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INSIDE

Continental Growth, Preservation, and Modification in Southern Africa

R. W. Carlson, F. R. Boyd, S. B. Shirey, P. E. Janney, *Carnegie Institution of Washington, 5241 Broad Branch Road, N.W., Washington, D.C. 20015, USA, carlson@dtm.ciw.edu*
T. L. Grove, S. A. Bowring, M. D. Schmitz, J. C. Dann, *Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
D. R. Bell, J. J. Gurney, S. H. Richardson, M. Tredoux, A. H. Menzies, *Department of Geological Sciences, University of Cape Town, Rondebosch 7700, South Africa*
D. G. Pearson, *Department of Geological Sciences, Durham University, South Road, Durham, DH1 3LE, UK*
R. J. Hart, *Schonland Research Center, University of Witwatersrand, P.O. Box 3, Wits 2050, South Africa*
A. H. Wilson, *Department of Geology, University of Natal, Durban, South Africa*
D. Moser, *Geology and Geophysics Department, University of Utah, Salt Lake City, UT 84112-0111, USA*

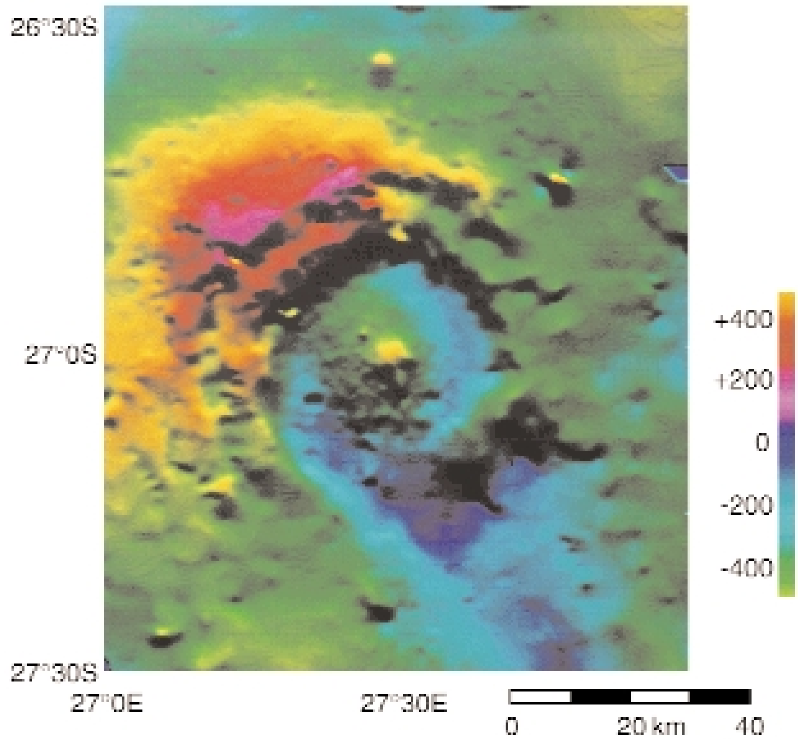

Figure 2. Bouguer gravity image (courtesy of South African Council for Geosciences) across Vredefort impact structure, South Africa. Color scale is in relative units representing total gravity variation of 90 mgal across area of figure. Yellow circular pattern close to geometric center reflects local gravity high that suggests that the core of the structure is underlain by dense mafic or ultramafic rock. Borehole located close to peak of gravity anomaly indicates that rocks beneath surface consist mainly of peridotite.

ABSTRACT

To understand the origin, modification, and preservation of continents on Earth, a multidisciplinary study is examining the crust and upper mantle of southern Africa. Xenoliths of the mantle brought to the surface by kimberlites show that the mantle beneath the Archean Kaapvaal craton is mostly melt-depleted peridotite with melt extraction accompanying crust formation in the Archean. Eclogitic xenoliths from the craton record subduction of altered oceanic crust beneath the craton at ca. 3 Ga. Proterozoic age peridotite found beneath the surrounding Proterozoic accretionary belts provides evidence for crust-mantle coupling and long-term stability of the upper 150 km of the lithosphere. Petrologic examination of Archean ultramafic magmas (komatiites) from South Africa indicates that some komatiitic magmas contain substantial quantities of water (>4 wt%). This finding strengthens the possibility that the cratonic lithosphere formed initially in a subduction zone setting, the demise of which led to accretion of the arc crust and thickening of the lithospheric mantle to create a stable, thick, continental lithosphere. Geochronologic studies of lower crustal xenoliths from the craton show a prolonged thermal evolution of the lower crust extending to 1 Ga. This thermal evolution is also reflected in ca. 1 Ga ages of some eclogitic diamond inclusions from the lithospheric mantle.

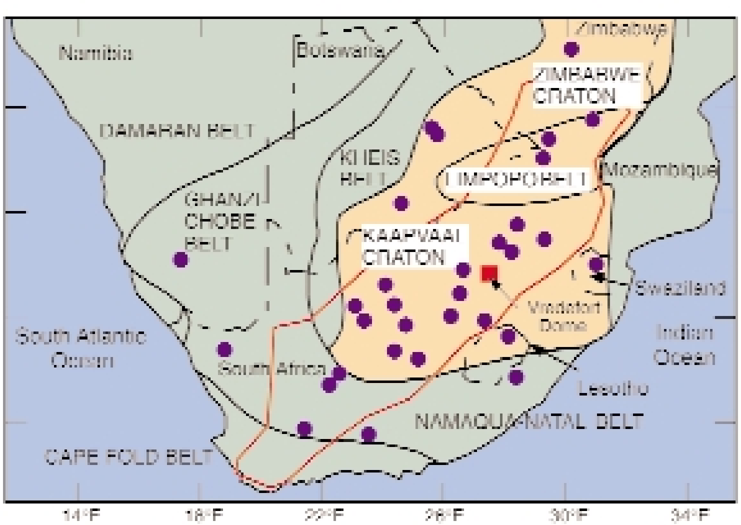

Figure 1. Geologic sketch map of southern Africa. Brown indicates areas underlain by Archean basement; green indicates Proterozoic metamorphic belts; blue dots indicate major kimberlites (Gurney et al., 1991); red square marks Vredefort impact structure. Portable, broad-band seismometer deployment covers area outlined in red.

INTRODUCTION

To explore the causes of continent formation and preservation, a multidisciplinary study involving geology, geochemistry, geochronology, petrology, and

Continental Growth *continued on p. 2*

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IN THIS ISSUE

CORRECTION: Cordilleran Section Field Trips 8 and 9

Field trip 8 for the Cordilleran Section meeting has NOT been canceled, contrary to what appears on page 31 of January 2000 *GSA Today.* Trip 8, Tertiary Geology of the Eastern Flank of the Central Cascade Range, Washington, is still on the schedule and should not be crossed out on the preregistration form.

Field trip 9, Quesnel Terrane—Always There?, IS canceled, and should be crossed out on the preregistration form.

Continental Growth *continued from p. 1*

seismology was initiated 3 years ago with support from the National Science Foundation Continental Dynamics Program. The study focuses on the current structure and geologic history of southern Africa. A general description of the project and list of participants can be found at www.ciw.edu/mantle/kaapvaal/. The centerpiece of the study is an array of 55 portable broadband seismometers placed in 82 sites along a rectangular array from Cape Town to Zimbabwe (Fig. 1; Carlson et al., 1996; James et al., 1999). This report summarizes early results from the geochemical, geochronologic, and petrologic components of the Kaapvaal Craton Project.

Southern Africa provides an excellent field laboratory to study the history of ancient continents. The region (Fig. 1) comprises the Archean Kaapvaal and Zimbabwe cratons, separated by a late Archean metamorphic terrane, the Limpopo Belt (Tankard et al., 1982). Overall, the Kaapvaal craton is made up of a number of granite-greenstone terranes with distinctive igneous rocks, deformation histories, and tectonic styles that were welded together to form the core of the continent (de Wit et al., 1992). Surrounding the cratons are accretionary belts added in the middle to late Proterozoic. Of particular interest, the southern African lithosphere has been penetrated by hundreds of kimberlite diatremes (Fig. 1) that have brought xenoliths of lower crust and upper mantle to the surface (Gurney et al., 1991).

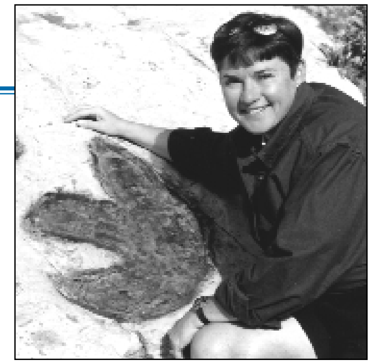
CRUSTAL GROWTH AND MODIFICATION

Whereas the geology of the shallow crust of the Kaapvaal craton is relatively well known, the deeper crust is not well exposed. One exception is the large circular Vredefort structure in the middle of the Kaapvaal craton (Fig. 2). It is widely regarded as a deeply eroded remnant of a 2.02 Ga impact crater (Kamo et al., 1996; Moser, 1997). Hart et al. (1990) suggested that the impact turned the crust on its side so that traversing from rim to center leads one from near-surface sediments through mid-crustal granite to granulite grade supracrustal rocks. At the center of the impact structure is a large positive gravity anomaly (Fig. 2) that has been drilled and found to consist predominantly of peridotite. Re-Os systematics of this peridotite are similar to those of the kimberlite-borne xenoliths from the Kaapvaal lithospheric mantle that have very low Re/Os and $^{187}Os/^{188}Os$ ratios, and Re-depletion model ages of 3.3 to 3.5 Ga (Tredoux et al.,

Contintental Growth *continued on p. 3*

Dialogue

Sara Foland, CEO



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At Dinosaur Ridge near Morrison, Colorado.

Quantifying the Science of Geology

> Geology is ... the study of Earth and other planets and planetary objects using any and all available techniques; it includes geochemistry and geophysics.
>
> *—GSA Council, 1989*

The January 2000 Dialogue discussed geology as an art form, in the context of our ability (or lack thereof) to define all the parameters from observation in this grand experiment we call Earth. The November 1999 column talked about how GSA is fostering integrative solutions to the complex geoscience problems that challenge us today. This month, we define our Society's role as facilitator for members and their colleagues to discuss and debate the science of geology.

