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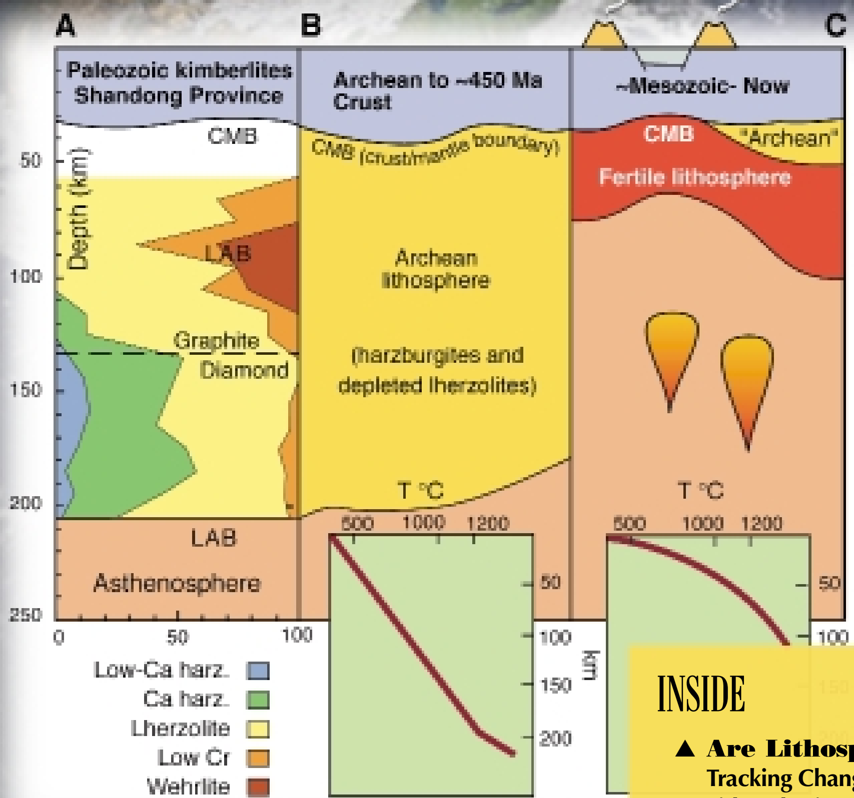
GSA TODAY

Vol. 11, No. 4 A Publication of the Geological Society of America April 2001

Are Lithospheres Forever? Tracking Changes in Subcontinental Lithospheric Mantle Through Time



INSIDE

GSA TODAY

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

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science article

Are Lithospheres Forever? Tracking Changes in Subcontinental Lithospheric Mantle Through Time

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ABSTRACT

The lithospheric mantle beneath continents is often the same age as the superjacent crust, but remains less well understood. Analysis based on a large database of xenoliths and xenocrysts shows that mantle domains that stabilized during different geologic eons have distinctly different mean compositions. There is a secular evolution from depleted Mg-rich low-density Archean mantle to more fertile, denser Phanerozoic mantle; the most significant differences are between the Archean and Proterozoic mantle. The compositional variations produce differences in the density and elastic properties of lithospheric mantle of different age. Archean and Proterozoic mantle roots are highly buoyant; they cannot be delaminated but require mechanical disaggregation (lithospheric thinning and/or rifting) and infiltration of upwelling fertile material to be destroyed or transformed. In contrast, Phanerozoic subcontinental lithospheric mantle is denser than the asthenosphere for observed thicknesses (~100 km) and can "delaminate" under stress. The contrasting properties of different mantle domains require lateral contrasts in composition, density, thickness, and seismic response in the present-day subcontinental lithospheric mantle. They also suggest a secular evolution in Earth's geodynamics from Archean to Proterozoic time, and an increased importance for lithosphere-delamination processes in Phanerozoic orogens.

LITHOSPHERE DOMAINS IN TIME AND SPACE

Knowledge of the architecture and evolution of the mantle portion of the continental plates—the subcontinental lithospheric mantle—is critical to understanding the large-scale processes responsible for the development of Earth's continents. Plate tectonicists use a mechanical definition (rigid plates) for the lithosphere, contrasting it with the less rigid asthenosphere. Geochemists consider the subcontinental lithospheric mantle to be a chemically depleted reservoir that is the residue of partial melting of Earth's asthenosphere. Seismologists define it using velocities and extrapolated densities and consider its base to coincide with the top of a low-velocity zone in tectonically young regions, and others use heat flow and magnetotelluric data to define it as a thermal boundary layer. These various definitions may coincide (or not) and give rise to a persistent and fascinating controversy over the physical nature of the lithosphere and asthenosphere and the boundary zone between them.

The subcontinental lithospheric mantle is isolated from the convecting mantle and thus tends to resist homogenization over time. At the lithosphere-asthenosphere boundary, the temperatures of the lithosphere and the uppermost asthenosphere coincide, and the greater buoyancy and viscosity of the lithosphere are important in maintaining its mechanical integrity. This emphasizes a thermal and rheological distinction between lithosphere and asthenosphere that also coincides well with seismic observations and with the geochemical signatures that are used in this paper to help define the location and character of the lithosphere-asthenosphere boundary.

Four-dimensional lithosphere mapping is a methodology that integrates petrological, geochemical, geophysical, and tectonic information to map the composition of the subcontinental lithospheric mantle (Fig. 1) and the location of its important boundaries through time (O'Reilly and Griffin, 1996). Volcanic rocks (basalts, lamproites, kimberlites) carry fragments of the subcontinental lithospheric mantle to the surface as xenoliths and xenocrysts (e.g., garnet, chromite, and diamond). Xenoliths can be used to recognize mantle rock types and processes, and to measure physical properties (e.g., elastic, electric, magnetic properties, density, and heat production). Volcanic episodes of different ages in one region can provide this information for different time slices, corresponding to the age of the host volcanism. Geophysical data can be used to extend the geological information laterally by matching geophysical signatures with mapped subcontinental lithospheric mantle sections.

This methodology can provide some important constraints on fundamental questions about Earth's geological evolution. These include the compositional structure of subcontinental lithospheric mantle formed at different times, the lateral variability of subcontinental lithospheric mantle composition and its effects on tectonics, and the extent to which lithospheric mantle can be recycled into the convecting mantle or irreversibly differentiated from it.

TOOLS DEVELOPED FOR FOUR-DIMENSIONAL LITHOSPHERE MAPPING

Paleogeotherms

Heat drives all Earth processes and the thermal state of the lithosphere affects its thickness and density (Morgan, 1984; Lachenbruch and Morgan, 1990). Geotherms are a plot of temperature variation with depth at a given time and place. Empirical paleogeotherms can be constructed using temperatures and pressures calculated from mineral assemblages in mantle xenoliths and can provide a framework for mapping the geochemical structure of the subcontinental lithospheric mantle. Unfortunately, xenoliths from which pressures (depths) of origin can be calculated (e.g., with coexisting orthopyroxene and garnet) are limited in their geographic distribution. Nevertheless, single-element thermometers and barometers (e.g., Ni and Cr in garnet; Ryan et al., 1996) based on element partitioning between garnet and mantle olivine and pyroxene allow the derivation of paleogeotherms from the more abundant suites of garnet xenocrysts.

We have constructed, or compiled from published data, paleogeotherms for more than 300 localities worldwide. These paleogeotherms represent the temperature variation with depth at the time of volcanic eruption; they are typically low beneath cratonic areas with Archean crust, higher beneath Proterozoic cratons, and still higher beneath Phanerozoic mobile belts (Fig. 2). In areas of active basaltic volcanism, geotherms are generally high and strongly convex, consistent with advective heat transport by magmas and underplating of basaltic rocks in the upper part of the subcontinental lithospheric mantle (O'Reilly and Griffin, 1985; O'Reilly et al., 1997). These empirical geotherms are preferred over models for the thermal state of the lithosphere that are based on the downward extrapolation of surface heat flow (e.g., Pollack and Chapman, 1977) because input parameters such as thermal conductivity and heat production are poorly constrained and variable, both with depth and laterally, in the crust.

The Crust-Mantle Boundary and Lithosphere-Asthenosphere Boundary

Once a geotherm is inferred, the many xenolith samples for which temperature (T) can be calculated are projected to the geotherm to estimate their depth of origin. In the resulting sections, the minimum depth of abundant ultramafic rocks (mantle peridotite) commonly coincides with the maximum depth of mafic granulite xenoliths and can be used to estimate the depth of the crust-mantle boundary (O'Reilly and Griffin, 1996). We approximate the depth to the geochemical lithosphere-asthenosphere boundary by the maximum depth from which low-Y (<10 ppm) garnets, characteristic of depleted lithosphere (Griffin et al., 1999; references therein), are derived; it typically coincides with temperatures of 1250–1300 °C (Fig. 3). Deeper garnets have high Y + Ti + Zr, interpreted as the signature of asthenosphere-related metasomatism. The depth of the lithosphere-asthenosphere boundary

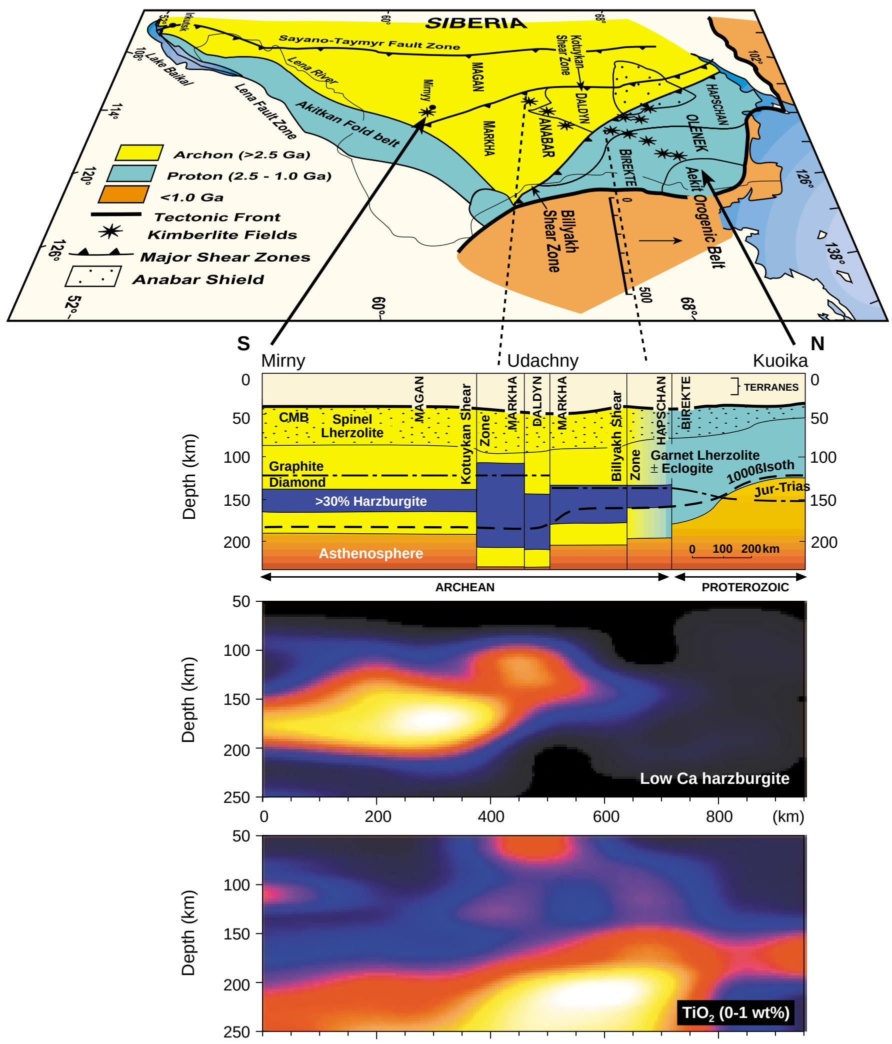

Figure 1. Example of lithosphere mapping across eastern Siberia, using xenoliths and xenocrysts (after Griffin et al., 1998a). Top view shows crustal terranes. Second view shows lithosphere sections mapped from xenoliths and xenocrysts in kimberlites (stars), delineating rock type distribution, the lithosphere-asthenosphere boundary and the 1000 °C isotherm (dashed). Next view shows distribution of low Ca-harzburgite, confined to Archean terranes. Lower view shows lithosphere-asthenosphere boundary reflected in Ti contents of garnets (higher in the asthenosphere). CMB—crust-mantle boundary.

