looking for a New Employee?

When was the last time you hired a new employee? Did you waste time and effort in your search for a qualified geoscientist? Let the GSA computerized search file make your job easier.

How does it work? Complete the Employer's Request for Earth Science Applicants form on this page. Remember to specify educational and professional experience requirements as well as the specialty area or areas of expertise your applicant should have. The GSA computer will take it from there.

You will receive a printout that includes the applicants' names, addresses, phone numbers, areas of specialty, type of employment desired, degrees held, years of professional experience, and current employment status. Résumés for each applicant are sent with each printout at no additional charge. For 1993, the cost of a printout of one or two specialty codes is $150. (For example, in a recent job search for an analyst of inorganic materials, the employer requested the specialty codes of geochemistry and petrology.) Each additional specialty is $50. A printout of the applicant listing in all specialties is available for $350. (Specialty codes printed in boldface type are considered major headings. If you request a listing of one of the subspecialties, applicants coded under the major category will be included but not those coded under the other related subspecialties.) If you have any questions about your personalized computer search, GSA Membership Services will assist you.

The GSA Employment Service is available year round. However, GSA also conducts the Employment Interview Service each fall in conjunction with the Society's Annual Meeting (this year in Boston, Massachusetts, October 25–28). You may rent interview space in half-day increments from GSA. Our staff will schedule all interviews with applicants for you, the recruiter. In addition, GSA offers a message service, complete listing of applicants, copies of résumés at no additional charge, and a posting of all job openings.

EMPLOYER FORM ▶

The Geological Society of America

3300 Penrose Place • P.O. Box 9140 • Boulder, Colorado 80301

EMPLOYER'S REQUEST FOR EARTH SCIENCE APPLICANTS

(Please type or print legibly)

NAME ______________________ **DATE** ________

ORGANIZATION ______________________

MAILING ADDRESS ______________________

CITY ____________ **STATE** ____ **ZIP CODE** ________ **TELEPHONE (**   **)** ____________
area code Number

SPECIALTY CODES (see list below)
List the specialty code numbers that you wish to order, or ☐ check here if you want the entire file of applicants in *ALL* specialties.

1. ________ 2. ________ 3. ________ 4. ________ 5. ________ 6. ________

POSITION DATA: What position(s) do you expect to fill? ______________________

In what area(s)? ______________________

Degree requirements ______________________ Number of positions available ________

SPECIALTY CODES

100 Economic Geology
101 coal geology
102 geothermal, etc.
103 metallic deposits
104 nonmetallic deposits
105 mining geology
120 Engineering Geology
150 Environmental Geology
160 Public Education & Communication
200 General Geology
220 Geochemistry
221 organic
222 high temperature
223 low temperature
224 stable isotopes
225 geochronology
250 Geomorphology
300 Geophysics
301 seismic
302 gravity/magnetics
303 seismicity
304 paleomagnetism
320 Hydrogeology
321 hydrochemistry
322 ground water
323 surface water
330 Library
350 Mathematical Geology
351 computer science
352 statistical geology
400 Mineralogy
401 crystallography
402 clay mineralogy
410 Museum (curator)
420 Oceanography
421 marine geology
422 coastal geology
450 Paleontology
451 invertebrate
452 vertebrate
453 micropaleontology
454 paleobotany
455 paleoecology
500 Petroleum Geology
501 exploration
502 subsurface strat.
520 Petrology
521 igneous
522 metamorphic
523 sedimentary (clastic)
524 sedimentary (carb.)
525 experimental
550 Planetology
575 Quaternary Geology
600 Regional Geology
620 Remote Sensing
621 photogeology
622 photogrammetry
630 Science Editing
650 Sedimentology
651 sed. processes
652 sed. environments
720 Stratigraphy
750 Structural Geology
751 tectonics
752 tectonophysics
753 rock mechanics
800 Volcanology

Applicants seeking employment in:
☐ Academic ☐ Government ☐ Industry ☐ Other ________

***Minimum* degree required:**
☐ None ☐ B.A. or B.S. ☐ M.A. or M.S. ☐ Ph.D.

***Minimum* professional experience:**
☐ None ☐ 1–5 years ☐ 6-plus years

Experience desired (years):

	None	1–5	6-plus
Administrative	☐	☐	☐
Exploration/Production	☐	☐	☐
Field	☐	☐	☐
Research	☐	☐	☐
Teaching	☐	☐	☐

Employment in: ☐ U.S. only ☐ U.S. with foreign assignments ☐ Either

Foreign Languages: ☐ French ☐ German ☐ Russian ☐ Other ________ ☐ Not required

I am interested in interviewing applicants through the GSA Employment Service at the 19____ Annual Meeting in ______________.