GSA's Strategic Planning Group took the key elements from the 1989 definition of geology and incorporated them into the following vision:

The Geological Society of America is a broad, unifying scientific society:

- Fostering the human quest for understanding Earth, planets, and life;
- Catalyzing new scientific ways of thinking about natural systems;
- Applying geoscience knowledge and insight to human needs and stewardship of the Earth.

This vision sets forth our charge as members of GSA and of society as a whole. From these statements, we also derive our values—science, stewardship, and service. In support of our vision and values, GSA, with its Divisions and Associated Societies, provides members with various venues to carry on open scientific debate. These venues are publications, meetings at the national and regional level, and various philanthropic programs for students and society.

Publications

We publish a variety of journals and books on a wide range of geoscience topics. In 1999, we published twelve Special Papers on subjects from faults in the northern Appalachians to the geomorphology of the Himalayas. *Geology* and the *Geological Society of America Bulletin* contained 451 articles (329 in *Geology;* 122 in *Bulletin*) in 3,072 pages. Our journals continue to be among the most frequently cited geoscience references, ranking as two of the top five geoscience journals in the Science Citation Index. Additionally, *Geology* and the *Bulletin* are well regarded as two of the most rigorously peer-reviewed publications. One map was produced in 1999, and work is being completed on the final Decade of North American Geology (DNAG) map (the Geological Map of North America). In response to many requests, we began a new field guide series that gathers in one volume all the supporting information for field trips held at the GSA Annual Meeting. *Geology* and the *Bulletin* are now available in PDF format on-line (www.geosociety.org). As we enhance the presentation with links and searchable archives, we will offer subscriptions to institutions and individuals. A feasibility study is underway to evaluate archiving past issues of our current journals and the lead science article from *GSA Today.*

Meetings

Each year GSA holds one national meeting and six regional Section meetings. The 1999 Annual Meeting in Denver had the largest number of submitted abstracts—2,942—ever. More than 108 technical and Pardee sessions covered topics as diverse as the subject of geology itself. Of the 6,389 registrants, 1,701 were students. The global nature of our science and our Society is indicated in the 465 attendees from foreign countries. Richard Kerr (*Science,* November 12, 1999, v. 286, p. 1279–1281) highlighted our meeting and noted that topics ranged from asteroids of today to the various geochronological techniques used to date critical moments in geological time. His review article exemplifies the topical diversity that our members and associates present from their research. The 2000 Section meetings, which begin in March, will provide students an opportunity to present their work in smaller, less intimidating venues.

Philanthropic Programs

The GSA Foundation and our members support 69 science, education, and outreach programs. Of these, student research grants, a program begun in 1933, provide the most direct and immediate support of geoscience. In 1999, GSA, in partnership with the National Science Foundation, supported 212 research projects (averaging $1,865 per grant; to date, GSA has given 6,555 research grants totaling $6,820,341 to students). Whether for an additional geochemical analysis, a few more days in the field, or travel to a meeting to share results, grants to students continue to be supported by GSA and its members. Toward our goal to promote integrative approaches to understanding natural systems, we are working with partners to establish a grants program for teams of graduate student researchers, representing earth, life, planetary, and/or social scientists and economists.

GSA, its Divisions, and our Associated Societies continue to provide members with forums for active debate. Although the formats for these forums may change over the next several years, the need for the most timely and highest quality opportunities for scientific debates will continue to grow.

Continental Growth *continued from p. 2*

1999). These data suggest that the deep crust–mantle transition is exposed in the Vredefort section.

Besides abundant mantle xenoliths, many southern African kimberlites contain excellent suites of lower crustal xenoliths. High-resolution U-Pb accessory-mineral geochronology of these lower crustal xenoliths furthers our understanding of the interrelationships between the surficial geologic record and nascent mantle geochronology. Sapphirine granulite xenoliths in the Lace, Voorspoed, and Star kimberlites, a southwest-trending alignment of kimberlites between the Vredefort structure and the city of Bloemfontein in the central craton, preserve evidence for a dramatic transient thermal pulse in the deep crust of the Kaapvaal craton. Thermobarometry of these garnet-quartz-sapphirine assemblages indicate extreme peak temperatures of >1100 °C at pressures from 1.0 to 1.5 GPa (Dawson et al., 1997). Zircon and monazite from these xenoliths give identical U-Pb dates of 2723 Ma, which are interpreted as dating early cooling and metamorphic zircon growth from the ultrahigh temperature metamorphism (Schmitz et al., 1998). This 2723 Ma episode of ultrahigh temperature metamorphism in the intracratonic lower crust appears to be synchronous with the initiation of Ventersdorp flood basalt volcanism (Armstrong et al., 1991).

In contrast to the Late Archean ages of central craton granulite xenoliths, the abundant garnet-bearing granulite and upper amphibolite facies xenoliths from the Markt kimberlite, at the southwestern edge of the craton, yield Mesoproterozoic metamorphic zircon U-Pb dates ranging from 1114 to 1092 Ma (Schmitz and Bowring, 1999). Similarly, metamorphic zircon and monazite in felsic to mafic granulite xenoliths from the northern

Continental Growth *continued on p. 4*

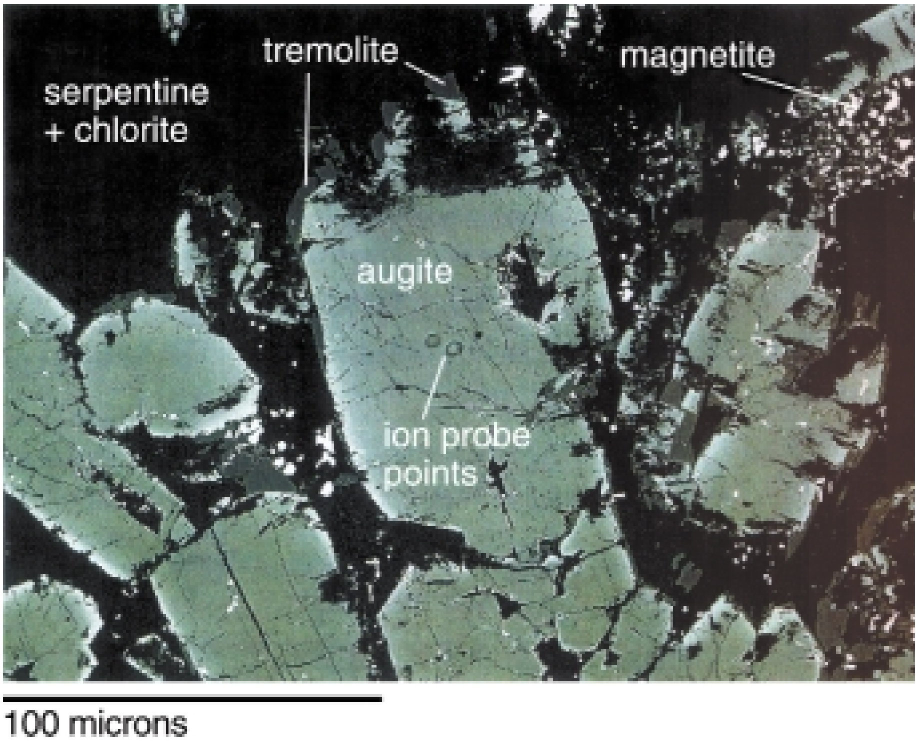

Figure 3. Backscattered electron image of minerals in a metamorphosed Barberton komatiite. Light gray, tabular minerals are preserved high-Ca igneous augitic pyroxenes. Pyroxene grains display change in contrast from dark in center to light at edges. Contrast shows igneous zoning from magnesian core to iron-enriched rim. Metamorphic amphibole (tremolite) surrounds pyroxene. Dark areas represent metamorphosed groundmass consisting of serpentine, chlorite, and magnetite. Sample is B95-7 from Parman et al. (1997). Ion microprobe pits are from measurements of rare earth elements (Parman et al., 1996).

Continental Growth *continued from p. 3*

Lesotho kimberlites, along the southern edge of the craton, have been dated at 1050–1000 Ma (Schmitz and Bowring, 2000). The new geochronology confirms that the lower parts of the thickened crust along the southern and eastern edge of the craton were modified in the Mesoproterozoic and indicates that the cratonic crust experienced a dynamic metamorphic history that significantly postdates the ostensible time of cratonization around 3.0 Ga.

TECTONIC SETTING OF CONTINENT FORMATION

Archean greenstone belts contain komatiite, an igneous rock that has an unusually high MgO content (22%–25%) compared to any volcanic rock observed today. Detailed mapping, geochemical, and petrographic study of komatiites in their type locality in the Komati formation in the Barberton Mountains, South Africa, provides several new clues to the origin and possible tectonic setting of formation of this magma type (Grove et al., 1996b). Some of the southern African komatiites retain part of their original igneous mineralogy (Fig. 3). The freshest Barberton komatiites have igneous olivine and/or pyroxene whose compositions are consistent with these komatiites preserving magmatic compositions (Parman et al., 1997). In addition, the mapping effort has led to the suggestion that some of the Komati units represent sills rather than flows (Grove et al., 1996b). In some of these sills, the composition of preserved igneous pyroxenes (Fig. 3) indicates that the magmas contained over 4 wt% water (Parman et al., 1997).

Wet primary komatiite magma is further supported by the appearance of spinifex crystallization textures as dissolved water in magma lowers nucleation rate and increases crystal growth rate, leading to the formation of the elongate, skeletal, olivine, and pyroxene crystals that typify the spinifex texture (Grove et al., 1996a). High water contents in primary komatiitic magmas could either imply substantially higher water content in the Archean mantle, or that the southern African komatiites formed in a convergent margin setting, the water being provided to the mantle source by dewatering of the subducted plate. In the latter case, the more Mg-rich nature of the komatiites compared to modern arc basalts could simply reflect hotter mantle temperatures, leading to higher degrees of melting in the Archean.