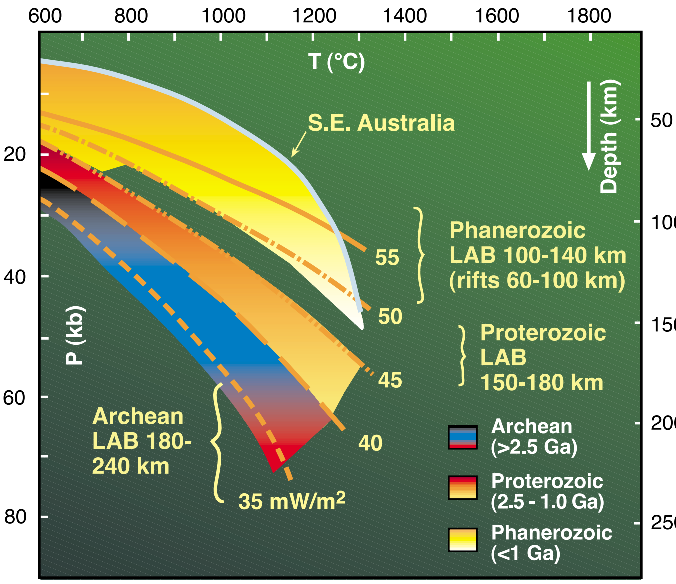

Figure 2. Range of *P-T* conditions and depths to lithosphere-asthenosphere boundary (LAB), commonly derived using xenolith and xenocryst suites entrained in volcanic rocks that penetrate crust of different tectonothermal age.

mapped in this way varies broadly with tectonic setting, being deepest (250–180 km) beneath undisturbed cratonic areas, and shallowest beneath Phanerozoic mobile belts or rifts (Fig. 2).

Chemical Tomography

Referring equilibration temperatures for xenoliths or xenocrysts to an inferred geotherm puts the geochemical information from each sample in a spatial context, so we can map the vertical distribution of rock types and styles of metasomatic alteration. The resulting lithological and/or geochemical columns (Fig. 4) provide one-dimensional maps, similar to drill-hole logs through individual subcontinental lithospheric mantle sections.

With multiple sampling points, mantle stratigraphy can be mapped and followed laterally, producing 2-dimensional and 3-dimensional images of the subcontinental lithospheric mantle that can be correlated with geophysical data and surface geology. On the Siberian Platform, Paleozoic to Mesozoic kimberlites (Fig. 1) provide mantle samples along a 1000 km traverse across Archean and Proterozoic terranes. Garnet data from more than 50 kimberlites along this trend define domains with distinctive mantle stratigraphy; these domains coincide with mapped crustal terranes (Griffin et al., 1998a; Fig. 1). This implies that the terrane boundaries are translithospheric and that each terrane carried its own lithospheric root during the assembly of the craton.

In the Slave craton of northern Canada, such mapping has revealed a distinctive two-layered lithospheric architecture beneath the Lac de Gras area (Fig. 4). The upper part of the subcontinental lithospheric mantle (to 140–150 km) consists of extremely depleted harzburgite, while the lower part (150–220 km) is significantly less depleted, though distinctively Archean in nature. The lateral extent of this structure (>14,000 km^2) has been mapped using concentrates from kimberlites and exploration samples (Griffin et al., 1998b), and is seen in magnetotelluric data (Jones et al., 2001). We have interpreted the lower layer as accreted plume material, consistent with the presence of abundant lower-mantle inclusions in diamonds from the region (Davies et al., 1999).

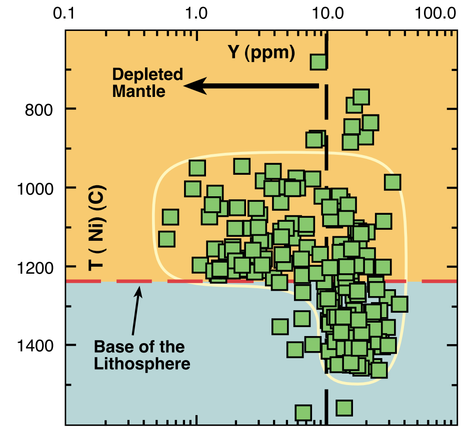

Figure 3. Geochemical definition of lithosphere-asthenosphere boundary beneath Shandong Province, China, using low-Y values characteristic of some garnets from depleted lithosphere, plotted against nickel temperature (T_{Ni}).

In the eastern Sino-Korean craton, volcanic eruptions separated by ca 400 Ma allow the lithospheric mapping to be extended to the fourth dimension (time). In Ordovician time, the mantle was thick, cool, diamondiferous, and typically Archean in composition (Fig. 5, A and B); it probably had survived for at least 2 Ga. Tertiary lamprophyres and basalts that erupted through the same terranes sampled only a thin (<120 km), hot and fertile lithosphere (Fig. 5; Griffin et al., 1998c).

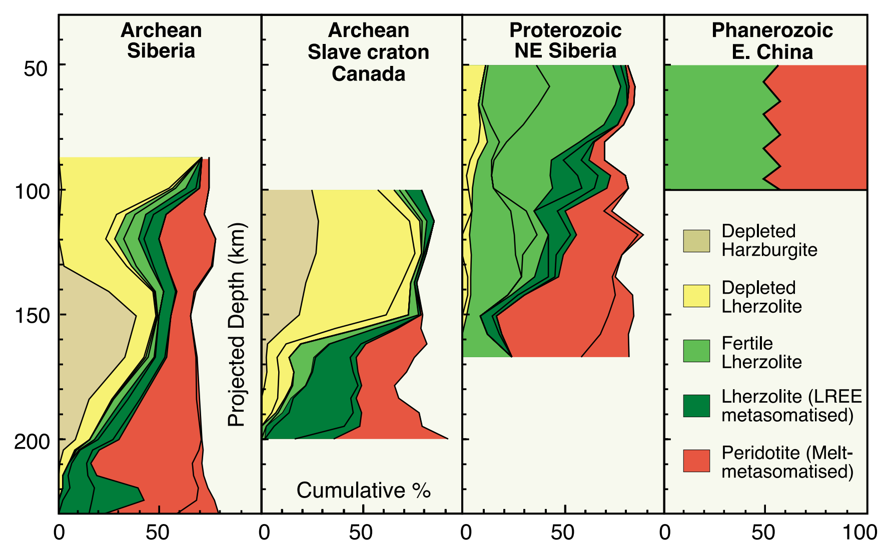

Figure 4. Chemical tomography sections showing relative abundances of different rock types in depth slices through lithospheric mantle. Sections are constructed by plotting data from garnet xenocrysts versus depth derived by projection of T_{Ni} for each grain to an inferred paleogeotherm (Griffin et al., 1999). Plotted garnet compositional types correspond only to xenolith types named in key, hence rock-type mix does not sum to 100% in each horizontal layer. LREE—light rare earth element.

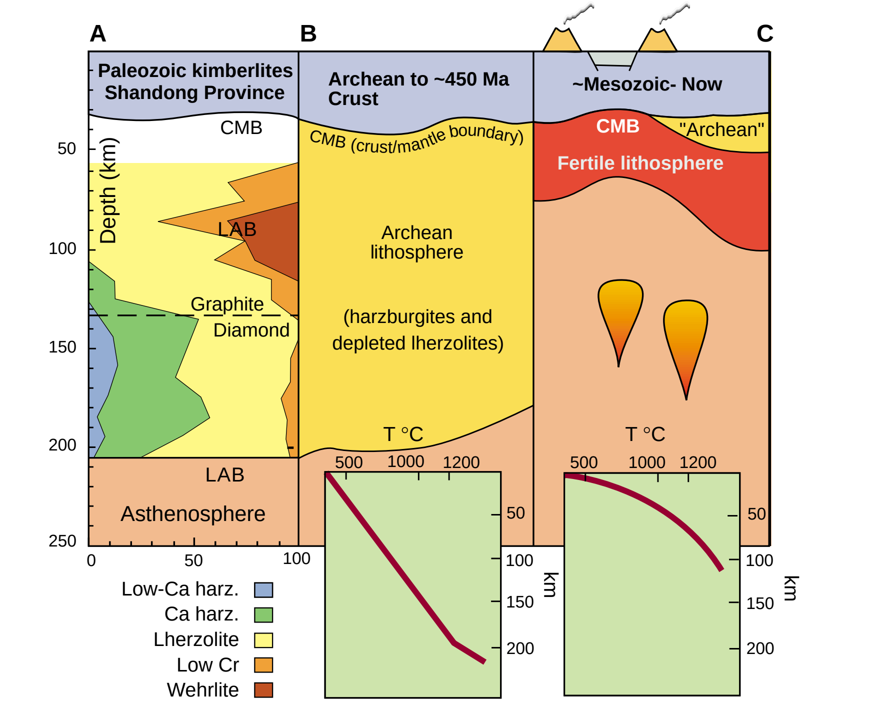

Figure 5. Lithosphere evolution in eastern part of Sino-Korean craton (after Griffin et al., 1998c). See text for discussion. A. Subcontinental lithospheric mantle stratigraphy derived from garnet data. B. Ordovician paleogeotherm derived from xenocrysts in kimberlites with Archean mantle thickness. C. Subcontinental lithospheric mantle section and geotherm derived from geophysical data and xenoliths in Tertiary basalts. CMB—crust-mantle boundary; LAB—lithosphere-asthenosphere boundary.

Secular Variation in Lithosphere Composition

Understanding the relationship of mantle lithosphere to its superjacent crust is important for understanding how continents are stabilized and whether plate tectonic and crustal growth processes have changed through time. The Cr_2O_3 content of xenolith garnets is a function of the Al_2O_3 content of their host rocks, which in turn is well correlated with other key major and minor elements (Griffin et al., 1998d, 1999). We have used these relationships to calculate the mean composition of the mantle from the Cr_2O_3 contents of more than 16,000 garnet xenocrysts from volcanic rocks worldwide. Figure 6 compares the calculated subcontinental lithospheric mantle compositions with the mean composition of xenolith suites for selected sections.

Average subcontinental lithospheric mantle composition is broadly correlated with the tectonothermal age of the crust penetrated by the volcanic rocks; younger continental crust is underlain by less depleted subcontinental lithospheric mantle (Griffin et al., 1998d, 1999). The data indicate that newly formed subcontinental lithospheric mantle has become progressively less depleted from Archean, through Proterozoic to Phanerozoic time, in terms of Al and Ca contents (and in Mg# and Fe/Al). Garnet peridotite xenoliths from young extensional areas (e.g., eastern China; Xu et al., 2000) are geochemically similar to primitive mantle, indicating very low degrees of melt depletion. Archean subcontinental lithospheric mantle also is distinctive in containing significant proportions of very depleted clinopyroxene-free peridotites (subcalcic harzburgites), emphasizing the marked compositional differences between Archean subcontinental lithospheric mantle and that beneath younger terranes (Figs. 1 and 4; Griffin et al., 1999). These observations expand Boyd's (1989, 1997) original recognition of a fundamental distinction between Archean cratonic subcontinental lithospheric mantle, represented by xenoliths in African and Siberian kimberlites, and Phanerozoic circumcratonic mantle, represented by xenoliths in intraplate basalts.

The broad correlation between subcontinental lithospheric mantle composition and crustal age is strong evidence that crustal volumes and their underlying lithospheric mantle formed at least quasi-contemporaneously, and can remain linked for periods of eons. The Archean-Proterozoic boundary represents a major change in the nature of lithosphere-forming processes, and a more gradual secular change has continued into the Phanerozoic. This secular evolution in process must be driven by global-scale secular changes in Earth; the most obvious of these is the secular cooling of Earth, which can produce gross changes in mantle convection styles (e.g., Davies, 1995).

The Density of Subcontinental Lithospheric Mantle Domains and Lithospheric Columns

Continents are long-lived records of geologic events in large part because of their long-term buoyancy, and it is important to understand the mantle contribution to this buoyancy structure. The relative proportions of olivine to garnet + clinopyroxene, and Mg#, are the main determinants of mantle

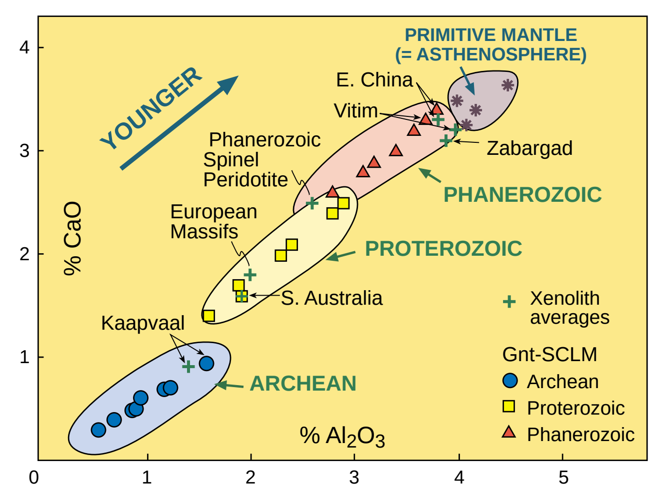

Figure 6. CaO-Al_2O_3 plot showing the range of mantle compositions for individual sections (matched with ages of the youngest tectonothermal events in the overlying crust) calculated using data from garnet xenocryst suites, with xenolith averages for comparison. SCLM—subcontinental lithospheric mantle; Gnt—garnet.

density. Mean mineral compositions for subcontinental lithospheric mantle of different ages have been derived from correlations between mineral and whole-rock compositions in xenoliths and then used, with interpolations of end-member mineral density data (Smyth and McCormick, 1995), to calculate the mean modes and densities of Archean, Proterozoic, and Phanerozoic subcontinental lithospheric mantle (Fig. 7; Poudjom Djomani et al., 2001). Mean density (at standard temperature and pressure) increases significantly from Archean (3.31 ± 0.016 Mg m^{-3}) to Proterozoic (3.34 ± 0.02 Mg m^{-3}) to Phanerozoic (3.36 ± 0.02 Mg m^{-3}) subcontinental lithospheric mantle.