1. I agree to use this service for valid recruiting purposes.
2. I agree that no placement charges will be assessed to any applicant participating in the GSA Employment Matching Service.

Signature (required) ______________________

Date ______________________

Total fee enclosed .... $________

Or invoice requested .... $________

phone 7-812-218-9224, fax 7-812-355-7952.

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

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

December

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

1994 Meetings

January

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

February

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

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

March

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

April

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

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

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

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

NEW GSA MEMBERS

The following 403 Members were elected to membership by Council action during the period from August 1992 through February 1993 (* indicates transfer from Student Associate to Member).

*Robert J. Alexander
Tim Allen
*David T. Allison
Steven Amter
*Raymond R. Anderson
*Robert J. Andres
*Greg B. Arehart
*Christopher J. Arnold
Margaret M. Avard
*Antonio Azor
*Andrew F. Bajc
Michael W. Barnes
*David A. Barnett
*Dilip K. Barua
*Brian L. Beard
Richard L. Bedell
*Dale C. Beeson
*Richard J. Behl
*Raymond E. Beiersdorfer
Taylor H. Bennett
Christopher J. Benson
*Augusto Bertolero
*Giovanni Bertotti
Paul M. Bishop
Edward L. Black
*Gale C. Blackmer
*Scott M. Blanchard
Sofia M. Bobiak
Justin B. Bolles
Jacqueline D. Bott
Michelle M. Bouwkamp
Margaret D. Bradley
Martin D. Brand
John F. Bratton
*Wendy D. Brindle
*JoAnn K. Brookes
*Norm Brown
Richard A. Brown
Robert B. Brown
Andrew L. Browne
Scott L. Brumagin
Steve N. Buckley
Bernhard Buehn
David J. Burdige
*Patrick A. Burkhart
*Jonathan L. Burr
*Keith W. Butler
*Barbara J. Byron
Steven F. Caldwell
Barry A. Carlson
James P. Carpentier
William G. Carter, Jr.
Enrique Casas
Patricia B. Cerrito
Richard E. Chandler
*Wei-Min D. Chen
*Judith Savaso Chester
Barry A. Cik
Fred P. Cocca
*Harvey A. Cohen
Dwight F. Coleman
*Karen A. Connors
James C. Coogan
*David A. Cook
*Jeanne L. Cooper
*Reinold R. Cornelius
Alejandra S. Cortes
Robin C. Corzatt
Richard P. Cousineau
*David A. Crown
*Raymond C. Culotta
Lucy M. Curran
*Luiz J. H. D'el-Rey Silva
*Brett V. Danko
*Jesse C. Dann
*Kathy J. Danti
*Robert S. Darling
James B. Davis
*Timothy L. Davis
Virginia De Lima
*Cesar I. Delgado
*Thomas D. Demchuk
*Robert K. Dennis
*Marilyn L. DeRosa
Louis A. Derry
Jeffrey C. Dick
*Jurgen Dirscherl
*Kevin F. Downing
Martin Doyon
Kimberly F. Drake
Sandra M. Eberts
William C. Edmund
*Don Elsenheimer
*Lisa L. Ely
*Peter A. Emmet
*Johan P. Erikson
*Martin D. Essex
*Thomas Richard Fargo
*Samuel P. Farnsworth
*William H. Farrand
Donald A. Fay
*Zhaodong Feng
*Everett H. Ferguson, Jr.
Charles W. Fetter
Luis D. Figueroa
*Haakon Fossen
*John P. Foxwell
*Deborah Freile
Jonathan A. Fuller
Molly Ann K. Gary
William M. B. Gavin
Wes Gibbons
*Danielle Giovenazzo
Jonathan M. Glen
David D. Glenn, Jr.
Michael A. Gonsalves
Gregory C. Gray
Stanley L. Grazis
*Kathryn M. Gregory
*Kurt A. Grimm
*Nancy R. Grindlay
Chris Groves
William R. Guertal
Altan R. Gulumoglu
Nusatriyo Guritno
Donald E. Guy, Jr.
Jay K. Hackett
Ralph J. Haefner
*Shirley A. Haehn
Jose M. Haensel, Jr.
*Steven J. Hageman
*Ricky A. Hagen
Patricia M. Hall
Melinda E. Hamsher
Dena F. Hanson
*Stephen B. Harper
Robert J. Harrington
Teresa N. Harris
*Craig J. R. Hart
Joseph A. Hau
Douglas W. Haywick
*Cheryl A. Hedgman
*Kevin P. Hefferan
Billie G. Hicks
*Alan R. Hildebrand
*Brittain E. Hill
*Christopher L. Hill
Daiji Hirata
*Corolla K. Hoag
*John A. Hoff
Jefferson P. Hoffer
*Jennifer A. Hogler
*Daniel K. Holm
Scott L. Horsnall
*Armann Hoskuldsson
Sven Hovmoller
*Roy P. Howell
*Hugh A. Hurlow
Chris R. Hyatt
*Gary M. Ingram
Stephen M. James
Steven J. Johansen
*D. Chad Johnson
Richard A. Johnson
William K. Johnson
Robert A. Johnston
A. Wayne Jones
Patrick J. Julig
*Leslie M. Kahn
*Suzanne Kairo
Sharon L. Kanfoush
C. Kent Keller
*Walton R. Kelly
*David V. Kemp
*Julie A. Kennedy
Raymond L. Kennedy
Claren M. Kidd
*Kathryn C. Kilroy
*James R. King
*Paul D. Klipfel
Lisbeth A. Kovach
Ken Kramlich
*Andrea P. Krumhardt
Shinichi Kuramoto
Sergey B. Kuzmin
Craig A. Lambert
*Laura D. Lampshire
*Antoni R. Laque
*Robert A. Larson
*Heather A. Laswell
Eugenia E. Lazarenko
*Calvin F. Lee
*Mary A. K. Lee
Lori L. Lesney
Elizabeth B. Lewis
Jian Lin
*Shoufa Lin
*Margo J. Liss
Mian Liu
*Songfa Liu
*Timothy Liverton