Supporting evidence for a convergent margin setting for komatiitic volcanism in the Kaapvaal craton comes from the Nondweni greenstone belt found ~200 km south of Barberton (Wilson and Versfeld, 1994a). The Nondweni sequence consists predominantly of mafic and ultramafic lavas with felsic volcanic rocks in a structurally intermediate unit (Wilson and Versfeld, 1994b). Compared to the Barberton komatiites, the Nondweni komatiites have relatively low MgO contents (<21 wt%) and higher silica contents (>50 wt%) and display pyroxene, rather than olivine, spinifex flows. Initial Nd isotopic compositions of the mafic and ultramafic lavas vary with lava composition in a manner that suggests progressive contamination of the differentiating lavas by felsic crust ~3.5 b.y. old, like that now found just to the north (Wilson and Carlson, 1989). This result indicates that the Nondweni sequence formed in proximity to the preexisting Kaapvaal craton, not in an intraoceanic setting.

Additional evidence for the importance of subduction in continent formation comes from eclogite xenoliths in oncraton kimberlites. Many eclogite xenoliths have oxygen isotopic compositions outside the normal range for mantle derived rocks (MacGregor and Manton, 1986; Shirey et al., 1999a), suggesting that some eclogite xenoliths represent the high-pressure equivalent of subducted ocean floor basalt. The correlation of Re abundance with oxygen isotopic composition in these xenoliths suggests that their Re-Os system was affected by hydrothermal alteration on the Archean seafloor (Shirey et al., 1999a). Curiously, all diamond-bearing eclogites from the Roberts Victor kimberlite analyzed so far have oxygen isotopic compositions overlapping mantle values. Also, diamond-bearing eclogites from the Roberts Victor and Newlands (Menzies et al., 1999) kimberlites show limited scatter about a 3 Ga Re-Os reference isochron, whereas diamond-free samples show considerable scatter on an isochron plot of Re-Os (Shirey et al., 1999a). These results may suggest that seafloor alteration oxidizes the oceanic crust sufficiently to retard diamond growth upon its subduction. Alternatively, the highly disturbed Re-Os systematics of diamond-free eclogites may indicate that diamond is lost from previously diamond-bearing eclogite by metasomatism and/or partial melting in the mantle (Shirey et al., 1999a).

The Archean age for diamond-bearing eclogites contrasts with Proterozoic ages for eclogitic diamond crystallization observed at several other kimberlite localities (Finsch, Orapa, Jwaneng, and Premier). These ages were based on the Sm-Nd isochron relationships between garnet and clinopyroxene inclusions (Richardson et al., 1999). Re-Os study of individual sulfide grains in diamonds from Orapa shows two age groups, one near the ca. 1 Ga age obtained for silicate inclusions and another giving a Re-Os isochron age near 3 Ga (Shirey et al., 1999b). These results clearly indicate more than one generation of eclogitic diamond growth in the Kaapvaal craton and suggest that subduction of oceanic crust, to depths within the diamond stability field, was occurring during formation of both the craton in the Archean and the surrounding accretionary belts in the Proterozoic.

MANTLE ROOT

As is typical of Archean cratons, preliminary seismic results from the Kaapvaal project (James et al., 1999) show that the Kaapvaal and Zimbabwe cratons are underlain by a thick, seismically fast "root" that extends to depths of at least 200–250 km. Samples of the upper 200 km of this root, brought to the surface by kimberlites, are predominantly peridotite that is highly depleted in those major elements (Ca, Al, Fe) that partition into melts (Boyd and Mertzman, 1987). Low Fe and low abundance of garnet resulting from less Al in the restitic peridotite (Boyd and McCallister, 1976) causes this residual peridotite to be less dense than fertile mantle at the same temperature. These characteristics gave rise to the idea of the "tectosphere" (Jordan, 1988) beneath cratons, consisting of a chemical boundary layer of melt-depleted peridotite that adds buoyancy and long-term stability to the overlying crust.

The antiquity of these mantle roots was first indicated by ancient (>2 Ga) ages for silicate and sulfide inclusions in diamonds (Kramers, 1979; Richardson et al., 1984). Re-Os dating of individual diamond sulfide inclusions confirms an Archean age for some diamonds (Pearson et al., 1998b; Shirey et al., 1999b). Other diamonds have sulfide inclusions with Re-Os ages ranging from mid-Proterozoic to Mesozoic (Pearson et al., 1998b; Shirey et al., 1999b). Thus, diamond growth in the lithospheric mantle was not restricted to the Archean, in accord with earlier results for silicate inclusions (Richardson et al., 1993), but appears to have occurred episodically, perhaps in association with subduction and/or magmatic underplating beneath the craton.

Walker et al. (1989) showed that Re-Os isotope systematics of whole rock peridotites track and potentially date the melt-depletion events important to lithosphere formation. In southern Africa, most peridotite xenoliths extracted from on-craton kimberlites give Archean Re-depletion model ages (Fig. 4), and show no clear trend in age versus depth of origin, at least to depths of 180–200 km (Walker et al., 1989; Pearson et al., 1995; Carlson et al., 1999). Thus, most of the upper 180–200 km of the Kaapvaal craton mantle root formed in the Archean and has been attached to the overlying crust since that time. This also is true of the mantle beneath the Limpopo belt, as indicated by Archean ages for xenoliths from the Venetia kimberlite, but not for the area beneath the 2.05 Ga Bushveld igneous complex (Eales and Cawthorn, 1996). Many of the mantle xenoliths from the Premier kimberlite, which penetrated the Bushveld complex, give ca. 2 Ga ages suggesting substantial modification of the mantle during intrusion of the Bushveld (Carlson et al., 1999).

The most obvious age differences in the mantle beneath southern Africa are seen in peridotite xenoliths from on- and off-craton (Fig. 4). Whereas the majority of xenoliths in on-craton kimberlites give Re-depletion model ages in excess of 2.5 Ga, all but one peridotite from off-craton kimberlites give model ages <2.4 Ga (Pearson et al., 1998a; Janney et al., 1999). These model ages overlap the oldest Nd and Pb model ages for the Proterozoic crust south and west of the craton. The rough correspondence between crustal and mantle lithosphere ages in the off-craton xenoliths show that thick lithospheric keels are not unique to Archean cratons but also can be formed, and remain attached, beneath Proterozoic continental crust.

BENEATH THE ROOT?

The crystallization products of melts derived from deep in the lithosphere, or perhaps beneath the lithosphere, are widely believed to be represented by the Cr-poor megacryst suite commonly found in kimberlites (Gurney and Harte, 1980). The depth of megacryst crystallization varies across the craton into the surrounding mobile belts (MacGregor, 1975), and is reflected in the composition of megacrysts (Boyd and Nixon, 1980). Preliminary results from a new regional survey of megacryst compositions indicate a close correspondence to craton boundaries and significant variability within the craton. These variations correlate spatially with seismic velocity variations.

Megacrysts that precipitated before significant interaction with lithospheric mantle occurred can be used to fingerprint the compositional characteristics of the mantle at deep levels within, and perhaps below, the depleted root. Two isotopically and temporally distinct varieties of kimberlite, groups I and II of Smith (1983), contain megacryst suites with distinct major and trace element (Bell et al., 1995a, 1995b), radiogenic isotope (Smith et al., 1995), and $\delta^{18}O$ (Schulze et al., 1998) compositions. Rare examples of isotopically intermediate kimberlites host megacrysts of correspondingly intermediate and mixed attributes (Bell, 1997; Bell and Mofokeng, 1998). The Sr, Nd, and Pb iso-

Continental Growth *continued on p. 6*

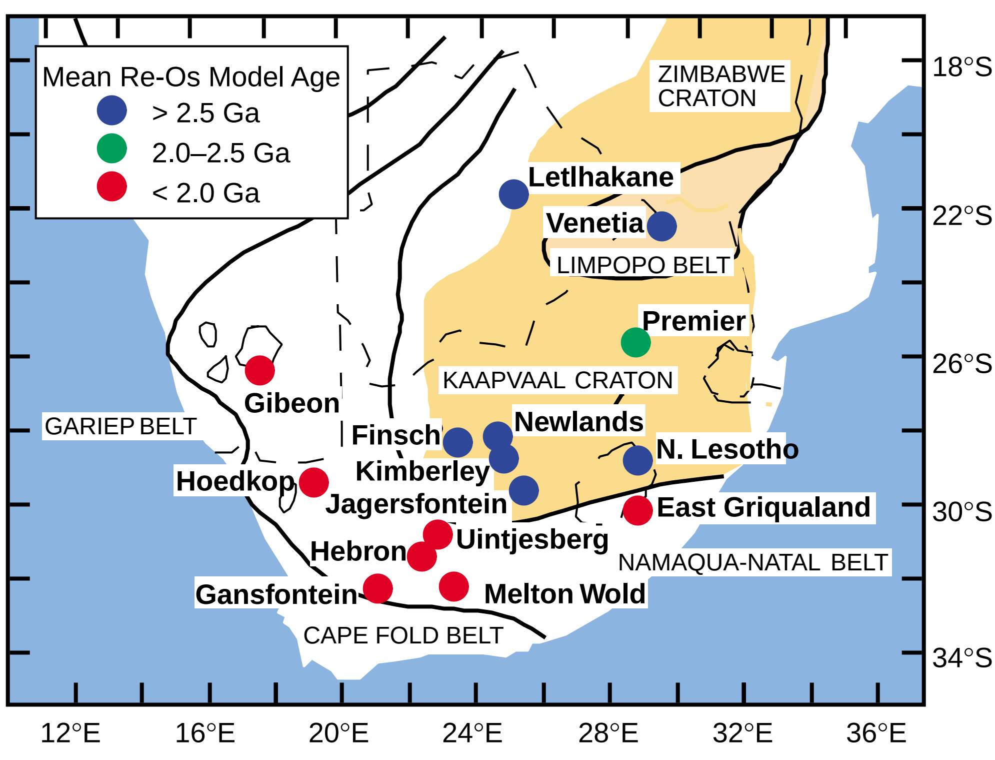

Figure 4. Map of southern Africa showing mean Re-depletion model ages measured for peridotite xenoliths from kimberlites erupted on- and off-craton. Each large circle is an individual kimberlite locality from which several xenoliths have been analyzed. Extent of Archean crust is outlined in yellow, brown is Limpopo metamorphic belt. Data from Pearson et al. (1995, 1998a), Carlson et al. (1999), Janney et al. (1999), and Pearson (1999).