Variations in mantle density with depth are controlled by the geotherm and the elastic behavior of the minerals at each temperature (T) and pressure (P). In Phanerozoic subcontinental lithospheric mantle, the change from spinel- to garnet-peridotite is also significant because of the higher geothermal regime and the T-dependence of the depth to the spinel-garnet transition. We used the range of geotherms characteristic of Archean, Proterozoic, and Phanerozoic subcontinental lithospheric mantle (Fig. 2) to estimate T at each depth; thermal expansion coefficients and bulk moduli for mineral end members were taken from Fei (1995) and Knittle (1995).

The cumulative density of different subcontinental lithospheric mantle sections was calculated as a function of their thickness and compared with the density of the asthenosphere (approximated as primitive mantle [McDonough and Sun, 1995] with a potential temperature of 1300 °C and an adiabat of 0.5 °C/km) at the lithosphere-asthenosphere boundary (Fig. 8). A typical Archean subcontinental lithospheric mantle section thicker than ~60 km is significantly buoyant; a 200 km section is 2.5% less dense than the asthenosphere at the lithosphere-asthenosphere boundary. Proterozoic subcontinental lithospheric mantle sections thicker than ~125 km are buoyant relative to the asthenosphere, while Phanerozoic subcontinental lithospheric mantle sections with advective geotherms decrease in density with depth and are very buoyant relative to the asthenosphere. However, Phanerozoic sections that have cooled to typical conductive geotherms are buoyant relative to the asthenosphere only if they are >110–120 km thick, which is unusual (Fig. 2).

Calculation of V_p and V_s

Our chemical tomography models of the subcontinental lithospheric mantle are compatible with observed seismic properties beneath different continents. Differences in density, coupled with the typical differences in geotherms between provinces of different tectonothermal age, result in different seismic velocities in different mantle volumes. At 25 °C, the compressional wave velocity (V_p) and shear wave velocity (V_s) of Archean subcontinental lithospheric mantle are higher than those of Phanerozoic subcontinental lithospheric mantle by about 0.4% and 1.4%, respectively (Fig. 7); the compositional differences account for ~25% of the worldwide range observed by seismic tomography. When typical geotherms (Fig. 2) are used to derive temperatures at 100 km depth for different tectonic settings, the calculated V_p and V_s beneath Archean cratons are higher by ~5% than those beneath Phanerozoic mobile belts (Fig. 7), corresponding to the ranges in velocity commonly seen by seismic tomography.

LITHOSPHERE PRESERVATION AND DESTRUCTION

The physical property data derived above provide important constraints on

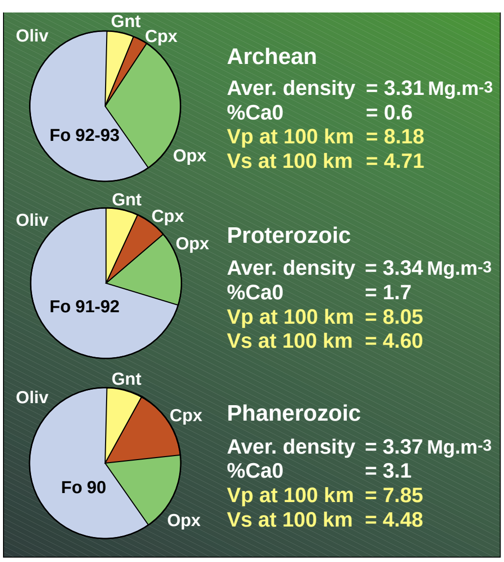

Figure 7. Modal and physical property data for lithospheric mantle of different ages (see text). Densities calculated at standard temperature and pressure, shear wave velocity (V_s) and compressional wave velocity (V_p) in km/s at 100 km (see text). Opx—orthopyroxene; Cpx—clinopyroxene; Gnt—garnet; Fo—forsterite; Oliv—olivine.

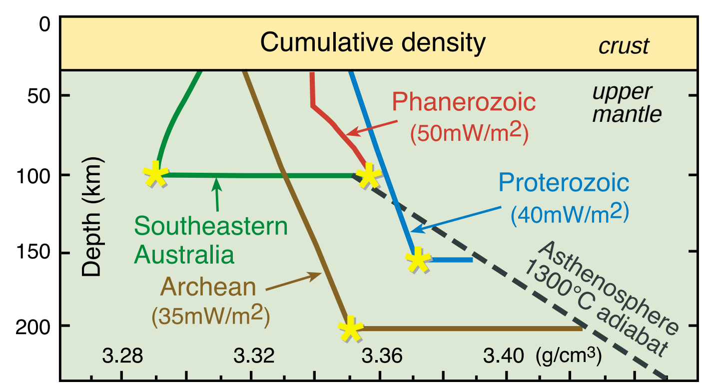

Figure 8. Cumulative density of typical subcontinental lithospheric mantle sections of different age. Dashed line shows asthenosphere density (potential T=1300 ºC). Yellow stars mark lithosphere-asthenosphere boundary on each lithosphere profile.

tectonic models that invoke the delamination and recycling of the subcontinental lithospheric mantle. Buoyant Archean lithosphere is unlikely to be delaminated through gravitational forces alone. Tectonic stacking, often invoked as a mechanism for delamination, will simply increase the relative buoyancy of the Archean subcontinental lithospheric mantle section, because the density of the asthenosphere increases faster (as the lithosphere-asthenosphere boundary is depressed) than that of the thickened subcontinental lithospheric mantle. This buoyancy, when combined with the refractory nature of Archean subcontinental lithospheric mantle, offers a simple explanation for the thickness and longevity of Archean lithospheric keels (Jordan, 1988). It also explains the common higher elevation of Archean terranes (e.g., Murray et al., 1997) although this is not seen in long-wavelength analyses of the geoid, probably due to the scale of data interpretation (Richards and Hager, 1988). The buoyancy of Archean subcontinental lithospheric mantle contributes significantly to the preservation of the overlying crust, protecting it from subduction and recycling (a "life-raft" model of craton formation). Conversely, crust formed in tectonic settings that did not involve the production of such keels would have been lost; this suggests that our record of Archean crustal processes may be significantly biased (also see Morgan, 1985).

If Archean subcontinental lithospheric mantle is too buoyant to be removed by gravitational forces and too depleted to be dispersed by melting, is it there forever? Changes tracked in the lithospheric mantle in several regions show that Archean mantle can be transformed. In the case of the eastern Sino-Korean craton (Fig. 5), detailed seismic tomography (Yuan, 1996) shows an upper mantle made up of vertically and laterally extensive blocks of high-velocity (probably Archean) mantle embedded in a matrix of lower velocity (presumably hot Phanerozoic) mantle, beneath a pronounced low-velocity zone. Yuan (1996) suggests that replacement of the Archean subcontinental lithospheric mantle has involved rifting, with contemporaneous upwelling of fertile asthenospheric material along breaks in the Archean root, leading to a dispersal and dilution of the Archean subcontinental lithospheric mantle, rather than its removal or delamination.

Any Proterozoic section more than ~150–180 km thick is moderately buoyant (Fig. 8), consistent with the preservation of lithosphere with Proterozoic Re-Os ages beneath Proterozoic cratons (e.g., Carlson et al., 1999; Handler et al., 1997) although a decrease in the geotherm below those modeled here might destabilize a section as thick as 150 km.

Typical Phanerozoic subcontinental lithospheric mantle sections (~110–120 km) are buoyant under conditions of high geothermal gradient (e.g., during their formation). However, they are at best neutrally buoyant after cooling to typical stable conductive geotherms and vulnerable to Rayleigh-Taylor instability (Houseman and Molnar, 1997) and will tend to delaminate and sink. Asthenospheric material welling up into the resulting "space" will cool to form a new, little-depleted subcontinental lithospheric mantle; this will raise geotherms and may cause melting in the overlying crust (Griffin et al., 1998d). As this new subcontinental lithospheric mantle cools down, it in turn will become unstable, and start the cycle again. This cyclic delamination may explain the ubiquitous presence of fertile xenolith suites in young basalts erupted through Paleozoic-Mesozoic orogenic belts (Griffin et al., 1999). If this model is correct, it suggests a fundamental difference between Phanerozoic and Archean tectonics, linked to differences in the processes involved in subcontinental lithospheric mantle production, and these processes ultimately must be reflected in changes in the production, preservation, and destruction of continental crust through time.

ACKNOWLEDGMENTS

The concepts discussed here owe much to discussions with many colleagues, including Joe Boyd, Rod Brown, Geoff Davies, Buddy Doyle, Kevin Kivi, Lev Natapov, Norm Pearson, Chris Ryan, Yuan Xuesheng, and Ming Zhang. We appreciated the constructive comments of the reviewers (R. Carlson, M. Roy, G. Humphries, and D. Smith) and of the editor (K. Karlstrom) that all improved the manuscript. Funding for this work has come from multiple sources, including Australian Research Council (ARC) grants to O'Reilly and Griffin, Macquarie University grants and industry. This is publication no. 234 from the ARC National Key Centre for Geochemical Evolution and Metallogeny of Continents (www.es.mq.edu.au/GEMOC/).

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Manuscript received December 6, 2000; accepted January 30, 2001.

DIALOGUE

Heard a Good Talk Lately?

Rob Van der Voo, *Chair, Annual Program Committee*

The answer is "yes," I hope. And chances are that one of those good talks was at a recent GSA meeting in Denver or Reno. Oh, you did not attend? You may be missing something. Let me explain some of the developments in programming of the national meetings.

There now are three ways in which sessions during the national meeting can be planned, programmed, and presented. We have had two years of experience with this new scheme, and it is apparent that members are generally pleased with the outcome. The three types of sessions are called Pardee Keynote Symposia, Topical Sessions, and Discipline Sessions. In addition, Associated Societies can organize a few symposia before the meeting (e.g., on Sunday), and there are short courses as well as lunchtime hot-topic sessions.

Only one Pardee Keynote Symposium is going on at any given time for a maximum of eight half-day Pardees during the meeting. All speakers are invited, and meeting organizers can request a budget of up to $2,000 from the Joseph T. Pardee Memorial Fund. Anyone can propose a Pardee Keynote Symposium. Given the limited number of Pardees and the inherent competition for their special status, it is important that proposals be carefully evaluated. This is done in early January by a panel of Joint Technical Program Committee (JTPC) members, rotating from year to year to represent seven of the Divisions and Associated Societies. I have attended a few Pardee Keynotes (regretting that I could not listen in on more). At one of them I was really excited about the science, and at the other I came away impressed with the stature of the speakers and their portrayal of important developments in their fields. Pardee proposals not selected can be modified to Topical Session proposals.

The Topical Session proposals (some 80–150 each year, typically) are also evaluated by the JTPC representatives. Most are approved, unless they seem to counter the mission of GSA. Unusual formats—such as those with more invited speakers than the automatically allowed number of four, those that combine oral and poster presentations, panel debates, and special ways of encouraging audience participation—must be specifically approved in advance.

Discipline sessions are filled with all the other papers not submitted to Pardees or Topical Sessions. These are grouped according to the categories that authors are asked to indicate on the abstract form. These sessions continue to be the main entrées on the menu of the meeting, but don't expect just meat and potatoes! You'll discover aubergines, paté de foie gras, mahi-mahi, and exquisite pastas. Oh well, you get the point.

So, what has really changed? Not the very important role of the Divisions and Associated Societies, who can (and do) propose as many topical sessions as they desire, although they no longer have a completely free hand in inviting unlimited numbers of speakers. Not the menu presented to the attendees, although it has become richer in content and strives to become more international. Not the audience profile, still ranging from the white-haired to undergraduates and from K–12 teachers to resource company researchers. No, what has changed is that all categories in the diverse membership have become more empowered. Everyone can (and should) send in proposals, while also participating in their Divisions and Associated Societies and helping to nominate or serve as JTPC representatives. As President Sharon Mosher wrote in this column in January: Participate, volunteer, and contribute suggestions—this is our society!

BOOK REVIEW

Impacts and the Early Earth

Edited by Iain Gilmour and Christian Koeberl, Springer, Berlin, Germany, 2000, 445 p., $110.00.