NEW GSA STUDENT ASSOCIATES

The following 766 Student Associates became affiliated with the Society during the period from August 1992 through February 1993.

Christopher Abate
Timothy Abbe
Mary Jo Abt
Christon M. Achong
Jim H. Adams
Kurt N. Addington
Joel M. Adrian
Randall J. Adsit
Martin R. Aguirre
Anna M. Agustsdottir
Joe H. Alexander
Alejandro E. Amigo
David A. Amir
Bradley D. Anderson
Fred J. Anderson
Kirk C. Anderson
Scott D. Anderson
Tammera Anderson
William T. Anderson, Jr.
Joseph E. Andrew
Kevin M. Ansdell
Russell A. Anthony
Robert M. Appelt
Jeffrey L. Appenzeller
K. Denise Apperson
John D. Arfstrom
Steven C. Armstrong
Bill W. Arnold
Jesse J. Arroyo
Matthew R. Audet
Eric M. Baer
Kenneth M. Bailey III
Christopher A. Baird
Brenda J. Baker
Gregory S. Baker
Kimberly A. Balsis
Sanjay Banerjee
James T. Barker
Lisa K. Barlow
Michelle L. Barnes
Walter A. Barnhardt
Robert C. Barr
Lilla Bartko
Jeffrey M. Bartling
Claudio Bartolini
Peggy O. Basdekas
Eric E. Bates
Warren C. Bates
Vicky L. Batson
Heikki Bauert
Mary E. Baxter
Gregory P. Beatrice
Rebecca L. Beavers
John H. Beck
Victoria M. Becker
Felicia M. Beeching
Christopher J. Bell
David X. Belton
Karen G. Bemis
John C. Bennett
Sonja L. Benson
Brent N. Bergeron
Ben G. Binger
Karen M. Boecker
William C. Boesch, Jr.
Louis A. Boldt
Janice L. Bolton
Randy D. Bookshar
Mark Bordelon
Francesca M. Borrelli
Jenny Boryta
Karen A. Boucher
Eileen M. Boudreau
Kevin J. Bradford
Rosetta H. Bredael
Sean T. Brennan
Carrie Brindisi
Benjamin A. Brooks
Harry E. Brown
Jon F. Brown
Amy E. Brustolon
Jason A. Buchman
Michael G. Burgess
Kathleen Burnham
Ashley S. Burns
Beverly A. Burns
Bradford R. Burton
Christopher J. Busing
Marya A. Butler
Daniel E. Byrne
Christopher L. Cahill
Jonathan Caine
Eric A. Caldwell
A. Ewan Campbell
Ted J. Campbell, Jr.
Christopher J. Canfield
Jesus E. Caracuel-Martin
Enrique A. Carballido
Douglas S. Card
Anne E. Carey
Christopher M. Carlson
Steven C. Carmer
John S. Carney
Danielle L. Carpenter
Melanie R. Carpenter
Maria E. B. Carr
Margaret W. Carruthers
Marco D. Carulli
Ed P. Carver
Richard E. Cashman
Teresa A. R. Castelhano
Reyna M. Castillo
George C. Caudle, Jr.
Donald P. Cederquist
Elena Centeno-Garcia
Jeff A. Cernoch
William J. Chadwick
Anjan Chakrabarty
Damon A. Chaky
Caroline J. Chambers
Paul D. Chasco
Xiaobing Chen
Ten-Hung Chu
Marek A. Cichanski
Deidra L. Ciriello
Christopher P. Cirmo
April K. Clare
Timothy L. Clarey
Jennifer E. Clark
Paul B. Clark
Sandra L. Clark
RL Cline
Canduace Cloy
Jeffrey A. Cohen
Jonathan M. Cole
Annette R. Colgan
Ruth L. Collings
Nancy E. Collins
Christin A. Conaway
Walter K. Conrad
Enzo M. Conti
Derek W. Cooper
Robin Cooper
Caroline A. Copeland
Kenneth L. Copenhaver
Matthias V. Cord
Daniel J. Cordier
Emily Cotlier
Walter K. Crawford III
Travis W. Crayosky
Kimberly L. Crisler
Charles H. Crocker
Michael S. Cronin
Michael G. Crowe
Warwick A. Crowe
Joseph J. Cudney
Catherine E. Cullicott
Matthew A. Cunningham
Lynn Curtis
John R. D'Agostino