Continental Growth *continued from p. 5*

topic compositions of megacrysts from group I kimberlites indicate a source for these magmas in a widespread, compositionally uniform reservoir with low $^{87}Sr/^{86}Sr$, high $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$ similar to the isotopic component called HIMU that is found in ocean island basalts (Smith et al., 1995). Hf-Nd isotope systematics of these megacrysts indicate the influence of a unique component with a composition reflecting a long-term depletion in Lu/Hf relative to Sm/Nd (Nowell et al., 1999), possibly derived from the sub-lithospheric mantle.

SUMMARY

Results from the Kaapvaal craton project highlight both stable and dynamic aspects of the history of continents on Earth. These findings clearly show that continents consist not only of their crustal provinces, but also include a thick section of underlying mantle that formed during a time interval similar to that of the overlying crust. Several aspects of our data could relate to a common petrogenetic process reflecting craton formation in a convergent margin setting. These include:

- evidence that southern African komatiites derive from wet primary magmas;
- lithospheric peridotites with compositions indicative of extremely high degrees of melt removal, possibly the residues of komatiite extraction;
- Archean ages for melt depletion measured for the peridotites;
- the presence of subducted Archean oceanic crust in the deep lithospheric mantle as sampled by eclogitic xenoliths.

In the southern African case, this process continued sporadically over ~500 m.y. and resulted in the creation of a lithospheric block that has survived at Earth's surface for over 3 b.y.

Once formed, the history of this continental block was not yet complete. Accretionary belts were welded to its margins in the Proterozoic, increasing the crustal thickness of the craton around its margins as shown by geochronological results from crustal xenoliths. As before, this episode of continent growth was not restricted to the crust. Both the relative youth of some Kaapvaal diamonds and the Proterozoic ages obtained for off-craton peridotite xenoliths show that continent formation and/or modification involved the underlying mantle to depths extending at least into the diamond stability field. The presence and characteristics of the kimberlite-borne megacrysts extend this interaction to the very base of the lithosphere. The results demonstrate the dynamic nature of the whole continent, from top to bottom, as it has interacted with the surrounding crust and mantle over Earth history.

ACKNOWLEDGMENTS

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Continental Growth *continued on p. 7*

Karlstrom Appointed *GSA Today* Science Co-Editor

Karlstrom on Nankoweap Butte, Grand Canyon.

Karl E. Karlstrom, University of New Mexico, is the new science co-editor of *GSA Today.* He replaces Suzanne M. Kay (Cornell University), whose term ended December 31, 1999. Karlstrom joins Molly F. Miller, Vanderbilt University, who was appointed in 1998.

Karlstrom received his M.S. and Ph.D. degrees at the University of Wyoming and taught at North Carolina State University and Northern Arizona University before accepting his current post at New Mexico. His main research interests involve the Proterozoic (and younger) tectonics of the western United States and processes of interaction of deformation, metamorphism, and plutonism in the deep crust. He has conducted field studies of Proterozoic rocks in the Arizona Transition Zone, Eastern Mojave desert, Grand Canyon (both Paleoproterozoic basement and the Mesoproterozoic-Neoproterozoic Grand Canyon Supergroup), and southern Rocky Mountains. He has been a member of GSA since 1982.

"Molly Miller and I hope to carry on the fine tradition set by Eldridge Moores and Sue Kay in making the lead articles of *GSA Today* some of the most visible papers in earth sciences," Karlstrom said. "*GSA Today* papers need to be both cutting-edge research (for the specialists in the field) and also understandable to the wider earth science community. We offer an important challenge to authors of lead articles: Can you effectively communicate important new ideas to a wide community?"

Proposals for "hot topic" papers for *GSA Today* must go to either Miller (Molly.F. Miller@Vanderbilt.edu) or Karlstrom (kek1@unm.edu) before a paper is submitted for consideration. All science articles for *GSA Today* are peer-reviewed. ■

Continental Growth *continued from p. 6*

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GSA President Named to Committee on National Medal of Science

Mary Lou Zoback, 2000 president and Fellow of the Geological Society of America, will soon be appointed by President Bill Clinton to the Committee on the National Medal of Science. The Medal of Science is awarded to individuals who have made outstanding contributions to science and engineering. The President's Committee on the National Medal of Science selects the recipients of the award, as many as 20 people per year. Geologist and geophysicist Mary Lou Zoback is currently chief scientist of the Earthquake Hazards program attached to the U.S. Geological Survey in Menlo Park, California.

A Teaching Companion to *This Dynamic Planet:* A USGS Project in Earth-Science Curriculum Development

Leslie C. Gordon, Robert I. Tilling, and Melanie Moreno, *U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, USA*

We present a status report on a project—*This Dynamic Planet: A Teaching Companion*—underway at the U.S. Geological Survey (USGS) to develop earth-science curriculum materials to complement and supplement two existing USGS publications on plate tectonics highly popular with teachers and students. While we are very enthusiastic about this project and look forward to its completion and widespread use in classrooms, we also have some thoughts that revolve around the basic question: Should we in the geoscience community be developing earth-science curriculum materials? Let us first describe the project and then share our views on this question.

Background

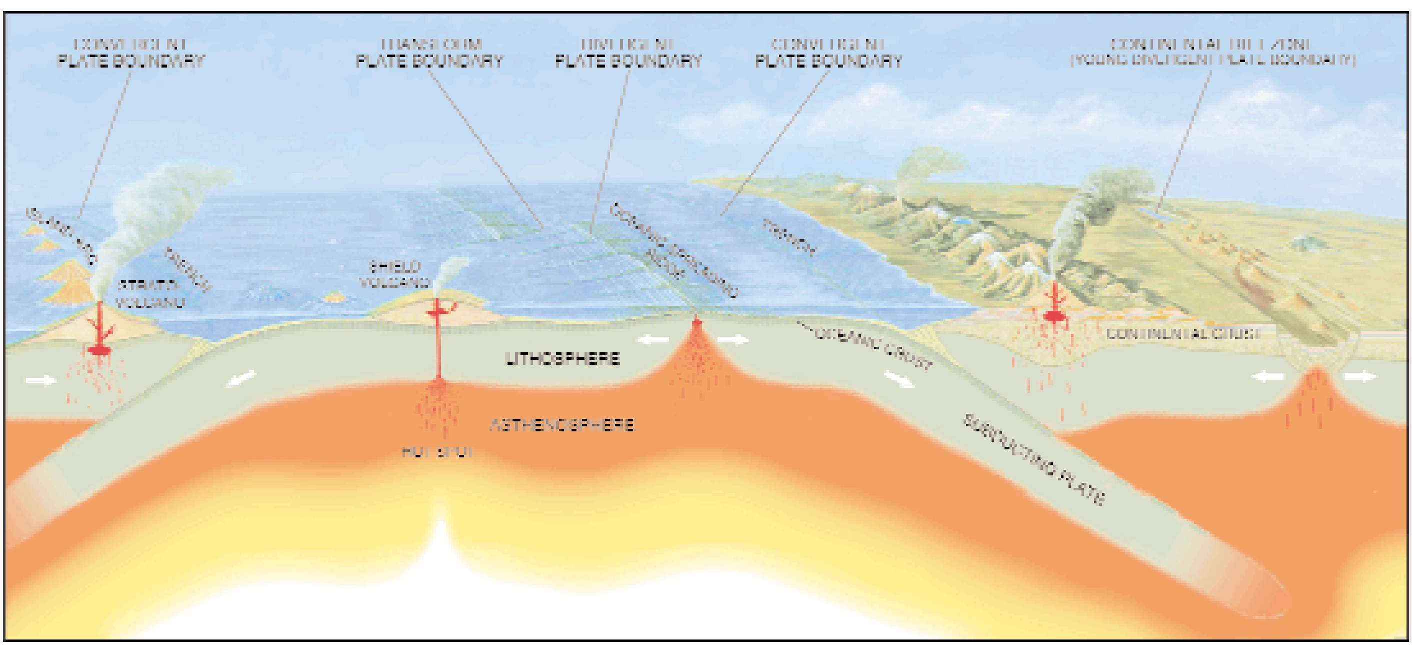
In 1989, the USGS and the Smithsonian Institution produced *This Dynamic Planet: A World Map of Volcanoes, Earthquakes, and Plate Tectonics*. A 1994 edition of the map included editorial changes to increase the legibility of the map, added locations of impact craters, corrected errors, and improved explanatory text. A general-interest booklet called *This Dynamic Earth: The Story of Plate Tectonics* was published in 1996 to complement the map. Some of the compilers of the original map thought that it might be useful to create a teachers' guide to the map, and over the ensuing years this general notion evolved into a USGS project to produce *This Dynamic Planet: A Teaching Companion*.

The *Teaching Companion* is designed to assist teachers in using both the map and booklet in the classroom, and to teach plate tectonics in grades 6–14. It will not be simply generic educational material on plate tectonics, because an abundance of such material already exists. Instead, the project focuses on the development of classroom materials specifically geared to the existing USGS plate tectonics wall map (*This Dynamic Planet*) and booklet (*This Dynamic Earth*). Our aim has been to develop a high-quality, focused assemblage of classroom activities: black-line masters for reproduction, student maps, explanatory text, references and resources, and other materials to facilitate the teaching of a unit on plate tectonics at middle- to high-school level. Teachers will have a package consisting of three interrelated components: the two existing USGS outreach products on plate tectonics and the new *Teaching Companion*. This package will be made available by the USGS for little or no cost to teachers through its established distribution channels and at various teacher conferences. We also seek to collaborate with other organizations for additional distribution to educators of students who are usually underrepresented in the earth sciences, and to teachers of subjects other than earth science.