Impact cratering was likely an intense geologic process early in Earth history, particularly ~3.9 Ga (*GSA Today*, August 2000). If so, it will be useful to learn how to identify impact events in the geologic record and explore how they may have affected the biologic evolution of our planet. *Impacts and the Early Earth*, a volume of 17 papers edited by Iain Gilmour and Christian Koeberl, explores this new (and old) territory. In the opening three chapters, the potential link between impact cratering and the origin of life on Earth is developed by examining the delivery of organic materials to Earth. The next six chapters explore ways to identify Proterozoic and Archean impact events from horizons of impact debris in the stratigraphic record, including those containing impact melt spherules and impact-generated diamonds. Three chapters then look at the characteristics of deeply eroded craters, including the nature of impact-generated faulting and shock metamorphism of basement rocks. The book ends with a series of chapters that discuss the frequency of impact cratering, impact melting at the Chicxulub impact site, and descriptions of impact craters produced during the Cambrian and Precambrian or produced in target rocks with those ages. While the book is not comprehensive, it does provide a good introduction into the issues involved in studying impact events early in Earth history with useful references to related work.

In addition to the science in the book, it is notable because it is the product of a significant new program in Europe. The European Science Foundation (ESF) has initiated a program called IMPACT, which is designed to study the geologic and biologic effects of impact cratering on Earth. The program has substantially broadened the participation of European scientists in impact cratering studies and has created a series of forums through which specific themes can be explored. While the first forum focused on impact events in early Earth history, four other forums have already been held, and three more are planned for the first six months of this year: Impact Markers in the Stratigraphic Record (Spain), Submarine Craters and Ejecta-crater Correlation (Norway), and a Short Course on Impact Stratigraphy (Italy). This substantial ESF program promises to produce a series of useful geologic treatises. Sadly, there are no comparable programs in North America.

David A. Kring
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Tucson, AZ 85721

GSA supports efforts to increase awareness of the value of geoscience within the greater scientific community, society at large, and among our own members. This column highlights efforts that contribute to the claim that geoscience matters. To submit information about similar efforts contact Director of Programs Dennis Goldman at dgoldman@geosociety.org.

Early in February, GSA program officer Katie KellerLynn and I spent a day with the leaders of the Geologic Resources Division (GRD) of the National Park Service. As GSA's liaison to the GRD, KellerLynn works with the National Park Service on all our joint efforts, including GeoCorps America™. In the morning, we all discussed broadening the GeoCorps program to include the National Park Service's water resources and air quality divisions. For the remainder of the day, the GRD leaders treated us to comprehensive updates on their programs and initiatives. Many of these are outgrowths of the partnership between GSA's Institute for Earth Science and the Environment (IEE) and the National Park Service. So many, in fact, that I ended the day astounded by what can be achieved through shared vision, long-term commitment, and persistent effort. The IEE-GRD team is a powerful tool for ensuring that geoscience matters in the management of our national parks, recreation areas, and monuments.

One major initiative was presented that is not currently in the IEE-GRD partnership portfolio. Zelda Bailey provided a thorough briefing on the National Cave and Karst Research Institute. As you will see in the following article by Bailey, the institute and its future should be on the radar screen of members whose research has anything to do with karst systems and/or caves.

Cathleen May

National Cave and Karst Research Institute

Caves and karst systems support fragile ecosystems, contain mineralogical resources, and are important water-supply sources. Improved knowledge of caves and karst systems leading to improved protection and management is important to ecosystem and public health and to sustainable economic development. Several congressional acts have addressed the need for inventories of cave and karst resources and the need to have a scientific basis for cave and karst management.

The Federal Cave Resources Protection Act of 1988 (Public Law 100-691) directed the secretaries of the interior and agriculture to inventory and list significant caves on federal lands, and provides a basis for protecting caves. Another enactment in 1990 (Public Law 101-578) further directed the secretary of the interior, through the director of the National Park Service, to establish and administer a cave research program and to prepare a proposal for Congress that examined the feasibility of a centralized national cave research institute. The Lechuguilla Cave Protection Act (Public Law 103-169), passed in 1993, recognized the international significance of the scientific and environmental values of the cave.

In October 1998, Congress passed the National Cave and Karst Research Institute Act (Public Law 105-325) that mandated the National Park Service to establish and operate the institute. The act stipulated that the institute be located in the vicinity of Carlsbad Caverns National Park in New Mexico (but not inside park boundaries), and that the institute cannot spend federal funds without a match of private funds.

Mission and Goals

The mission provides a framework for the National Cave and Karst Research Institute to achieve its congressionally defined goals and to guide development of an appropriate scope of activities in the national interest: "The National Cave and Karst Research Institute furthers the science of speleology by facilitating research, enhances public education, and promotes environmentally sound cave and karst management."

The goals (purposes) of the institute are clearly and simply stated in the text of the 1998 act. Following are expanded statements of goals that provide a broader view of the operational intent of the institute.

- Further the science of speleology through coordination and facilitation of research.
- Provide a point of contact for dealing with cave and karst issues by providing analysis and synthesis of speleological information and serving as a repository of information.
- Foster partnerships and cooperation in cave and karst research, education, and management programs.
- Promote and conduct cave and karst educational programs.
- Promote national and international cooperation in protecting the environment for the benefit of caves and karst landforms and systems.
- Develop and promote environmentally sound and sustainable cave and karst management practices, and provide information for applying these practices.

Timeline to Full Implementation

The interim director for the National Cave and Karst Research Institute reported in July 2000 for a two-year period to move forward with National Park Service efforts to establish the institute by defining the purview and scope of operation, designing an organizational structure, forming partnerships, finding funding sources and a physical facility, and defining research needs. The institute will pass through several phases before it fully reaches the capacity to sponsor a wide range of activities.

The interim phase is anticipated to span about three years (August 1999 to August 2002). This phase began when a steering committee convened to articulate expectations for the institute and to draft specifications for recruitment of an interim director, and will end when the interim director completes the initializing tasks.

The gearing-up phase is likely to take one additional year (2003) and would consist of staff recruitment, moving into a building (possibly a temporary facility), initial operational setup, and the transition from the interim director to the director. If funding and ability to operate permit, research grants could be distributed during this phase and the real work of the institute can begin.

The basic institute phase would take another one to two years (2004–2005) while the experience of the staff and the capacity of the institute gradually increase and financial resources for full operation are accumulated. If a building is constructed, it may be completed during this phase. A grant process would be operational, and results of research supported by the earliest grants may become available.

The fully operational phase should be attained by 2006, when the institute becomes a significant and recognized resource in cave and karst research, education, and support of cave and karst management.

Current Activities

A federal working group was formed to assist the interim director in developing the operating plan for the National Cave and Karst Research Institute and to represent and communicate with their agencies and non-federal constituency groups.

A partnership agreement was signed between the institute and New Mexico State University, which has a campus in Carlsbad, for a small amount of office space and administrative support during the interim and gearing-up phases.

Although no formal agreement has been signed among the National Cave and Karst Research Institute, New Mexico Tech, and the City of Carlsbad, several meetings have been conducted to lay the groundwork for long-term partnerships. The City of Carlsbad and New Mexico Tech are petitioning the New Mexico legislature for funds to construct a building for the institute. A cooperative agreement for building space could provide the required match to federal funding for basic institute operations.

The institute is working with the National Park Service Mexico Affairs Office to form partnerships and collaborative activities with Mexico related to cave and karst resources. Plans are being made to meet with representatives from Mexico.

Although the National Cave and Karst Research Institute is not yet organized or fully functional, several collaborative projects with other agencies and cave and karst organizations are planned during the interim phase that will provide name recognition and important products sponsored by the institute.

Ideas for research needs are being compiled through discussions with a wide variety of interest groups, scientists, and resource managers. As a list grows, groupings of research areas should emerge and would form the basis for articulating national research needs. Focus groups are being convened at professional meetings to provide a wider forum for input into the research needs. Through this process, the institute can provide a national scope and overarching goals to cave and karst research.

Zelda Chapman Bailey, *Interim Director, National Cave and Karst Research Institute*

photo by John Karachewski

Geoscientists:

INVITE CONGRESS INTO YOUR WORLD

Rachel Sours-Page
2000–2001 GSA–U.S. Geological Survey Congressional Science Fellow

Since I arrived on Capitol Hill on October 10, 2000, I have lived through the never-ending finale to the 106th Congress (which I was assured would end within a week of my beginning in Representative Earl Blumenauer's office), the uncertainties surrounding our presidential election, and now the transition in administrations and all of the changes that take place when one political party controls the House, the Senate, and the presidency for the first time in many years. These have been exciting and tumultuous times, indeed.

As a scientist arriving in Washington, D.C., I had some fantastical ideas about what I could accomplish. I thought that my presence here would be immediately recognized and appreciated, and that I would dutifully serve as a liaison between the scientific (geoscience) community and the legislature. When asked what I would be doing with this year, I told people that I would be something like a science advisor, helping to educate members of Congress so that they could make intelligent, scientifically based decisions.

What I have found is something quite different. While political decisions often have their foundations in scientific research (Everglades restoration, genetically modified foods, and the National Missile Defense System), many levels of interest groups and staff members separate Congress, as a whole, from that science. Science appears in the congressional office only in the form of factoids and polls. In addition, not only is science unspoken on "the Hill," legislators are so far removed from it that there is little perceived need for it. After four months in Congress, I have found that the battle for scientists on Capitol Hill is not to present science coherently, but to make the case for science to factor in to decisions at all.

With that said, I would consider Representative Blumenauer (D-Ore.), and, in fact, any congressperson who seeks out congressional fellows, to be an exception to the rule. Representative Blumenauer has made a concerted effort to surround himself with experts, or "certified smart people," as he calls them. It speaks volumes about a congressman that in this world of information overload, he would seek the facts underlying the jargon. My office has two fellows—me and one sponsored by the American Planning Association.

For the benefit of those congressmen who are not fortunate enough to have fellows, there are many ways that we, as geoscientists, can share our resources and reintroduce science into the legislative process. For example, my time in Representative Blumenauer's office is dedicated to issues related to water. I became the water legislative assistant because I wrote on my resume that my Ph.D. focused on marine geology—that was my compromise in trying to describe mid-oceanic-ridge basalts to the layperson in two words or less. Representative Blumenauer saw the word marine, and, sitting on the Water Subcommittee of the Transportation and Infrastructure Committee had a need for someone to deal in water, and so he chose me. Water... rocks, what's the difference, right?

The congressman's two big water agenda items for the year involve reforms of the U.S. Army Corps of Engineers (USACE) and the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP). His work with the USACE stems from growing public concern for the diminished integrity and accountability within the corps due to secretary of the Army's report confirming some fuzzy math in project cost-benefit analyses. To this end, I have started (on the congressman's behalf) the Corps Reform Caucus, a bipartisan group interested in working toward a financially and scientifically accountable Army Corps of Engineers. He is also aware of a great many projects, mostly beach nourishment and flood control projects that have questionable scientific merits. Representative Blumenauer would like to see the corps implement both an independent peer review and an increase in local community participation in the planning stage of projects. Both of these are areas in which geoscientists could be involved.

There are other ways in which geoscientists can instill science into the legislative consciousness. First, we should always look for the opportunity to invite Congress into our world. Invite your representative (or their staff) to your university, show them your facilities, your students' research, and give them reasons to be proud. Tell them where your funding comes from, and what you need to maintain (or improve on) this level of excellence in the future. You cannot assume that they will know that the National Science Foundation budget is crucial to your livelihood.

Second, provide "one-pagers." Congressional staff love one-page summaries of issues. If you know of natural hazards being ignored in your community (Are they building on a slope prone to landslides? Is that new development in the flood plain? Isn't that waste-management plant being built on a fault?), write a one-pager on the hazards and where they exist in your community. Educate your representative, make him or her aware of how geoscience issues affect a community, and they are more likely to be involved. Also, if you make yourself known as a good resource, they are more likely to call on you with future questions. These small steps will give back to the geoscience community many times over—they will bring the geosciences to the forefront of the legislature's radar screen and simultaneously put our science to use to build better communities.

This manuscript is submitted for publication by Rachel Sours-Page, 2000–2001 GSA–USGS Congressional Science Fellow, with the understanding that the U.S. government is authorized to reproduce and distribute reprints for governmental use. The one-year fellowship is supported by GSA and by the USGS, Department of the Interior, under Assistance Award No. 1434-HQ-97-GR-03188. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government. *Rachel Sours-Page can be reached at Rachel.Sours-Page@mail.house.gov, (202) 225-4792, 1406 Longworth House Office Bldg., Washington, D.C. 20515.*

2001 GSA SECTION MEETINGS

SOUTHEASTERN SECTION

April 5–6, 2001 — Sheraton Capital Center, Raleigh, North Carolina. Information: Edward Stoddard, Dept. of Marine, Earth & Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695-8208, (919) 515-7939, skip_stoddard@ncsu.edu.
Register onsite.