Edward J. D'Amato
Thomas G. Dahlin
Gwen M. Daley
Patricia L. Daniel
Paul A. Daniels, Jr.
Benjamin F. Dattilo
Christina M. Daub
Michelle L. David
Gilbert L. Davidson
Gregory L. Davis
J. Matthew Davis
Paul C. Davis
Timothy E. Dawson
Russell G. Dedmon
Carol M. Dehler
Christie M. Demosthenous
Heather M. Dennis
Jane F. Denny
Steven R. Dent
Paul V. Dickfoss
Chris R. Dintaman
Gregory M. Dipple
Michael E. Dixon
Ron M. Dixon
Terry W. Dixon
William J. Dixon
David M. Dobson
Eron J. Dodak
Aimee K. Dolan-Laughlin
Jovita B. Dominic
Jennifer L. Dovin
Dean M. Dozier
Wojciech M. Dubis
George C. Dudkiewicz
W. Warren Dunbar
Thomas B. Dunklin
James A. Dvorak
Gail F. Eaton
Evan N. Edinger
Thomas Ehrendorfer
William E. Eilers
Aley-El-Din K. El-Shazly
Sara C. Elbert
Erika R. Elswick
Christopher D. Elvrum
Phyllis K. Engel
William C. Erickson
Kate Erikson
Daniel C. Erni
Mark C. Everett
Paul M. Evins
Brian D. Fairchild
Brian P. Faith
Claudia M. Falkner
Remi N. Farvacque
Chris Faucette
Curtis J. Faulkner
Daniel R. Faulkner
Sherry L. Felix
Eric W. Fellerstein
Elisa M. Ferguson
Paul E. Ferri
Jonathan R. Filer
Mary A. Fisher
Timothy G. Fisher
Jeremy Fishman
Keith A. Fleming
Tom Flood
Arnim Fluegge
Dejan T. Follweiler
Eric M. Fournier
Lane P. Fowler
Richard K. Fowlow
Umberto Fracassi
Burvee M. Franz III
Nicole Fraser
John A. French
Amy K. Friends
Jacqueline Frizano
James A. Froehlich
Li Fu
Shannon K. Fulton-Bowers
Dengliang Gao
Andres E. Garcia
Christopher K. Gardner
Edward T. Gardner
Andrea R. Garside
Michael D. Gatien
Douglas E. Gay
William F. Geers
Christine J. Gerdon
Frank Gerullis
Jayant Ghoshal
Susan A. Gibbons
Sally L. Gillies
Robert G. Gillson III
Martha S. Gilmore
Sylvie Giral
Joanne Giunta
Brian R. Globerman
Keith E. Goggin
Sami R. Goldman
Sandra Goodman-Cash
Janet L. Goodwin
Caitlin Gorman
Angela S. Gowan
Joseph S. Grabill
Susann N. Grainger
James S. Granata II
Jennifer L. Grant
Allen A. Grantham
Aaron Green
Heather R. Green
John E. Griffin
Stephen W. Grimes
Grady C. Grissom
Javier Guerrero
Laura A. Guertin
Alfred C. Guiseppe
Neeraj Gupta
Laura M. Habig
Ann M. Hagni
Jessica K. Hall
Roland D. Hall
Stephen A. Hall
Amy L. Halleran
Doann M. Hamilton
Michael J. Handke
David S. Hansen
Alexandre G. Haralampiev
Jan Harken
Dana B. Harper
Anne K. Harris
Nancy R. Harris
Mark D. Hattersley
David A. Hawkins
Kevin R. Hayes
Andrew B. Heckert
Bruce R. Heinzen
Elizabeth A. Heise
Patricia A. Heiser
Laura A. Helsel
Christopher A. Hemschot
Juliana Hendrix
Anne E. Henry
Julie D. Herman
Stephen G. Herzog
Paulette B. Hibben
Russell L. Hickerson
Scott E. Hiers
Christi A. Hill
Virginia S. Hill
Mark D. Hilyard
Jennifer J. Hinds
Andrew T. Hoak
Anthony R. Hoch
Sherri L. Hodder
Joanne L. Hoffard
Jonathan B. Holden
Helena M. Hollauer
Caleb W. Holyoke III
Seon W. Hong
Jeffrey S. Honke
James S. Hooper
Robb E. Houston
James C. Huddleston
Rondall J. Hudson
Konrad A. Hughen
Richard O. Hughes III
Robert B. Hughes
Lily A. Hume
Christopher C. Humphrey
Jason P. Hunter