Goals and Progress

The original *Dynamic Planet* map and booklet garnered awards and were hailed as beautiful and full of excellent information, yet few teachers used them as part of their curriculum or in a lesson. Our goal in producing the *Teaching Companion* is to assist teachers and students in moving beyond regarding the map as wallpaper, and to use the booklet as more than a collection of pretty pictures.

In August 1998, 17 teachers from across the United States came to Menlo Park, California, to begin work on the *Companion*.



José F. Vigil

PLATE TECTONIC PROCESSES

The outermost layer of Earth is broken up into a dozen or more solid rock slabs (called *tectonic plates*) that are moving slowly relative to one another. These motions are illustrated by this artist's conception of a slice into Earth from the wall map "This Dynamic Planet: World Map of Volcanoes, Earthquakes, Impact Craters, and Plate Tectonics" by the U.S. Geological Survey (USGS), the Smithsonian Institution, and the U.S. Naval Research Laboratory.

During this week-long workshop, participants devoted about half of their time to learning about the latest scientific developments in the field of plate tectonics from USGS and other researchers. The remaining time, teachers worked in small groups creating a series of draft activities and related resources in the areas of natural hazards, natural resources, the historical development of plate tectonic theory, and understanding plate tectonic motions and boundaries. Two smaller workshops in June and August 1999, which included several teachers from the 1998 workshop as well as teachers and USGS scientists new to the project, focused on reviewing, editing, and revising the draft document and creating new materials as necessary to fill gaps. Updates on the progress of the *Companion* have been published as abstracts at several geoscience-education conferences. These conferences proved to be excellent sources to find teachers and others, as participants, collaborators, and partners for the project.

Envisaged End Product

The *Teaching Companion* was developed with the idea that not everyone has access to the Internet, nor is interested in high-technology learning. The *Companion* is self-contained, and the activities call for few materials, most of which are inexpensive and easily obtainable. However, for those classrooms on the cutting edge of technology, the map and booklet are on the Internet, http://pubs.usgs.gov/pdf/planet.html, and http://geology.usgs.gov/publications/text/dynamic.html, respectively, and we have listed World Wide Web resources for most of the activities.

The *Companion* will be published in loose-leaf form, not only to make it easy to remove pages for photocopying, but also to add new or revised material conveniently. Any of the black and white illustrations can be photocopied on plastic transparencies for use with overhead projectors. Likewise, color illustrations can be made into color transparencies or photographed to make 35-mm slides. The materials are meant to be integrated easily into existing curricula and to supplement other lessons about plate tectonics and its influences on our planet and on people.

The activities in the *Teaching Companion* are organized similarly to the booklet, *This Dynamic Earth*, with sections on "The Basics," "The Development of a Theory" (history, evidence, and evolving human thought), "Understanding Plate Motions," "Human Connections" (natural hazards and resources), and "Out of this World" (extraterrestrial plate tectonics). All activities are cross-referenced to the map, or pages in the booklet, and are correlated with both the *National Science Education Standards*, and *Geography for Life: National Geography Standards, 1994*. Although science and geography are two obvious curricular areas in which to teach plate tectonics, we hope that our notes on curriculum links in each activity make it easy to include them while studying math, history, economics, and other social studies.

The *Teaching Companion* also contains teaching tips on how to use the *Companion*; an overview of the basic principles of plate tectonics (science concepts); extra illustrations and maps that have multiple uses with any curriculum; print and electronic references to guide students in further exploration; classroom activities covering five basic areas; and a table of contents, index, and errata for *This Dynamic Earth*.

What's Next?

The next phase is to conduct professional development training for teachers. A curriculum is no better than the teacher's ability to teach it. Simply handing out packages of materials to teachers does not guarantee their effective use in the classroom. Teachers need adequate preparation in the science content behind the lesson, need to be familiar with materials, and need to know where to obtain materials and resources. The earliest of these teacher workshops served not only to begin training teachers in the subject matter and using the materials, but also provided valuable feedback to the developers for refining the materials. Some of the activities in the *Companion* were previewed at the 1999 GSA Annual and Cordilleran Section meetings. Two workshops are planned for the 2000 Annual National Science Teachers Association (NSTA) meeting. Both scientists and teachers who developed the materials are conducting the workshops. Future workshops will continue to be both distribution mechanisms and training sessions for implementation of the *Teaching Companion*.

We are currently seeking middle and high school classroom teachers to field-test and review the draft materials. We also seek other educators and scientists to assist with the continuing review and improvement of the *Teaching Companion*.

Opportunity, Challenges, and Advice

In creating a *Teaching Companion*, the USGS seized an opportunity to capitalize on its two previous highly successful outreach products on plate tectonics; it clearly demonstrated the benefits of a systematic, value-added approach to creating educational products. While we think that the *Companion* will provide a much-needed, useful product for teachers, we do not recommend other geoscientists jumping wholesale into curriculum-development activities, primarily because many good classroom materials already exist. Instead, we firmly believe that the most important role the geoscience community can play is to be more actively involved in professional development for teachers. Most K–12 teachers want to learn more about science content and need more support and training to use teaching materials effectively.

What does this mean practically for those of you who would like to be involved in a curriculum-development project, and how can we in the scientific community be constructively involved? What we have most to offer to teachers and curricula developers is our scientific skills, judgment, and expertise. Scientists are needed to check content accuracy, but classroom teachers and other education specialists are necessary to ensure that the activities are workable and practical in the classroom and are age-appropriate for the desired target audience. While we can serve as subject matter experts, we must not presume to be knowledgeable in pedagogy.

Rather than tackling broad general scientific topics, pick a specific area that needs attention. There is little need for more classroom materials about the basics such as the rock cycle, types of volcanoes, or erosion processes. (The flip side of this coin is to be careful not to choose a subject too narrow or esoteric for your audience; students still need to learn the basics.) Ask yourself what current technical publications, maps, or programs already exist that can benefit from supplementary educational materials. What publications created for the news media, or for Congress could be adapted for classroom use? What is new in your field of research that is relevant and interesting to students?

Drawing from our experience with the *Teaching Companion* project, we offer some advice. Before embarking on any such project, do your homework first; find out what kinds of materials are already available, and who is currently doing something similar. Cooperation with a publisher and distribution network needs to be considered from the beginning of the project. Work together with those who already have some experience in the field. Recognize that your way of thinking and presenting material may be different from the thought processes and needs of the education community. Include teachers in the design of the product; ask them what they would find most useful. Review past projects (successes and failures) and evaluate what you can do differently or similarly. You certainly do not want to duplicate existing materials, especially those that are demonstrated failures. Developing good curriculum materials is a long-term commitment that demands thorough up-front planning while retaining the flexibility to change plans mid-project when necessary. Plan for ample field-testing and rewriting of the material, and be prepared for the whole process to take much longer than you expect. ■

Toward a Stewardship of the Global Commons

Engaging “My Neighbor” in the Issue of Sustainability Part II: The Context of Humanity: Understanding Deep Time

A. R. Palmer, *Boulder, Colorado, and* ***E-an Zen,*** *Reston, Virginia*

Intimations of an understanding that Earth had a significant history are found in the writings of Herodotus during the 5th century B.C. While traveling on the Nile Delta, he realized that the sediments had accumulated from river floods and that thousands of years had been required to form the visible part of the delta deposits. However, the contrast between human history and geologic history was not fully articulated for more than two millennia.

A bit over two centuries ago, James Hutton recognized the significance to Earth history of the angular unconformity at Siccar Point on the southeast coast of Scotland, setting in motion the modern science of geology. Horizontal beds of sandstone that formed the land surface beneath Hadrian’s Wall, already old in terms of Scottish history, rested on the vertically upturned edges of still older sedimentary rocks. Those older rocks must have been lithified from unconsolidated horizontal sediments before being deformed to their present attitude and eroded to form an ancient land surface *beneath* the sandstones. Here was indisputable evidence that Earth had a history that far pre-dated human history. Thus the time context for humanity was clearly established, and all subsequent geologic work reinforces it.

We are a part of the fabric of Earth’s biosphere and we are not likely to disappear anytime soon; but there is growing concern about our effect on the global ecosystem and the quality of life that can be sustained for our descendants. By recognizing the vastness of Earth history compared to human history, we internalize what John McPhee has termed “Deep Time,” and we gain an essential perspective from which to consider the results and consequences of our human impacts on Earth.

Preserved human artifacts and written records show clearly that modern humans have essentially experienced only the present landscape. Even if that landscape has been locally modified by geologic processes, the painted caves of the Pyrenees remain as caves and some ancient city ruins of Mesopotamia and tombs of predynastic Egypt remain standing on flood plains. The clear archaeological evidence for recency of the advent of modern *Homo sapiens* dramatize the awesome changes wrought on our planet by humans in the recent historical past. It is only necessary to look out of an airplane window while flying over the central United States to see how much of the land surface has been altered by human activity in less than two centuries. Satellite images document how much urban sprawl in the United States has changed the landscape and natural ecosystems within even shorter spans of a few decades.

Geologists have no problem with the concept of deep time, but it is clearly a concept that is not widespread at a very high level of consciousness in the general public. Raising the level of public awareness of this concept is our challenge and our responsibility. As one contribution to this challenge, the concept of deep time and the context of humanity has been captured visually in GSA’s affordable 20-minute teaching video “The Earth HAS a History.”

Several other ways to get the key idea of deep time into the public domain are suggested in sidebars accompanying this essay on GSA’s Web site at www.geosociety.org/criticalissues (coming soon).

Next time: Doubling Time: It Works for ANY Rate of Change. ■

Subaru of America Expands Partnership with GSA

Subaru of America has committed direct cash benefits of $270,000 plus ancillary support over a two-year period to deepen its partnership with GSA. The contract for involvement will run from January 2000 to January 2002.

Subaru will deepen this strategic partnership through the following activities.