CORDILLERAN SECTION

April 9–11, 2001 — Sheraton Universal Hotel, Universal City, California. Information: Peter W. Weigand, Dept. of Geological Sciences, California State University–Northridge, 18111 Nordhoff Street, Northridge, CA 91330-8266, (818) 677-2564, peter.weigand@csun.edu.
Register onsite.

NORTH-CENTRAL SECTION

April 23–24, 2001 — Bone Student Center, Normal, Illinois. Information: Robert S. Nelson, Illinois State University, Dept. of Geography–Geology, Campus Box 4400, Normal, IL 61790-4400, (309) 438-7808, rsnelso@ilstu.edu.
Register onsite.

ROCKY MOUNTAIN & SOUTH-CENTRAL SECTIONS

April 30–May 2, 2001 — Sheraton Old Town Hotel, Albuquerque, New Mexico. Information: John Geissman, University of New Mexico, Dept. of Earth & Planetary Sciences, 203 Northrop Hall, Albuquerque, NM 87131-1116, (505) 277-3433, jgeiss@unm.edu.
Register onsite.

The Biggs Award

To reward and encourage teaching excellence in beginning professors of earth science at the college level, GSA announces

The Tenth Annual Biggs Award for Excellence in Earth Science Teaching for Beginning Professors

Eligibility
Earth science instructors and faculty from all academic institutions engaged in undergraduate education who have been teaching full time for 10 years or fewer. (Part-time teaching is not counted in the 10 years.)

Award amount
An award of $750 is made possible by support from the Donald and Carolyn Biggs Fund, the GSA Geoscience Education Division, and GSA's Science, Education, and Outreach Programs. This award also includes up to $500 in travel funds to attend the award presentation at the GSA Annual Meeting.

Deadline
Nominations for the 2001 Biggs Earth Science Teaching Award must be received by May 1, 2001.

For more information, contact: Leah Carter, Program Officer, Grants, Awards, and Medals, The Geological Society of America, P.O. Box 9140, Boulder, CO 80301, lcarter@geosociety.org, (303) 447-2020, ext. 137.

for Excellence in Earth Science Teaching

Living in a Microbial World:

New GSA Division Puts the Focus on Geobiology and Geomicrobiology

A new GSA Division was proposed during an organization meeting at the Summit 2000 GSA Annual Meeting in Reno. The Geobiology and Geomicrobiology Division met with much support and awaits only final GSA Council approval in May.

Geobiology and geomicrobiology are new fields of study in geology for students and professionals interested in how life has influenced and been influenced by Earth's environmental history. Geoscientists interested in and involved in geomicrobiological and geobiological studies include paleobiologists and paleontologists, geochemists and mineralogists, sedimentologists and geohydrologists, among others.

This new division provides a common forum for the wide range of participants (students, faculty, researchers, and professional geologists) interested in these fields. Division goals include:

- promoting the research findings of division members at sectional, national, and international GSA meetings;
- establishing a forum for discussion by the entire group at meetings and via the Internet;
- promoting interdisciplinary education for future geobiologists and geomicrobiologists from K–12 through university education levels; and
- stimulating communication with geoscientists and scientists from other disciplines who are interested in learning more about these new areas of study.

At the meeting held in Reno, those organizing the division discussed plans to maintain a quarterly newsletter, organize theme sessions and symposiums at GSA meetings, and post outreach and education initiatives on the Web. The group also wants to host topical and career-development workshops, provide student support for travel to meetings, and create merit-based awards for students. Plans are under way to work with major granting agencies to establish funding initiatives, and to offer discounts for division members on journals such as the *Geomicrobiology Journal* and the new journals *Geobiology* and *Astrobiology*. The group also plans to publicize the new division by offering hats, pins, and T-shirts to all those interested.

For more information about the new division, or to lend your support, contact Sherry Cady, Portland State University, cadys@pdx.edu, or Christopher Fedo, George Washington University, cfedo@gwu.edu. ▲

Down an anything-but-lazy river with GSA

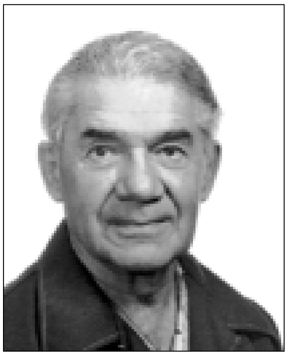
Over the years, GSA has put on many float trips down the Grand Canyon as part of the GeoVentures program. Judging from the positive responses and comments from participants, the trips have been well received.

Past trips have been from 5 to 7 days long in order to meet time and cost constraints indicated by participants. However, longer trips would give a much better opportunity to experience and explore the Grand Canyon in a truly satisfactory manner. "Quite a few people have expressed the opinion that a longer trip would be preferable," said Ivo Lucchitta, long-time GSA member and frequent Grand Canyon GeoTrip leader. "Some have pointed out that longer trips end up being cheaper on a per-day basis because fixed costs such as getting to and from Las Vegas, buying gear, and so on, are the same for a long as for a short trip.

"We are exploring the possibility of organizing a longer trip, probably from 12 to 14 days long," said Lucchitta. He noted that there is an incentive in making the trip soon because of the possibility that park rafting policies may change in the future.

If you are interested in taking a longer float trip down the Grand Canyon, please contact Edna Collis, ecollis@geosociety.org, (303) 447-2020, ext. 134, GSA, P.O. Box 9140, Boulder, CO 80301-9140.

GSA Foundation Update



Alexander Wanek

The Alexander and Geraldine Wanek Fund for Graduate Studies Established

Julie A. Wetterholt, *GSA Foundation Staff*

The Foundation is pleased to announce the establishment of the Alexander and Geraldine Wanek Fund for Graduate Studies. Created by a generous gift of life insurance from Alexander Wanek and his wife, Geraldine, the intent of this endowment is to support graduate student research grants. This year, the fund will generate approximately $3,500 for distribution by the GSA Committee on Research Grants.

Alexander Wanek died of congestive heart failure on August 29, 2000, at the age of 84. He was born June 7, 1916, in Chicago. He and Geraldine McKamie married February 5, 1943, in Alexandria, Louisiana.

Wanek served in the U.S. Army from November 1940 to February 1946. He spent two years in the European Theater where he was part of the 121st Cavalry reconnaissance unit, and he was in the Battle of the Bulge. He earned the rank of captain.

Wanek received a bachelor's degree at the University of New Mexico in 1948 and joined GSA in 1953. He worked for the U.S. Geological Survey (USGS) for 28 years throughout New Mexico, Colorado, California, and finally Alaska. He and his wife moved to Sequim, Washington, in 1975, where she resides.

While most of Wanek's career was spent conducting mineral fuels investigations in the Southwest, northwestern Washington, and northern Rocky Mountains, and Mineral Classification of Public Lands in Alaska, his interests and skills were even broader. In addition to his expertise in coal and petroleum resources, mapping, and engineering geology, he was also interested in marine resources, petroleum economics, appraisal, and evaluation, and in the geology of phosphate resources. He is the author of more than 50 published USGS reports spanning almost three decades. According to his wife, Wanek was "totally devoted to geology."

Additional memorial gifts can be made to the Wanek Fund in care of Donna Russell, Director of Operations, GSA Foundation, P.O. Box 9140, Boulder, CO 80301.

Digging Up the Past

Most memorable early geologic experience

"The thrill of discovering massive cementation of the barrier reef wall in Belize at 100 meters sub-sea with a two-person research submersible."

—Robert N. Ginsburg

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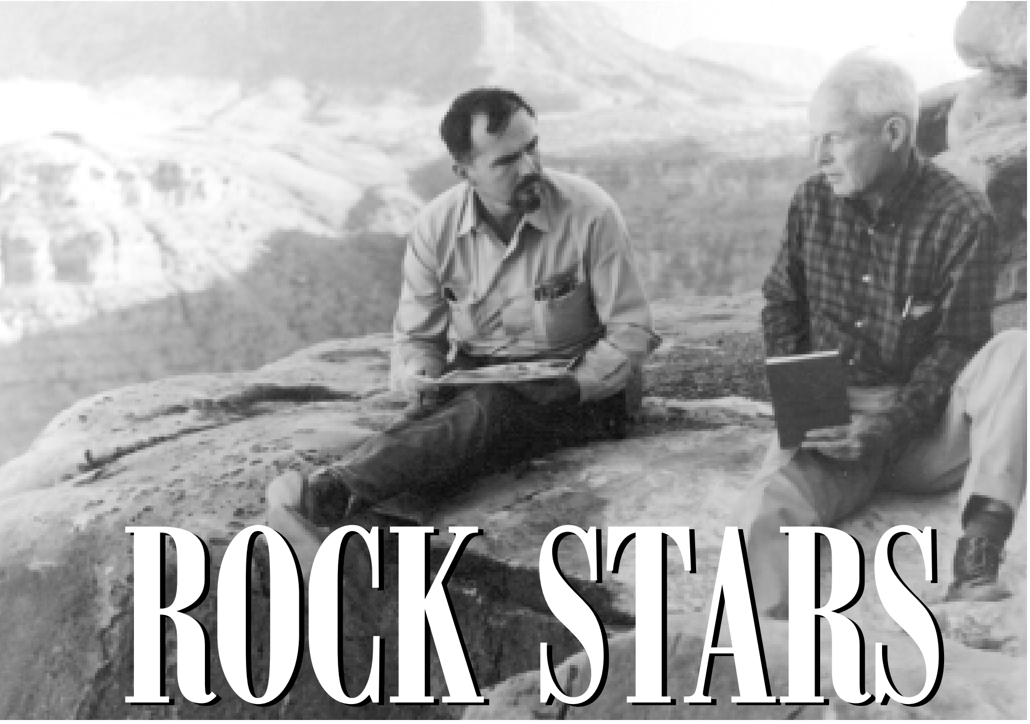


Gene Shoemaker, left, pictured here with Edwin McKee, founded the Astrogeology Branch of the U.S. Geological Survey and was a leader of terrestrial and planetary meteorite impact research.

Eugene M. Shoemaker and the Integration of Earth and Sky

Mary G. Chapman, *U.S. Geological Survey, 2255 N. Gemini Drive, AZ, USA 86001, mchapman@usgs.gov*

From Prodigy to Stargazer

The first of two children, Eugene Merle Shoemaker (1928–1997) was born in Los Angeles, California. His mother was a schoolteacher. His father, a strong, enthusiastic man, was a teacher, coach, farmer, and trucker. Gene's early years were spent in Buffalo, New York. His mother enrolled him in kindergarten before the age of 4, and in the fifth grade (age 8), she suggested he take science classes at the Buffalo Museum of Science in a program of geology and related classes for high-school and college-level students. Gene talked about the program for years afterward, saying "It opened my eyes to geology, focused my interests, and turned me into an avid rock collector."

The Shoemakers returned to Los Angeles when Gene finished junior high, and his father hired on as a Hollywood movie studio stagehand. At 16, Gene graduated from high school and began his freshman year at nearby Caltech. As a teaching assistant there, he taught much older students who were returning to school on the GI Bill, and he grew his trademark mustache in order to look older. Until I read books by Wilhelms and Levy, I didn't know Gene was a Caltech cheerleader, but that fits completely, as he was the one to talk to when you needed to be pumped up about science. He received his B.S. and M.S. degrees from Caltech in 1947 and 1948.

In 1948, Gene joined the U.S. Geological Survey (USGS) and began exploring Colorado and Utah for uranium deposits. That first summer, thinking about nuclear fuel and rocket development during World War II, it suddenly occurred to him that during his lifetime, man would go to the Moon. Gene wanted to be the first lunar geologist.

Colorado Plateau and Marriage

Gene developed his field skills on the Colorado Plateau between 1948 and 1957. Gene had an adventurous spirit and, in 1949, took his first river trip down Glen Canyon; river running became a lifelong hobby that later led to an important publication. He was awarded another M.S. degree in geology at Princeton and began working toward a Ph.D., but postponed this goal to return to the USGS and the plateau.

In 1951, he married Carolyn Jean Spellmann, a schoolteacher from Chico, California, whose talent in pinpointing comets and asteroids would lead to important joint discoveries. Carolyn and Gene had three children.

Papers published during this time focused on the structures of maars, salt anticlines, Hopi-Butte diatremes, and laccoliths of the plateau. Gene also produced geologic maps of Colorado quadrangles pertinent to uranium prospecting. His USGS research and mapping on the plateau, sponsored by the Atomic Energy Commission (AEC), brought him geographically and intellectually near the now-famous Meteor Crater east of Flagstaff, Arizona. He sampled the crater to investigate its origin as a volcanic feature, an interpretation favored by a predecessor in lunar studies, G.K. Gilbert (1843–1918; first chief geologist of the USGS). Rather than volcanic detritus, he found curiously fused grains of coconino sandstone.