NEW GSA FELLOWS

The following 28 Members were advanced to Fellowship in May 1993.

Genevieve Atwood
Mark D. Barton
William R. Brice
Laurie Brown
Michael Brown
Paul E. Carrara
Ed H. DeWitt
Donald O. Doehring
R. Douglas Elmore
P. Jay Fleisher
Michael J. Gaffey
Margaret J. Guccione
Christopher D. Henry
Robert B. Miller
Thomas E. Moore
Robert A. Morton
Kathryn M. Nichols
Alan R. Niem
Carolyn G. Olson
Stavros S. Papadopulos
Nicholas M. Ratcliffe
John W. Shervais
Sorena S. Sorensen
Frank S. Spear
David H. Speidel
John F. Sutter
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GSA ANNUAL MEETINGS

■ 1993

Boston, Massachusetts
Hynes Convention Center
October 25–28

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

Abstract Deadline: July 7
Preregistration Deadline: September 24
Technical Program Schedule: September *GSA Today*

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

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

■ 1994

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

Chairman: Darrel S. Cowan, University of Washington

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

Theme for 1994 Seattle Meeting

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

Call for Continuing Education Course Proposals
PROPOSALS DUE BY OCTOBER 1

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

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

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

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

■ FUTURE

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

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

July *BULLETIN* and *GEOLOGY* Contents

Are you missing out? If you're not a *Bulletin* or *Geology* subscriber, you may miss the articles listed below. Subscribe today and receive all 1993 issues, even if you've already paid your 1993 dues. Call Membership Services today at 1-800-472-1988.

The Geological Society of America
BULLETIN
Volume 105, Number 7, July 1993

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GEOLOGIST/HYDROGEOLOGIST: We are a multi-state consulting firm searching for individuals to lead our investigation teams. These individuals will be responsible for on-site hazardous waste characterization of facilities. The position requires a degree (preferred geologist/hydrogeologist) with 2 to 5 years experience. An excellent compensation, benefits, and bonus program is provided. Applicant must be willing to relocate. All resumes must be accompanied with a salary history to be considered. Send resume and salary history to Director of Personnel, P.O. Box 4552, Charleston, WV 25364-4552.