- Continue as the name sponsor for the 2000 GSA Annual Meeting to be held in Reno, Nevada;
- Support further development of Earth Week 2000;
- Support further development of a Women in Science Award;
- Support a mentor program that will bring a high school earth science educator to GSA headquarters for an academic year to act as a resource in the development of an interactive Web site, as well as further innovative educational programs;
- Provide a donation to the GSA Foundation for each car that is purchased by a GSA member, starting immediately;
- Provide vehicles to shuttle GSA officers at the Reno meeting;
- Provide two vehicles for headquarters staff use during the contract period; and
- Work with the GSA Foundation in design and development of an interactive booth for the Annual Meeting exhibits that combines both the GSA Foundation and Subaru.

As the official car of GSA, Subaru will use the journal *Geology* to reach members by placing a full-page, four-color advertisement on the back cover of five issues in 2000.

PENROSE CONFERENCE REPORT

Terrane Accretion along the Western Cordilleran Margin: Constraints on Timing and Displacement

Conveners: *J. Brian Mahoney, University of Wisconsin—Eau Claire*
Basil Tikoff, University of Wisconsin—Madison
Julie Maxson, Gustavus Aldolphus College
Ralph A. Haugerud, U.S. Geological Survey

A fundamental controversy in North American Cordilleran tectonics is the timing and magnitude of large-scale terrane translation along the western Cordilleran margin during Late Cretaceous and Eocene time. A major discrepancy exists between tectonic models derived from geophysical (paleomagnetic) and geologic data sets. Paleomagnetic data consistently indicate large-magnitude translation of allochthonous terranes along the continental margin between ca. 90 and 55 Ma, whereas geologic data suggest a significantly smaller degree of displacement. Reconstruction of the tectonic evolution and paleogeographic configuration of the western Cordillera margin, particularly during the Late Cretaceous and Eocene, requires knowledge of the timing and magnitude of terrane translation.

The North American Cordillera is an ideal laboratory for examining the conflicting geological and paleomagnetic data sets, and this controversy has major implications for other orogenic belts. If multidisciplinary geologic correlations and terrane linkages in the North American Cordillera are suspect, then established geologically based tectonic models in other orogenic belts worldwide may require reassessment. Conversely, if paleomagnetic analyses in the North American Cordillera are called into question, then paleomagnetic reconstructions established in other orogenic belts or for different time periods become equally suspect. The recurring nature of the discrepancy throughout the Cordillera makes it clear that the problem is systematic, and resolution of the controversy requires examination of the processes and methods used to formulate tectonic reconstructions.

The Penrose Conference "Terrane Accretion along the Western Cordilleran Margin: Constraints on Timing and Displacement" was convened June 18–25, 1999, in Winthrop, Washington, to evaluate the quality and limitations of data sets contributing to the translation paradox. Seventy-seven scientists from six countries provided geological expertise that ranged from Honduras to the tip of Alaska. The conference was designed to provide a multidisciplinary examination of differing data sets, and a broad range of expertise was brought to bear on the problem. A key element of the conference was the assembly of multiple investigators representing different disciplines from throughout the North American Cordillera focusing on a singular objective: constraining terrane translation along the western margin.

Format

The conference subdivided the topic into spatial and topical areas of discussion. The continental-scale scope of the problem, the widespread distribution of researchers, and the breadth of expertise represented required a format that would provide both a regional overview and topical discussions of the problem. The contentious nature of the debate raised the spectre of unproductive argumentation, and the format was designed to allow free-flowing discussion. Discussion sessions were structured to provide each researcher a chance to present, and to encourage interaction among participants. Posters were on display throughout the meeting and acted as the focus for many discussions.

The first discussion session was a spatial overview of Cordilleran terranes, subdivided into segments from south to north. The geologic setting of each segment was described by an established researcher. All other researchers working in the region then briefly described their area of interest and research specialty. The spatial overview very effectively set the tone of the meeting by introducing the regional geologic setting, highlighting outstanding controversies, introducing all researchers in each region, and providing a comprehensive review of the geologic setting of the continental margin for all participants.

The primary focus of the conference was a critical evaluation of the processes and methods used to examine accretionary tectonics and terrane translation. A variety of methods are used to evaluate the tectonic evolution of the Cordillera, and each method has inherent limitations and biases. The methodology sessions were organized by discipline and included paleomagnetism, geochronology, lithostratigraphy, biostratigraphy, structure, igneous and metamorphic geology, geophysics, and mantle dynamics. Participants in each session were encouraged to discuss the utility of their methods, including strengths and weaknesses, for constraining terrane translation. Each segment had a similar format: an overview talk that highlighted the benefits and limitations of the method, a brief (~5 minute) introduction into the methodological approach of each researcher in the discipline, a panel discussion, and dedicated time for poster discussion. Several researchers from each discipline formed a panel that fielded questions from all participants. The panel discussions were particularly effective in generating useful dialogue among participants. This format encouraged questions about strengths, limitations, and biases of research methods, and led to frank discussions about the positive and negative aspects of different approaches. The willingness of participants to discuss the limitations of their particular techniques was the principle reason the meeting was a success.

Field Trips

A field trip led by Ralph Haugerud and J. Brian Mahoney, from the accreted terranes of the San Juan Islands, across the crystalline core of the North Cascades, and into the allocthonous sedimentary basins of the Methow terrane introduced the complex geology, protracted geologic history, and domainal character of the North Cascades. Discussions concerned terrane correlations, constraining displacement across high-strain zones, terrane mobility along the continental margin, and the complexities of unraveling the regional geologic history.

On a mid-conference trip, participants examined terrane boundaries in the North Cascades and discussed structural and stratigraphic relationships along the Insular-Intermontane superterrane boundary. J. Brian Mahoney and Ralph Haugerud described proposed stratigraphic ties between the Cascades and the Methow terrane in Albian time, and between the Methow terrane and the western edge of the Intermontane superterrane in the Late Cretaceous.

Spatial Overview

A beginning spatial overview of Cordilleran terranes served to highlight similarities and differences in regional geology between Mexico and Alaska. Chris Scotese set the stage for the discussion by presenting recent paleogeographic reconstructions of the continental margin and describing ongoing problems in his reconstructions.

Fernando Ortega-Gutierrez began the overview with a description of the geologic setting and paleogeographic history of central Mexico. He described several transects through Mexico, introduced ter-

Penrose Conference *continued on p. 12*

Penrose Conference *continued from p. 11*

rane nomenclature, and described the terranes of western Mexico as thin tectonic flakes imbricated onto a Precambrian Grenvillian suture. Tom Anderson followed with a sequential reconstruction of the Triassic to Eocene geologic history of northeastern Mexico. He emphasized the importance of Middle Jurassic sinistral displacement along the southwestern margin, and advocated a simple closure model for the Gulf of California.

Darrel Cowan reviewed the Cretaceous-Tertiary evolution of the Sierra Nevada system and described variations in the angle of subduction over the past 100 m.y. He emphasized the fundamental difference between thin-skinned Sevier-type deformation between 100 and 80 Ma and thick-skinned Laramide-type deformation between ca. 75 and 55 Ma. He brought the Sierran system into the debate by encouraging the group to consider what type of features we would expect to develop in an arc-forearc assemblage adjacent to a major transcurrent fault system. Jim Monger introduced the terrane assembly of the Canadian Cordillera and described the along-strike continuity of tectonostratigraphic units and the across-strike segmentation of the Cordillera into two “high-grade” belts (Omineca and Coast) and three supracrustal belts (Rocky Mountain, Intermontane, and Insular). He argued that the North America Cordillera is the key place to resolve the translation dilemma, owing to the north-south orientation of the margin and the east-west orientation of cratonal provinces and climatic zones, which should provide an ideal measure for terrane translation. Sarah Roeske described the tectonic evolution of the northern Canadian and Alaskan Cordillera. She emphasized the immense size of the translated terranes, major dextral strike-slip systems within some accretionary complexes (e.g., Chugach), and that the often-overlooked geology of Alaska is critical to the translation debate.

Processes and Methodologies

The examination of processes and methodologies began with a discussion of paleomagnetic techniques and data sets by Randy Enkin, who provided an excellent introduction to critical evaluation of data sets by explaining how to critically evaluate a paleomagnetic study. He examined the potential problems and bias inherent in paleomagnetic studies, and pointed out that a high-quality paleomagnetic investigation systematically evaluates potential problems, such as compaction shallowing, thermal overprinting, and other sources of experimental error. Panel discussions with paleomagnetic experts addressed the robustness of various paleomagnetic data sets, and there was a notable lack of consensus regarding the quality of various data sets and density of reliable data points throughout the Cordillera. There was a clear consensus that the paleomagnetic data are remarkably consistent, although resolution of the debate requires a substantially larger paleomagnetic data base.

Timing constraints on terrane accretion and translation were introduced by Dave Kimbrough and Bill McClelland. Kimbrough emphasized the magnitude of Late Cretaceous igneous events along the western margin, noting that the large scale of the Peninsular Ranges batholith and other features required tonalite production through partial melting of enormous volumes of upper-mantle peridotite. He described a major pulse of magmatism at 95 Ma in the batholith, which other researchers identified as an important time frame for Cordilleran evolution. McClelland argued that terrane linkages must be demonstrated by tight timing constraints on structural imbrication, stratigraphic overlap, tectonostratigraphic correlations, and pinning plutons. He described geologic constraints on development of the Coast Shear Zone in the northern Canadian Cordillera, intruded by the undeformed “great tonalite sill” between 80 and 55 Ma, placing an upper limit on the age of deformation in the shear zone. Jim Mortensen discussed constraints on movement on the Denali and Tintina fault systems, which are limited to ~450 km dextral offset in pre-Eocene time. Elena Centeno-Garcia discussed timing constraints on the evolution of the Guerrero terrane in central Mexico, which displays structural, stratigraphic, and isotopic evidence of two-phase deformational history, with major contractional and sinistral displacement between 208 and 156 Ma, and transpressional deformation of the Guerrero-Alistos arc prior to 83 Ma.

Sedimentologic and stratigraphic techniques are an important component of terrane analysis, and many participants cautioned about the reliability of proposed correlations. J. Brian Mahoney emphasized the need for multidisciplinary analyses in tectonostratigraphic analyses, including complimentary lithostratigraphic, paleontologic, geochemical, isotopic, provenance, and paleomagnetic linkages. Jim Haggart presented paleontologic data that argues for a northern origin of the Insular superterrane during Jurassic and Cretaceous time. Ralph Haugerud provided an insightful description of the assumptions inherent in geologic mapping. Individual presentations and panel discussion highlighted the need for reliable tectonostratigraphic correlations, the questionable reproducibility and utility of petrographic analyses, and the uncertainty over the interpretation of detrital zircon results.