Cratering Studies

In 1957, the AEC thought underground nuclear explosions might produce an effect similar to that of an explosive volcano. To find out where plutonium would go in an underground volcanic explosion, Gene studied the effects of shock in nuclear craters. He immediately saw the resemblance of these craters to Meteor Crater. From 1957 to 1960, he did his classic research on the structure and mechanics of meteorite impact, based on Meteor Crater.

Under pressure from Princeton to complete his degree, Gene wrote up this work and received his Ph.D. in 1960. His landmark paper on cratering studies at Meteor Crater noted the overturned crater rim strata, similar to that observed at nuclear craters. This and later work challenged the classic idea of uniformitarianism, emphasizing catastrophic effects. His cratering work influenced and contributed to studies of E.C.T. Chao. Gene became one of Chao's co-authors in an internationally acclaimed paper on the discovery of natural coesite at Meteor Crater. (Coesite, a high-pressure form of silica created during impacts, had been created in a laboratory by Coes in 1953.) Gene studied impact cratering throughout his life, both by exploring Earth, particularly Australia, and by studying the planets using remote sensing and mapping.

Lunar Pursuits and the USGS Astrogeology Team

In 1957, Gene prepared a preliminary map of Copernicus Crater on the Moon. Using only photographs and telescopic measurements, he showed that he could unravel the sequence in which layers of rock were deposited. This map and Gene's infectious enthusiasm convinced NASA officials to sponsor a lunar geology program directed by the USGS. In 1961, Gene began the USGS Branch of Astrogeology at Menlo Park, California. During the 1960s, he introduced crater counting as a method to date the lunar surface, led USGS teams that investigated the Moon's structure and history, and developed methods of planetary geologic mapping using telescopic images of the Moon.

Gene wanted to be an astronaut, but in 1962 was diagnosed with Addison's disease and knew he couldn't pass the stringent physical examination. Instead, he served as acting director of NASA's Manned Space Sciences Division, which developed and financed the scientific program on manned space flights. He was involved in the Lunar Ranger and Surveyor programs and continued with the manned Apollo programs.

In 1963, Gene pushed to establish a USGS Field Center in Flagstaff, Arizona, which had a tradition of astronomical observation and was close to Meteor Crater and a volcanic field, both of which were valuable for lunar comparisons. He helped train the Apollo astronauts in geologic fieldwork around Flagstaff, and, as the first lunar landing was televised, gave expert geologic commentary from a seat next to Walter Cronkite of CBS-TV.

After Surveyor I landed on the Moon in June 1966, Gene resigned as a NASA administrator and took on full-time research responsibilities as the chief scientist with the Astrogeology Branch of the USGS. Although he enjoyed working on Apollo 11, 12, and 13, the travel was taxing and the politics wearisome. Gene turned to academia, teaching at Caltech, and focused on terrestrial topics and astronomy. He returned to lunar studies in 1994, serving as science-team leader for Project Clementine, which incorporated new data concerning the Moon.

Caltech, Academic Life, and Asteroid Surveys

From 1962 to 1985, Gene blended his astrogeology research for the USGS with part-time teaching at Caltech. He chaired its Division of Geological and Planetary Sciences from 1969 to 1972, but preferred to teach. According to one of his doctoral students, Susan Werner Kieffer, he was an unfailingly generous and intellectually honest mentor, preferring not to add his name to students' work. His stay at Caltech allowed him time to pursue his interest in age dating using paleomagnetism to date the Moenkopi Formation of the Colorado Plateau. He founded two paleomagnetics labs—at the USGS in Flagstaff and at Caltech.

At Caltech, Gene became a co-investigator with Larry Soderblom (USGS) on Project Voyager. Ahead of his time, Gene wondered about the future effects and rates of impacts on Earth. In 1973, with Eleanor Helin, he initiated the Palomar Planet-Crossing Asteroid Survey and designed a new stereomicroscope for asteroid and comet detection on photographic film.

In the late 1970s, Gene proposed that Carolyn work with him, and she began a study of astronomy. In 1982, the two began the Palomar Asteroid and Comet Survey. For the next 15 years, they worked at the USGS in Flagstaff, with periodic excursions to Palomar to observe the skies and summer trips to Australia to map impact craters on Earth. Their work was featured in a 1997 National Geographic documentary "Asteroids: Deadly Impact." Gene retired from the USGS in 1993, but held an emeritus position with the USGS and was affiliated with Lowell Observatory in Flagstaff.

Diversification and Awards

Gene influenced science in numerous ways. He combined his knowledge of the Colorado Plateau with his love of river running to re-shoot, with his friend and USGS co-worker, Hal Stevens, the photogaphs taken on John Wesley Powell's second exploration of the Colorado River (1871–1872). The new images showed that many features looked as they had in Powell's time, but that landslides, floods, or other short-term events caused some major changes. This spoke against strict uniformitarianism in river systems. The men published "In the Footsteps of John Wesley Powell" in 1987.

Gene's exploration of Australia resulted in the discovery of one new crater, the confirmation of 20 proposed craters, and mapping of tektite fields. A decade-long sky survey for Earth-crossing asteroids and comets culminated in the discovery, with wife Carolyn and David Levy, of Comet Shoemaker-Levy 9. This comet impacted Jupiter in 1994, giving the world of science a major new insight into both the dynamics of comets and the planetary science of Jupiter.

Gene was the recipient of myriad awards, including honorary doctorates, the NASA Medal for Scientific Achievement (1967), National Academy of Science Member (1980), the GSA's Arthur L. Day Medal (1982) and G.K. Gilbert Award (1983), the U.S. National Medal of Science (1992, the highest scientific honor bestowed by the president of the United States), American Academy of Arts and Science Fellow (1993), and many others.

Gene was a brilliant, exuberant, vibrant, and warm man whose booming voice, angry antics over copy machines, and laughter rang down USGS hallways. His temper, contrasted with his normally cordial nature, was famous; one fan still cherishes a mangled coke can Gene had beaten in an angry fit with a metal detector that fooled him into thinking the can was a piece of Canyon Diablo meteorite.

Gene died in a car accident on July 18, 1997, in Alice Springs, Australia, on a field-mapping trip with Carolyn, who survived and continues her work at the USGS. Colleagues knew of his unfulfilled dream to reach the Moon, and they granted his wish. On January 6, 1998, a small polycarbonate capsule carrying an ounce of his cremated remains traveled to the Moon aboard NASA's Lunar Prospector spacecraft.

For more on Shoemaker:

Bell, J.N., 1971, Eugene Shoemaker, *in* Science Year: The World Book Science Annual 1972: Chicago, Field Enterprises Educational Corp., 443 p.

Boatman's Quarterly Review, 2000, Gene Shoemaker: Journal Grand Canyon River Guides, Inc., v. 13, no. 1, p. 28–41.

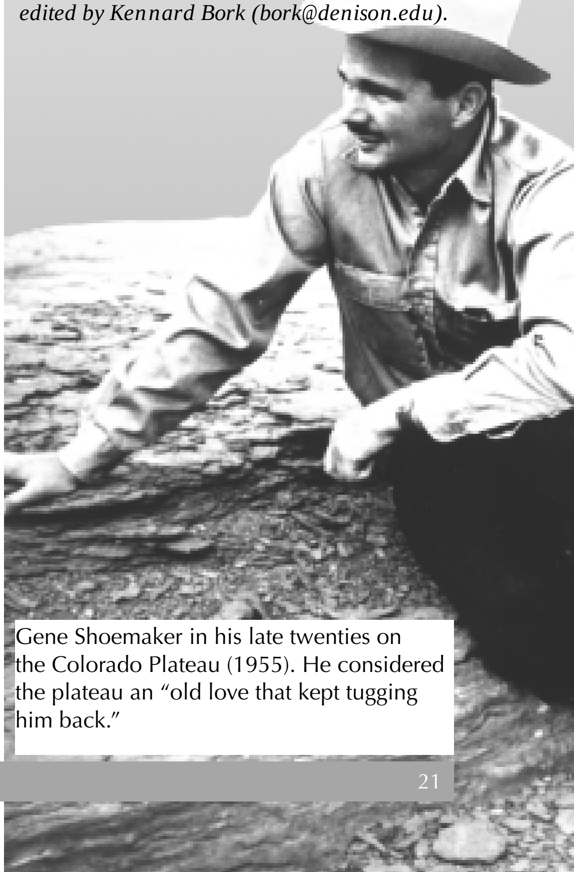
Levy, D.H., 2000, Shoemaker: The man who made an impact: Princeton, New Jersey, Princeton University Press, 256 p.

Shoemaker, C.S., 1999, Ups and downs in planetary science: Annual Review of Earth and Planetary Science, v. 27, p. 1–17.

U.S. Geological Survey, 2000, Eugene M. Shoemaker (1928–1997): wwwflag.wr.usgs.gov/USGSFlag/Space/Shoemaker/GeneObit.html.

Wilhelms, D.E., 1993, To a rocky moon: A geologist's history of lunar exploration: Tucson, Arizona, University of Arizona Press, 477 p.

The Rock Stars series is produced by the GSA History of Geology Division. This profile was edited by Kennard Bork (bork@denison.edu).



Gene Shoemaker in his late twenties on the Colorado Plateau (1955). He considered the plateau an "old love that kept tugging him back."

ANNOUNCEMENTS

About People

GSA Fellow **Melvin Schroeder** was inducted into the Texas Science Hall of Fame in January in a ceremony in San Antonio, Texas. Schroeder has taught and conducted research at Texas A&M University since 1954. In 1960, he began a program at the school to train elementary and middle school teachers that continued until 1996. He still teaches part-time at Texas A&M.

GSA Fellow **Russell Slayback** was awarded the Ben H. Parker Memorial Medal at the annual meeting of the American Institute of Professional Geologists (AIPG). The Parker Medal, AIPG's most prestigious honor, is awarded for outstanding service to the profession of geology. Slayback, a professional hydrogeologist for the past 40 years, currently serves as chairman of the groundwater and environmental engineering services firm of Leggette, Brashears & Graham, Inc.

GSA Fellow **Rob Van der Voo** of the University of Michigan has been awarded a Benjamin Franklin Medal of The Franklin Institute in the field of earth sciences for his outstanding contributions to the field of paleomagnetism and his reconstruction of ancient continental positions that have led to a better understanding of plate tectonic processes for the past billion years of earth history. His endowed medal will be presented on April 26 at a ceremony in Philadelphia.

In Memoriam

Phil M. Hammons
Denver, Colorado
December 21, 2000

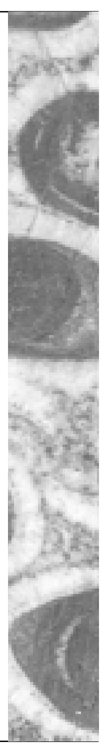
Patrick M. Hurley
Mount Dora, Florida
October 21, 2000

John C. Ludlum
Morgantown, West Virginia
November 12, 2000

Harry Ludowise
Vancouver, Washington
Summer 2000

James F. McAllister
Los Altos, California
September 29, 2000

Allen G. Winslow
Austin, Texas
November 4, 2000



Call for Comments

Dear Colleague,

The National Science Foundation (NSF) is seeking comments on its Earth System History (ESH) Program. Research in ESH is an initiative of the U.S. Global Change Research Program coordinated by NSF and funded by contributions from the Divisions of Atmospheric Sciences, Earth Sciences, Ocean Sciences, and the Office of Polar Program at NSF, as well as the Office of Global Programs at the National Oceanic and Atmospheric Administration (NOAA).

Over the years, ESH has served a growing community of researchers engaged in an energetic and evolving research effort with the goal of understanding natural variability in the Earth's system beyond the instrumental record and across geologic time, especially in terms of climate-related processes.

To achieve these goals, ESH emphasizes interdisciplinary and coupled research to understand the mechanisms, processes, and linkages between critical elements of the atmosphere, biosphere, cryosphere, hydrosphere, and terrestrial systems. Accordingly, the ESH program supports research in quantification and development of biotic, physical, and geochemical proxy indicators, geochronological techniques, and statistical analysis relevant to ESH goals. Furthermore, scientific questions in ESH are organized within six broadly defined Areas of Special Interest that include: (1) Paleoclimate Variability at Annual-Decadal Resolution; (2) Rapid Climate Change; (3) Extreme Warm Conditions; (4) Spatial Patterns and Continuous Records of Climate Change; (5) Arctic Paleoclimate Studies; and (6) Modeling of Past Climate Change. The current ESH Program announcement can be viewed on the NSF Web site at www.nsf.gov/pubs/2000/nsf0011.html.

Given the scientific community's interest in ESH, as evidenced by the growing number of research proposal submissions, it seems timely to consider the question: "Are the current ESH Areas of Special Interest relevant to emerging scientific research directions?" In an effort to ensure that ESH reflects the state of the art in science and addresses important scientific questions, your thoughts on the future intellectual focus of ESH research are requested. It would be most effective if you offered your evaluation of the current Areas of Special Interests and what scientific questions ESH might pursue in the future.