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

Penn State is an equal opportunity/affirmative action employer.

ENVIRONMENTAL SCIENTIST/ENGINEER: Entry level position. We are a multi-state consulting firm searching for individuals to collect samples and verify cleanup of hazardous wastes sites. These individuals will be responsible for sample collection, report writing, and interfacing with management. The position requires a bachelors degree in an environmental science or related field. An excellent compensation, benefits, and bonus program is provided. Applicant must be willing to relocate. Send resume to Director of Personnel, P.O. Box 4552, Charleston, WV 25364-4552.

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Geological consulting firms & individuals! Use this low- cost GSA advertising medium to promote your services throughout the geological community. More than 25,000 earth scientists from around the world, working in every discipline, read this news magazine every month. Talk to them! See above for rates, details, and closing dates. Or call 1-800-472-1988 for additional information.

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Used books bought & sold! Free Geoscience catalogue with 1800+ rare- and out-of-print titles.Will quote on collections of used geoscience books/journals. Dieter Schierenberg, b.v., Rare Books & Periodicals, Prinsengracht 485-487, 1016 HP, Amsterdam, The Netherlands, fax 31-20-626-5650.

Opportunities for Students

Student Research Grant. The Society for Luminescent Microscopy and Spectroscopy is offering a $300 grant to support a student research project in which luminescence microscopy is used as a major research tool. Applicants should submit a brief proposal (max. 600 words) and a bibliography of related papers (max. one page). Applicants should ask their research advisor to send a supporting letter, which evaluates the student's ability to perform the proposed research and the significance of the research.

Applications and letters should be postmarked no later than October 15, 1993, and sent to: Dr. Michael Owen, Department of Geology, St. Lawrence University, Canton, New York 13617.

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

Opportunities for Graduate Studies in the Earth and Planetary Sciences in Australia. Outstanding opportunities exit for graduate research in the Victorian Institute of Earth and Planetary Sciences (VIEPS). Located in Melbourne, Victoria, Australia, VIEPS is a collaborative venture between La Trobe, Melbourne, and Monash Universities. VIEPS provides students with graduate programs in Geology, Geophysics, Geography & Environmental Sciences and Atmospheric Sciences. For graduate students interested in working in Australia support is available through the Australian Commonwealth Government Scholarships. The OPRS (Overseas Postgraduate Research Scholarship program for study in Australia) award is critical to meeting the cost of study in Australia but their deadline is late September 1993. These awards can be combined with scholarships available from the host institutions. For more information contact: The Coordinator, VIEPS, GPO Box 2729X, Melbourne, Victoria 3001, Australia, fax 61 3 479 1272 and email vieps_office@mojave.latrobe.edu.au.

GSA SECTION MEETINGS

1994 Call for Papers

South-Central Section

March 21–22, 1994
University of Arkansas
Little Rock, Arkansas

Abstract Deadline: November 30, 1993

Submit completed abstracts to:
William Bush, Arkansas Geological Commission, 3815 Roosevelt Avenue, Little Rock, AR 72204, (501) 324-9165.

Cordilleran Section

March 21–23, 1994
California State University
San Bernardino, California

Abstract Deadline: November 29, 1993

Submit completed abstracts to:
Joan E. Fryxell, Dept. of Geological Sciences, California State University, 5500 University Parkway, San Bernardino, CA 92407-2397, (909) 880-5311.

Northeastern Section

March 28–30, 1994
SUNY at Binghamton
Binghamton, New York

Abstract Deadline: December 2, 1993

Submit completed abstracts to:
H. Richard Naslund, Dept. of Geological Sciences, SUNY, Binghamton, NY 13902-6000, (607) 777-4313.

Southeastern Section

April 7–8, 1994
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Abstract Deadline: December 1, 1993

Submit completed abstracts to:
A. Krishna Sinha, Dept. of Geological Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0420, (703) 231-5580.

North-Central Section

April 28–29, 1994
Western Michigan University
Kalamazoo, Michigan

Abstract Deadline: January 6, 1994

Submit completed abstracts to:
Ron Chase, Dept. of Geology, Western Michigan University, Kalamazoo, MI 49008, (616) 387-5500.

Rocky Mountain Section

May 4–6, 1994
Fort Lewis College
Durango, Colorado

Abstract Deadline: January 13, 1994

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