Paul Umhoefer began the discussion of structural techniques in terrane analysis, emphasizing the very low preservation potential of structures developed during major translation. He used the modern San Andreas system as an example, where up to 1200 km of offset occurred, but only 300–500 km of displacement is attributed to recognized faults. M. L. Crawford discussed the limitations of igneous and metamorphic analyses, which primarily provide information about mid- to lower-crustal processes. She emphasized the volume of magma produced in the Coast Mountains of the northern Canadian Cordillera between 100 and 88 Ma and 68 and 53 Ma, and suggested that these volumes required major orthogonal contraction during these periods. Ray Price described several kinematically linked tectonic episodes, including northeast- and southwest-vergent contraction, sinistral transpression, orthogonal convergence, dextral transpression, dextral transtension, and relative tectonic stability, all between 180 Ma and the present.

The final methodology session began with an overview of the recent major geophysical initiatives in the northern Canadian Cordillera. Ron Clowes described the initial results of the SNORCLE Lithoprobe transect, a crustal refraction profile from the Slave Province to the Insular superterrane. Linc Hollister described the implications of the ACCRETE profile for exhumation of the northern Coast Plutonic Complex and imaging of transpressive structures in the region. Ray Russo presented a dramatic model of the role of aesthenospheric mantle in terrane tectonics. He made the point that the terranes are probably not thin tectonic flakes, but contain lithospheric keels that control upper mantle flow. The model vividly illustrated the three-dimensional aspect of terrane translation. Basil Tikoff described probable far-field effects of terrane translation, emphasizing that the movement of thick-rooted arc terranes will have major regional effects, such as the formation of fold and thrust belts perpendicular to the margin. His description of a potential tectonic mechanism by which a major crustal block could move along the western Cordilleran margin sparked lively discussion among participants.

The final session of the meeting was a panel discussion on the recognition of large-scale terrane translation in the North American Cordillera. This session became a group forum on the possibility and plausibility of terrane translation during Cretaceous to Eocene time, and it was readily apparent that outstanding problems or inadequate data sets prevent resolution of the problem. Categories of the problem are: (1) better *timing constraints* are needed to define both the magmatic evolution of the arc system(s) and deformational episodes along the margin; (2) the quality of currently proposed lithostratigraphic and tectonostratigraphic *correlations* varies widely, and may require reexamination; *provenance* ties, particularly detrital zircon analyses, must be interpreted with caution; (3) *paleomagnetic data sets* must become more robust, with a higher density of data points throughout the Cordillera; (4) the scale of the problem must be recognized, which requires the incorporation of local and regional data sets into continental models; the apparent discontinuity of tectonostratigraphic units and fauna between Mexico and the northern Cordillera must be explained; the kinematics of plate motion must be reassessed; why Alaskan *tectonic reconstructions* differ from those to the south and where the Kula-Farallon triple junction was during the proposed translation also must be investigated; and (5) the *geodynamics* of terrane translation is poorly understood, and may require three-dimensional models of lithospheric motion; the kinematics and offset magnitudes in major shear zones are inherently difficult to assess and should be interpreted with caution; the *geologic signature* of terrane translation and why there is no structural evidence recording translation of the Insular superterrane must be examined.

The diversity of scientific perspectives, both disciplinary and geographic, allowed the translation debate to be examined from a broad, systematic viewpoint, and participants in the conference came away with new insights and understandings of the philosophy and methodology of other workers. The translation paradox will not be solved by a single researcher employing a single technique, but will be resolved by a community of workers engaged in multidisciplinary research.

Acknowledgments

This conference was made possible through the logistical and financial support of the Geological Society of America and the National Science Foundation (grant number EAR-9817962). Lois Elms (Western Experience, Inc.) handled logistical arrangements superbly, as usual. The conveners wish to thank Carrie Rowe and Michael Schmidt (University of Wisconsin–Eau Claire) for assistance during the conference, and Sam Campbell for providing a base of operations in Seattle. Nancy Amdahl (University of Wisconsin–Eau Claire) provided indispensable organizational assistance. Jim Peterson (Western Washington University) and Hugh Hurlow (Utah Geological Survey) assisted with the mid-meeting field trip in the Methow basin. The conveners extend their sincere gratitude to the participants, who provided the intellectual energy, scientific curiosity, professional camaraderie and positive attitudes necessary to make this conference a success.

Conference Participants

Tom Anderson
Christopher Andronicos
Judith Baker
Kari Bassett
Peter Bird
David Blake
Dave Brew
Brad Burton
Elena Centeno-Garcia
Valerie Chamberlain
Dominique Chardon
Ron Clowes
Darrel Cowan
Weecha Crawford
Allison Dean
Kathleen DeGraaff
Yildirim Dilek
Eric Eddlemon
Randy Enkin
Carol Evenchick
Rich Friedman
Peter Haeussler
Jim Haggart
Michelle Haskin
Ralph Haugerud
Catherine Hickson
Lincoln Hollister
Bernie Housen
Todd Housh
Alexander Iriondo
William Irwin
Steve Israel
Carl Jacobson
Cesar Jacques-Ayala
Stephen Johnston
Murray Journeay
Lori Kennedy
Mark Kiessling
Dave Kimbrough
Ken Kodama
Harold Lang
Paul Link
Steve Lund
J. Brian Mahoney
John Marzolf
Julie Maxson
Bill McClelland
Michael McWilliams
Jochen Mezger
Jim Monger
Tom Moore
Jim Mortensen
Peter Mustard
Fernando Ortega-Gutierrez
James Peterson
Ray Price
Tim Raub
Leslie Reid
Jim Riesterer
Sarah Roeske
Robert Rogers
Charles Ross
Carrie Rowe
Ray Russo
Paul Schiarizza
Mike Schmidt
Ronald Schott
Chris Scotese
Doug Smith
Chris Suczek
Dave Symons
Derek Thorkelson
Basil Tikoff
Paul Umhoefer
Sandra Wyld ■

GSA Welcomes Three New Associated Societies

The Association of Earth Science Editors (AESE), the History of Earth Sciences Society (HESS), and the National Ground Water Association (NGWA) are the newest GSA Associated Societies, approved by the Council at its October 1999 meeting.

The Association of Earth Science Editors, founded in 1967, aims "to strengthen science editing; to foster education, and to promote the exchange of ideas of general and specific problems of selection, editing, and publication of research manuscripts, journals, serials, periodicals, and maps pertaining to the earth sciences." AESE has about 325 members throughout the United States, in Canada, and abroad. AESE holds an annual fall meeting and publishes a quarterly newsletter, in addition to recognizing outstanding editorial and publishing contributions. AESE noted that the primary goals of affiliation with GSA are to communicate and interact more widely with earth scientists, educators, and librarians and to offer the expertise and knowledge in earth science writing, editing, publishing, and geologic-map production that are available from AESE members. Additional information is available from the association's Web site at www.aese.org.

The History of Earth Sciences Society aims to (1) serve both historians and earth scientists with a mutually beneficial exchange of ideas; (2) provide breadth of membership composition and outlook through an open member policy which is international in scope; (3) publish a refereed journal to serve as an outlet for scholarly works in the history of earth sciences; and (4) promote greater prominence for historical studies of ideas concerning Earth, and for workers and institutions involved in such research. HESS envisions a significant symbiosis resulting from Associated Society status: it does not hold an annual meeting, so the GSA meeting will be a valuable addition to HESS member benefits, and HESS produces a major subdiscipline-related publication that will be an additional resource for GSA members. Founded in 1982, and having about 500 members, HESS publishes two issues annually of *Earth Sciences History.* The current president is Kennard B. Bork of Dennison University.

The National Ground Water Association (founded in 1948 as the National Water Well Association) serves approximately 16,000 members in four membership divisions. The association's mission is to enhance the skills and credibility of all groundwater professionals, develop and exchange industry knowledge, and promote the groundwater industry and understanding of groundwater resources. NGWA activities include an annual meeting, operation of an information clearinghouse, continuing professional education courses, several publications, and a political action committee. NGWA plans to continue its active participation as a co-organizer of educational programming at the GSA annual meetings, and looks forward to assisting with the hydrogeology programs at GSA Section meetings. NGWA headquarters are in Westerville, Ohio; the contact person is Executive Director Kevin B. McCray. The Web site address is www.ngwa.org. ■

Forensic Scientists Organize Association

A group of geologists and forensic scientists are forming a new association, the American Society of Forensic Geologists. The association will provide a forum to discuss: use and application of forensic geology as it applies to criminal and civil investigations and litigation; latest advances in forensic technology and laboratory science, especially as they pertain to forensic geology, mineralogy, and site investigation and interpretation; and training for investigators and scientists in the use of forensic geology.

Aims

The group plans to conduct seminars and conferences related to all phases of forensic geology; to provide consultative services to federal, state, and local law enforcement agencies and forensic laboratories; to encourage the education of geologists and forensic scientists by awarding grants; and to establish a national certification board for forensic geologists and scientists.

Membership Classifications and Dues

Active members: Any person who is a member of a local, state, federal, national, or private laboratory and who engages in the examination of geologic evidence as it pertains to civil and criminal investigations, and scientists and geologists involved in academic, literary, or educational areas whose work extends or promotes forensic geology.

Associate members: Any interested person not eligible for active membership, and students of the forensic or geologic sciences who are actively participating in the academics of either field and who have an interest in the forensic geology discipline.

Fellow members: Individuals who by their efforts in various endeavors have developed and enhanced the discipline of forensic geology, as determined by the Board of Directors

Annual dues (U.S. dollars) are $25 for active members and $15 for associate members. The association is incorporated under the laws of the state of Virginia.