Please submit your comments by electronic mail to Jennifer Giesler (jgiesler@agu.org) in the ESH Secretariat at the American Geophysical Union by June 30, 2001. All verbatim comments will be collated, with full attribution, and presented to the ESH Steering Committee. The ESH Steering Committee will then analyze the comments and provide NSF with recommendations based on community input.

We thank you in advance for your help in shaping the future of scientific research in ESH.

David J. Verardo, *NSF Director of Paleoclimate*

Richard Poore, *NSF Director of Marine Geology & Geophysics*

Lisa J. Graumlich, *Chair of the ESH Steering Committee*

Grant Available

The American Chemical Society Petroleum Research Fund welcomes geoscience research proposals from academic institutions. The grants are for fundamental research that need not be directly connected to petroleum, but rather may provide a basis for subsequent research connected with the broad petroleum field. Funded subject areas have included stratigraphy, sedimentology, paleontology, hydrogeology, geomorphology, structural geology, tectonics, geophysics, and geochemistry (organic and inorganic). In recent years, success rates have been 30%–40%. For examples of recently funded projects, see www.acs.org/prf. For further information, contact Tom Blackburn, t_blackburn@acs.org.

E-mail Group for Sedimentologists

Now Online

David C. Kopaska-Merkel, head of the Ground Water Section at the Geological Survey of Alabama, announced the formation of sednet, an e-mail group for the discussion of sedimentology. Kopaska-Merkel said sednet can be used to ask and answer questions, as a forum for disseminating announcements or other news, or for discussing issues related to employment, publishing, data archiving, and anything else of interest to sedimentologists. To join, send a blank e-mail message to sednet-subscribe@eGroups.com. You'll be sent a confirmatory message. Reply to that message and you are a member. Or, visit www.eGroups.com, and look for sednet.

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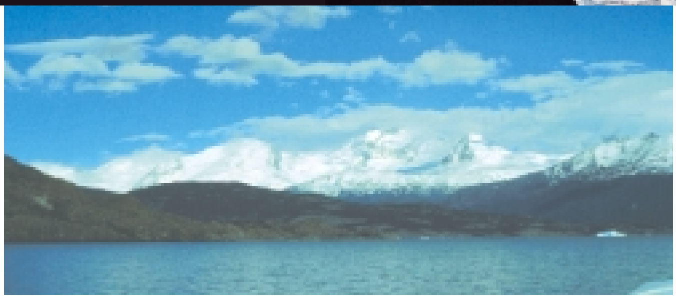
2001 GeoVentures



Lago Argentino. Photo by J. Reynolds.

GeoTrip

New Year's at the End of the World: The Geology of Southern Patagonia, Including Tierra del Fuego
Dec. 26, 2001–Jan. 10, 2002
15 days, 14 nights
Scientific leaders: James Reynolds, Brevard College, Brevard, North Carolina; Dorothy L. Stout, Cypress College, Cypress, California.

Jim Reynolds has spent the past 15 years investigating the uplift history of the Andes. Using magnetostratigraphy, Jim and his colleagues are developing a relatively precise chronostratigraphy across the many tectonic provinces that we will visit. In addition to his work at Magstrat, LLC, and Brevard College, he holds an adjunct position at the University of Pittsburgh.

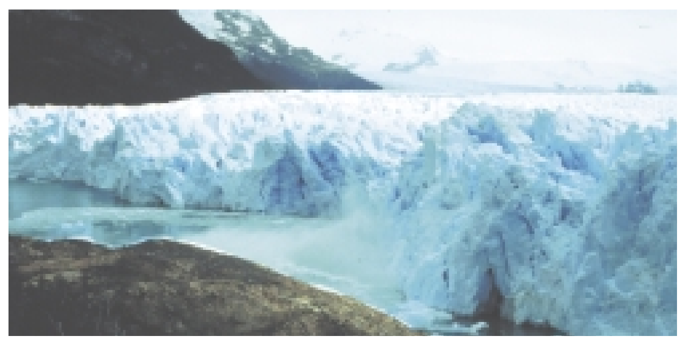
Since 1978, Dottie Stout has been leading geological expeditions around the world, including trips to China, South America, Africa, Europe, Indonesia, Australia, and Russia. Dottie is past president of the National Association of Geology Teachers and is temporarily on leave as a program director at the National Science Foundation.

Description

Our trip will start in Ushuaia, Argentina, the southernmost city in the world, at the base of the Cordillera Darwin on the Beagle Channel along the southern shore of Tierra del Fuego. The austral summer can be pleasant, but is seldom truly warm. We'll look at the glaciers, rocks, and the tectonic setting along the channel before we cross the mountains to the Patagonian steppes that comprise the northern part of the island. After crossing into Chile and taking the ferry across the Straits of Magellan to the South American mainland, we'll head eastward along the straits through the oil and gas fields to the penguin rookery near Punta Dungeness, Argentina. We'll observe the interplay between sea-level changes, glaciations, waves, currents, and extreme tidal ranges that shaped the coastline, while dodging the numerous rheas and guanacos on the plains. From there, we'll go to Río Gallegos and then to Glaciers National Park in the Patagonian Andes. We'll watch icebergs calve off of the Perito Moreno glacier into Lago Argentino, take a daylong boat trip on the lake, and slalom through the icebergs while Andean condors soar overhead. A low pass through the mountains will take us to Torres del Paine National Park in Chile to see the most spectacular mountains in the Andes. After a boat trip up the Ultima Esperanza fjord at Puerto Natales, we'll head to Punta Arenas and our flight home.

Fees and Payment

$4,200 for GSA members, $4,300 for nonmembers. A $300 deposit is due with your reservation and is refundable through Sept. 1, less a $50 processing fee. Total balance is due Sept. 1. Minimum: 20; maximum: 30. Included: Guidebook; airfare from Atlanta to Ushuaia via Buenos Aires; ground transportation; lodging for 13 nights (double occupancy); and meals for 14 days. Not included: Airfare to and from Atlanta, Georgia; and alcoholic beverages.



Perito Moreno glacier. Photo by J. Reynolds.

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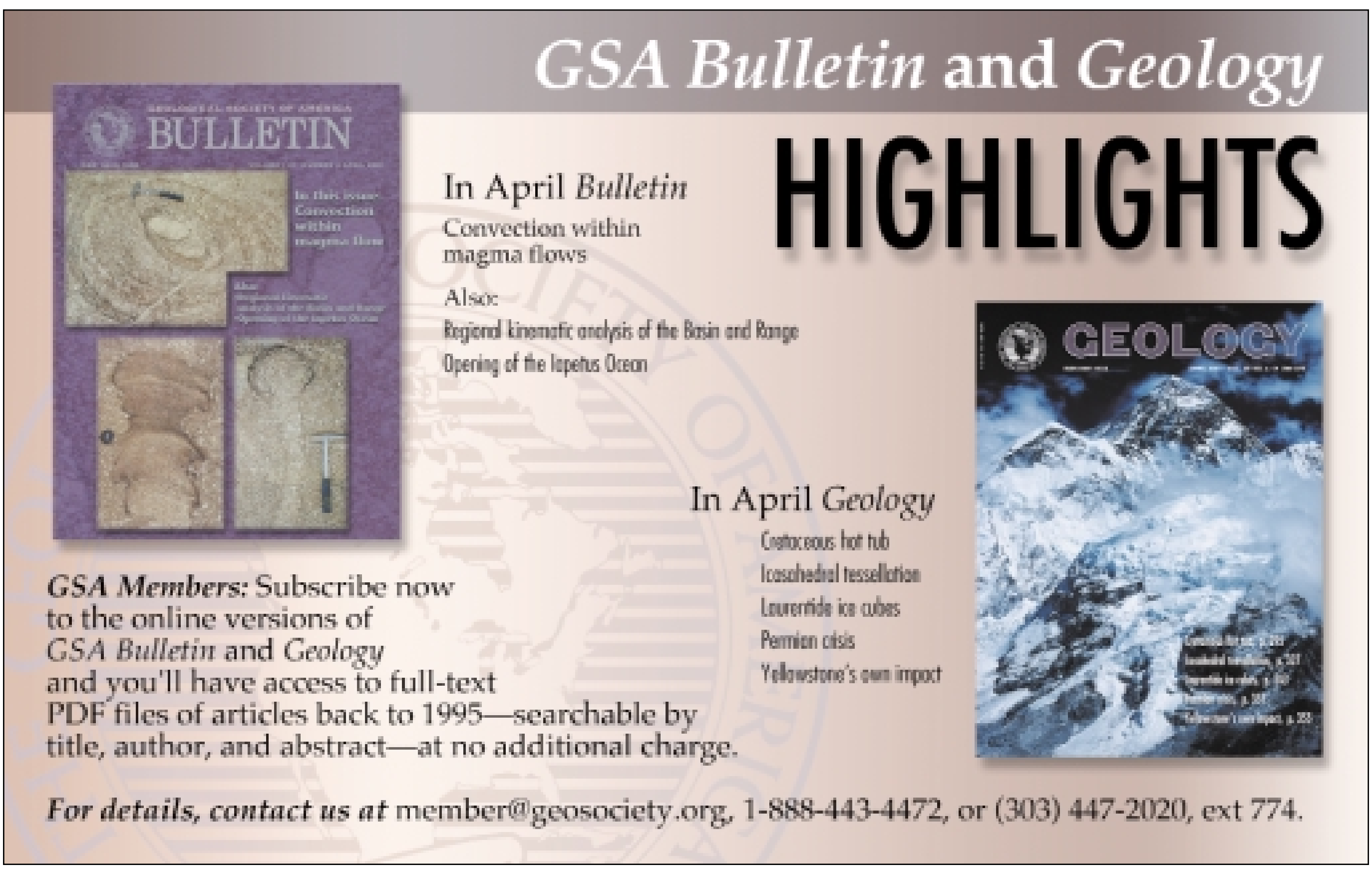

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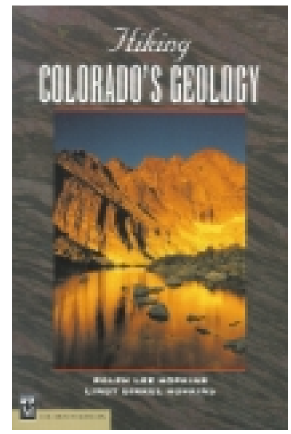

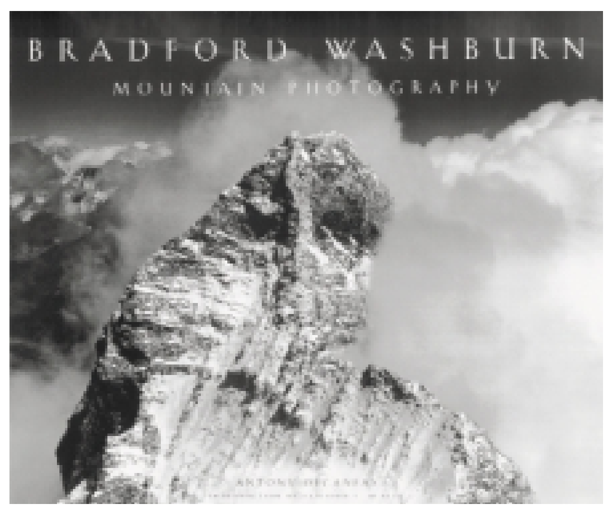

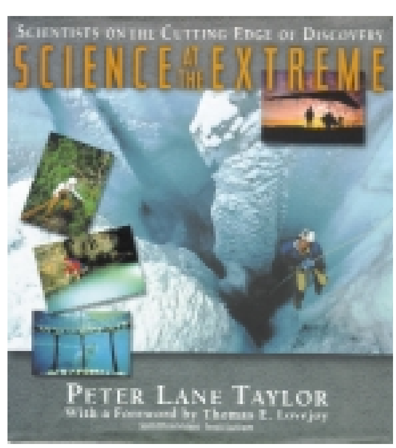

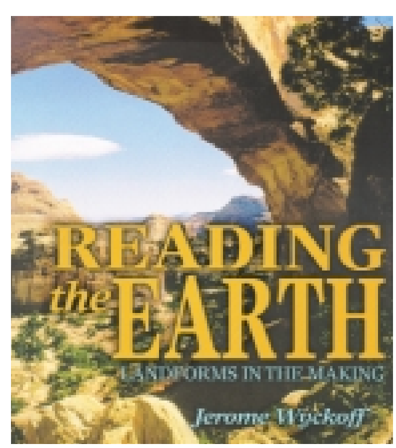

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Positions Open

U.S. GEOLOGICAL SURVEY MENDENHALL POSTDOCTORAL RESEARCH FELLOWSHIP PROGRAM

The U.S. Geological Survey (USGS) invites applications for the Mendenhall Postdoctoral Research Fellowship Program for fiscal year 2002. The Mendenhall Program is envisioned to bring current expertise in the earth sciences to assist in the implementation of the strategic plan of the USGS and the science strategy of its programs. It is also intended to provide postdoctoral fellows a research experience that enhances their personal scientific stature and credentials. Fiscal year 2002 begins in October 2001.

Opportunities for research are available in a wide range of areas, including: coastal erosion processes and modeling coastal change; interdisciplinary application of remote sensing; noble gas geochemistry; microbes and geologic substrates in estuaries; climate change, geologic processes, land use and land-surface feedbacks; estimating future strong ground motions; high-resolution imaging of earthquake rupture processes and fault structure; controls on magma ascent, stagnation, and eruption; economic modeling of geologic energy resources; and environmental biogeochemistry.

The postdoctoral fellowships are 2-year USGS appointments with full benefits and salaries. Applications are being accepted through May 18, 2001, with appointments starting between October 1, 2001, and April 1, 2002, depending on availability of funds. A complete description of the program, research opportunities, and the application process are available via the worldwide web at http://geology.usgs.gov/postdoc. Applicants must be U.S. citizens. The U.S. Geological Survey is an equal opportunity employer.

UNIVERSITY OF MINNESOTA—DULUTH

The Department of Geological Sciences at the University of Minnesota—Duluth invites applications for a temporary 9-month sabbatical replacement in geochemistry starting Sept. 1, 2001. The successful applicant will be expected to teach introductory classes in geochemistry, Earth's resources and/or oceanography as well as a graduate seminar in geochemistry. Essential qualifications are ABD with a minimum of two years research in the geosciences. We seek a versatile geoscientist who can collaborate with faculty and graduate students in the Dept. of Geological Sciences (http://www.d.umn.edu/geology) and the Large Lakes Observatory (http://www.d.umn.edu/llo).

Applicants should send a curriculum vitae, a statement of research and teaching interests, and the names, addresses, e-mail and telephone numbers of at least three references to: Dr. Penelope Morton, Search Committee Chair, Department of Geological Sciences, University of Minnesota—Duluth, 10 University Drive, Duluth, MN 55812

Applications will be accepted until the position is filled; however, review of complete applications will begin April 15, 2001.

The University of Minnesota is an equal opportunity educator and employer.

INVERTEBRATE FOSSIL PREPARATOR/COLLECTIONS AND RESEARCH ASSISTANT POSITION

The Department of Geology of The Field Museum has an immediate opening for an Invertebrate Fossil Preparator. Primary duties involve supporting two active research programs through fossil preparation, data collection, and assisting with the collection management of one of the top paleontology collections in the world. We are seeking someone experienced with preparation of macro and microfossils: specimen embedding, thin-sectioning, SEM, acid preparation, air abrasion and other techniques for physically removing invertebrate fossils from the matrix. The successful candidate should be adept in communicating with scientists, educators and the general public. A B.A. with training in invertebrate paleontology and familiarity with databases is desired. To apply, please send your CV with names of three references who are familiar with your work to: Dr. Peter Wagner, Dept. of Geology, The Field Museum, 1400 S. Lake Shore Dr., Chicago, IL 60605. For further information, phone (312) 665-7625 or e-mail: lidgard@fmnh.org. EOE M/F/D/V.

SIMON FRASER UNIVERSITY DEPARTMENT OF EARTH SCIENCES LECTURER IN GEOLOGY

The Department of Earth Sciences at Simon Fraser University invites applications for a lecturership in geology commencing September 1, 2001. This is a teaching (non-research) appointment and the successful candidate will be an excellent teacher in lecture, seminar, and field-school modes of instruction. An M.Sc. in geology is required and a doctorate is desirable. The lecturer will be required to teach a varied subset of first and second-year introductory undergraduate courses including, but not limited to, physical geology, historical geology, paleontology, mineralogy and petrology and possibly one or more senior courses in the candidates particular area of expertise.

For additional information about this position, see http://www.sfu.ca/earth-sciences/lecturer.htm.

In accordance with Canadian Immigration requirements, this advertisement is directed to Canadian citizens and permanent residents. Simon Fraser University is committed to the principle of equity in employment and offers equal employment opportunities to qualified applicants. The position is subject to budgetary approval.

Applicants are requested to submit a curriculum vitae with particular emphasis on teaching experience and performance, and the names and addresses of three referees. Applications or requests for further information should be directed to: Dr. E.J. Hickin, Chair, Department of Earth Sciences, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6; phone: 604-291-4657; fax: 604-291-4198; e-mail: hickin@sfu.ca.

The closing date for applications is April 30, 2001.

POST-DOCTORAL RESEARCH HYDROLOGIST OR SOIL SCIENTIST

The USDA Forest Service, Southern Research Station, Center for Forested Wetlands Research, is seeking applicants for a temporary, postdoctoral Research Hydrologist or Soil Scientist (GS-12) to implement and manage a phytoremediation research program on the Savannah River Site, S.C. The individual selected for this position will develop scientific and technical approaches for the remediation of tritium from groundwater plumes using vegetation-based strategies. A large-scale (27 ac.) forested irrigation site has been established with the intent of transferring tritium to the atmosphere through evapo-transpiration. Efforts to quantify and predict the tritiated water balance with respect to soils, vegetation, evaporative energy, and irrigation cycles shall be developed by the candidate. The selected individual will have primary responsibility for project management; operational maintenance of an irrigation system; measurement, and sampling of hydrologic, meteorological, contaminant, and vegetation variables; developing and improving water balance models; reporting results; and interfacing with a team of managers and scientists. For further details and information on how to apply please contact: Chris Barton, Ph.D.; phone: (803) 725-8157; e-mail: barton@srel.edu. Applicant must be a U.S. citizen.

PROGRAM MANAGER, EARTH SCIENCE EDUCATION AMERICAN GEOLOGICAL INSTITUTE

The American Geological Institute (AGI) invites applicants for the position of Program Manager, Earth Science Education. Candidates must have a degree in the geosciences and must have exceptional presentation and communication skills. A doctoral degree is preferred but master candidates with appropriate experience will be considered. Classroom teaching experience is a plus.

The position provides an unparalleled opportunity for an Earth science professional committed to advancing the status of science education in the nation's schools. The successful candidate will manage and directly contribute to a variety of AGI's K–16 geoscience ongoing projects at AGI national headquarters in Alexandria, Virginia. He/she will interact on a day-to-day basis with project investigators, directors of state and national education programs, professional societies, and corporations. He/she will report directly to the AGI director of education and will work closely with the director in identifying and developing new programs and funding support to enhance K–16 education initiatives.

Applicants should send a letter of interest with salary expectations, vita, and names/address of three references to the AGI Education Search Committee, American Geological Institute, 4220 King Street, Alexandria, VA 22302-1502 (fax: 703-379-7563). Appointment is anticipated no later than June 2001. Applications will be accepted until the position is filled. For more information about AGI, its programs and activities, visit our Web site at http://www.agiweb.org/. AA/EOE.

GEOBIOLOGY—PENN STATE

The Department of Geosciences at Penn State invites applications for a tenure-track faculty position in geobiology emphasizing organism-environment interactions. We seek an individual with broad training in geosciences and/or biosciences who will complement our existing strengths in geobiology, Earth system history and biogeochemistry. Candidates' interests in organism-environment interactions may include, but are not limited to, vertebrate paleontology, invertebrate paleontology, paleobotany, micropaleontology, biodiversity dynamics, paleoecology, paleoceanography, and paleoclimatology. Strong quantitative skills and interdisciplinary training are desirable. This position is part of an intercollege hiring initiative on organism-environment interactions jointly funded by the Penn State Environmental Consortium and the Department of Geosciences.

We will fill the position at the assistant professor or early associate professor level. Applicants should demonstrate potential for developing a vigorous research program and high-quality teaching at both the graduate and undergraduate levels. Review of applications will begin immediately and will continue until the position is filled. Interested candidates should submit the following application materials: a complete vita, a statement outlining teaching and research interests, examples of published work, and the names and addresses of at least four (4) references. Send application materials to: Head, Department of Geosciences, 503 Deike Building, The Pennsylvania State University, University Park, PA 16802.

Penn State is committed to affirmative action, equal opportunity, and the diversity of its workforce. For more information on the Department of Geosciences, go to http://www.geosc.psu.edu.

Services and Supplies

RECENT, RARE, AND OUT-OF-PRINT BOOKS. Find our online catalog at http://home.earthlink.net/~msbooks for books on geology, mining history, ore deposits, U.S. Geological Survey, and western Americana; e-mail: msbooks@earthlink.net. For free printed catalogs, send your request and area(s) of interest to MS Book and Mineral Company, P.O. Box 6774, Lake Charles, LA 70606-6774.

Opportunities for Students

Research and Teaching Assistantships at Temple University: Research and teaching assistantships are available for the Fall term (September 2001) in our Masters Program in Geology at Temple University. The 2-year Masters Program offers advanced courses and thesis research opportunities in environmental geology, hydrogeology, geochemistry, environmental geophysics, cyclic stratigraphy, soil science/paleosols, K-T boundary studies, and materials science. Financial support for every student includes stipend, book allowance and full tuition for 2 years. Research assistantships and summer support are available for studies in cyclic stratigraphy of Cretaceous rocks in Dorset, England, and the French Jura; in Cenozoic paleosols, vertebrate taphonomy, and paleoenvironments in Badlands National Park, South Dakota, in development of a ZrO_2-based high-temperature pH electrode, and environmental geophysics. Graduates of our program have an excellent record of employment and acceptance into doctoral programs. For information and applications please write, call, or e-mail Edwin J. Anderson, Department of Geology, Temple University, Philadelphia, PA 19122 (Tel. (215) 204-8249, Fax (215) 204-3496, e-mail andy@astro.temple.edu). Applications will be accepted until these positions are filled. Please visit our web site at http://www.temple.edu/geology for additional information.

Evolution of the North Carolina Coastal System, Opportunities for Graduate Research. The modern coastal environments of North Carolina are strongly influenced by the underlying Quaternary geologic framework. A team of researchers at East Carolina University is commencing a planned multiyear project in collaboration with state and federal agencies to understand this relationship between ancient environments and modern processes. Objectives of the project include defining barrier island and estuarine origin and evolution, the coastal record of sea-level and climate change, geologic controls on coastal and estuarine erosion, storm impacts, water quality and resources, and sand resources. Contact Stan Riggs at riggss@mail.ecu.edu, Reide Corbett at corbettd@mail.ecu.edu, Dave Mallinson at mallinsond@mail.ecu.edu, or Steve Culver at culverss@mail.ecu.edu for further information on the project. Contact Terri Woods at woodst@mail.ecu.edu for application information to the master's program in the Department of Geology, East Carolina University, Greenville, NC 27858. Contact Steve Culver if you are interested in pursuing a Ph.D. through ECU's Coastal Resource Management Program (Director, Dr. Lauriston King, kingl@mail.ecu.edu).

Graduate Study in Marine Sedimentology. The LSU Department of Oceanography and Coastal Sciences is seeking applicants for graduate study in marine sedimentology. Potential research topics include sedimentology of modern deltas, radioisotope geochronology of recent deposits, and impacts of combined event sedimentation and bioturbation on the sediment record. We are seeking highly qualified individuals with demonstrated capacity for independent work. Students seeking either the Ph.D. or M.S./Ph.D. in geological oceanography should apply by completing and submitting the graduate program preapplication (found at http://www.oceanography.lsu.edu/application.html) for a start date as soon as May 2001. For questions or to request a mailed preapplication, contact Dr. Sam Bentley, sjb@lsu.edu, (225) 388-2954, Coastal Studies Institute and Department of Oceanography and Coastal Sciences, Howe-Russell Geosciences Complex, Louisiana State University, Baton Rouge Louisiana, 70803, USA.

Graduate Student Research Grants, The Society for Organic Petrology (TSOP). TSOP invites applications for two graduate student research grants of up to $1,000 each. The purpose of the grants is to foster research in organic petrology (which includes coal petrology, kerogen petrology, organic geochemistry and related disciplines) by providing support to graduate students who demonstrate the utility and significance of organic petrology in solving the thesis problem.

The TSOP Student Grants Program supports qualified graduate students from around the world who are actively seeking advanced degrees. Preference is given to full-time students in master's (or equivalent) degree programs but applications are also encouraged from Ph.D. candidates and part-time graduate students. Monetary awards are to be applied to expenses directly related to the student's thesis work, such as summer fieldwork, laboratory analyses, etc. A portion (not to exceed 25%) of the award funds may be used to attend a TSOP Annual Meeting.

Grant application deadline is May 15, 2001. Grants will be awarded in September 2001. Detailed information and an application form are available on the TSOP Web page: http://www.tsop.org, or from S. J. Russell, Shell E & P Technology Co., Bellaire Technology Center, 3737 Bellaire Blvd., Houston, TX 77025, USA; tel: +1-713-245-7603; fax: +1-713-245-7599, or e-mail: srussell@shellus.com.