For Information

If you are interested, contact Erich P. Junger, American Society of Forensic Geologists, 620 Bridlewood Dr., Culpeper, VA 22701, (540) 272-0104, ejunger@aol.com. ■

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At the 1999 Annual Meeting in Denver, 174 applicants checked in to interview at the Employment Service area; 123 of those were preregistered with the service, and 51 registered on-site. Thirty-six employers rented booths and scheduled a total of 452 interviews for 97 open positions, while an additional seven employers with 11 openings searched our applicant listings and used our message exchange service. Employers included those from universities and colleges, state and federal government, and nationwide environmental consulting firms. Traditionally, employers using our service have tended to request applicants with doctoral degrees, but requests for applicants with bachelor's or master's degrees are increasing.

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For more information and forms, please see the July 1999 *GSA Today*, or the GSA Web site at www.geosociety.org/profdev/empsvc1.htm; or contact Nancy Williams at nwilliams@geosociety.org, or (303) 447-2020, ext 117. ■

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Section Meetings To Feature Mentor Workshops

Five of GSA's Section Meetings are featuring unique mentoring workshops at their spring meetings. These interactive workshops, known as the Roy J. Shlemon Mentor Program in Applied Geology are designed for graduate and advanced undergraduate students. While the content of each workshop will vary, depending upon the individual Mentors presenting the program, each workshop will deal with "real life" issues about professional opportunities and challenges in applied geoscience.

"Career Interests in Consulting: Some Practical Advice" is the topic for the workshop being offered at the Northeastern Section on Sunday, March 12, 1 p.m.–5 p.m. Three practicing geoscientists with different educational backgrounds and career emphases will engage workshop students in thought-provoking dialogue. This team of mentors includes Randy S. Kertes, experienced in soil and groundwater remediation, environmental assessments, and air quality issues; Evelyn M. Maurmeyer, specializing in coastal processes, wetlands creation and mitigation, and environmental impact analyses; and Jeffrey A. Whidden, skilled in litigation support techniques and environmental liability assessments.

For more information and details on registration for the workshop nearest you, please check GSA's Web site at www.geosociety.org/science/mentor.htm. Hurry, registration is limited. ■

Corrections—Southeastern Section Meeting Announcement, December 1999 *GSA Today*

The toll-free telephone number for the Westin hotels has been changed to 1-800-WESTIN1. The direct number for the Westin Francis Marion hotel in Charleston, South Carolina, site of the GSA Southeastern Section 2000 meeting, is (843) 722-0600.

The short course "Introduction to Sequence Stratigraphy" will be held on Saturday, March 25 and Sunday, March 26 instead of March 24 and 25 (see *GSA Today*, December 1999, p. 20).

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karlin@mines.unr.edu

Both at University of Nevada
Dept. of Geological Sciences
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2000 GSA SECTION MEETINGS

Northeastern Section — March 13–15, 2000, New Brunswick, New Jersey, Hyatt Regency Hotel. Information: Robert E. Sheridan, Dept. of Geological Sciences, Wright Lab, Rutgers University, 610 Taylor Road, Piscataway, NJ 08854-8066, (732) 445-2015, rsheridn@worldnet.att.net. *Preregistration deadline: February 4, 2000.*

Southeastern Section — March 23–24, 2000, Charleston, South Carolina, Westin Francis Marion Hotel. Information: Michael P. Katuna, Dept. of Geology, Charleston College, Charleston, SC 29424-0001, (843) 953-5589, katunam@cofc.edu. *Preregistration deadline: February 11, 2000.*

South-Central Section — April 3–4, 2000, Fayetteville, Arkansas, Center for Continuing Education, University of Arkansas. Information: Doy L. Zachry, Jr., Dept. of Geosciences, 118 Ozark Hall, University of Arkansas, Fayetteville, AR 72701-1201, (501) 575-3355, dzachry@comp.uark.edu. *Preregistration deadline: February 18, 2000.*

North-Central Section — April 6–7, 2000, Indianapolis, Indiana, Government Center and Marriott Courtyard Downtown. Information: Robert D. Hall, Indiana University–Purdue University, 723 W. Michigan Street, Indianapolis, IN 46202-5132, (317) 274-7484, rhall@iupui.edu. *Preregistration deadline: February 25, 2000.*

Rocky Mountain Section — April 17–18, 2000, Missoula, Montana, Missoula Community Theater. Information: Donald W. Hyndman, Dept. of Geology, University of Montana, Missoula, MT 59812-1019, (406) 243-2241, dhyndman@selway.umt.edu. *Preregistration deadline: March 10, 2000.*

Cordilleran Section — April 27–29, 2000, Vancouver, British Columbia, Canada, Robson Square Conference Center. Information: Peter S. Mustard, Dept. of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6, (604) 291-5389, pmustard@sfu.ca. *Preregistration deadline: March 17, 2000.*

2000 GeoVentures

GeoTrips

Geology of the Grand Canyon—Lee's Ferry to Pierce Ferry

Photo by Ivo Lucchitta

April 7–14, 2000—8 days, 7 nights
Scientific Leader: Ivo Lucchitta, U.S. Geological Survey, Flagstaff, Arizona

Fees: $1,750 for GSA Members; $1,850 for nonmembers.

Deformation, Dinosaurs, and Darwin

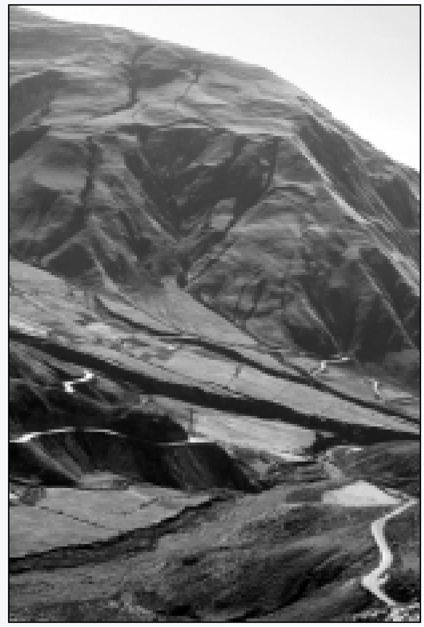


Photo by James H. Reynolds

Salta, Argentina
July 23–August 12, 2000—21 days, 20 nights
Scientific Leaders: James Reynolds, Magstrat, LLC, Webster, North Carolina, and Brevard College, Brevard, North Carolina; Dorothy L. Stout, Cypress College, Cypress, California

Fees: $3,900 for GSA Members; $4,000 for nonmembers.

GeoHostels

Valley of Fire in Southern Nevada, Toroweap Valley of the Grand Canyon, Zion and Bryce Canyon National Parks of Southern Utah

Dixie College, St. George, Utah
June 10–15, 2000—5 days, 6 nights
Scientific Leaders: Spence Reber, Chevron USA (retired); Janice Higgins, Dixie College, St. George, Utah

Fees: $800 for GSA Members; $900 for nonmembers.

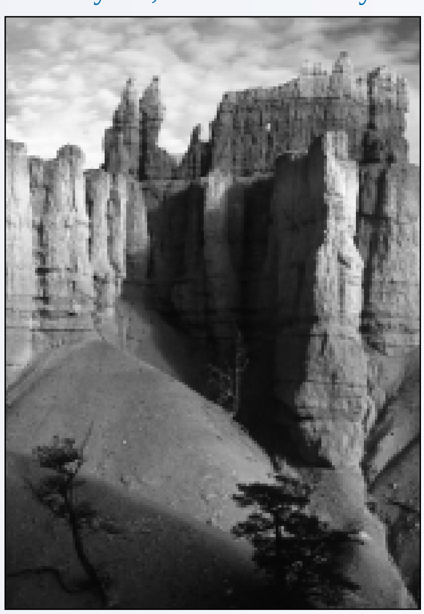


Photo by Martin Miller

Geology of the Lewis and Clark Expedition: Lost Trail Pass to the Columbia River

University of Montana, Missoula, and Sacajawea Select Inn, Lewiston, Idaho
July 15–20, 2000—5 days, 6 nights
Scientific Leaders: Rob Thomas and Sheila Roberts, Western Montana College, Dillon

Fees: $900 for GSA Members; $1,000 for nonmembers.

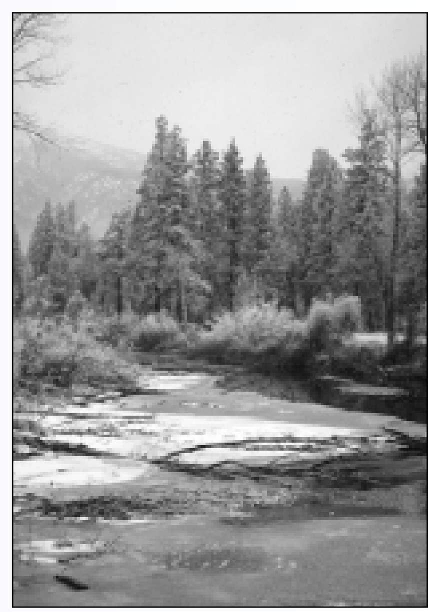


Photo by Rob Thomas

Please see the January 2000 issue of *GSA Today* for information on accommodations, age requirements, health recommendations and special needs, and cancellation procedures, or check GSA's home page: www.geosociety.org/meetings/gv.

LETTERS

Refining Rodinia

The paper by Karlstrom et al. in *GSA Today* (October 1999), mainly aims to refine Rodinia such that the AUSWUS reconstruction is preferred in favor of the SWEAT reconstruction, although it also includes the position of Baltica. Sitting on the edge of the Baltic Shield, we are concerned about the description of its geological history. We were curious about the reconstruction where Baltica is fixed in a position adjacent to East Greenland, not only for the 1.6–1.3 Ga interval, but for the entire periods 1.6–1.0 (Fig. 2, A, B) and 0.9–0.6 Ga (Fig. 2C). However, numerous papers indicate a Mesoproterozoic break-up from a supercontinent. In particular, the Mesoproterozoic mafic dike swarms intruding at ca. 1.46–1.41 Ga, and extensive mafic dike swarms and sills at ca. 1.25–1.18 Ga, should be noted as indicators of intense stretching of the Baltica crust, likely related to initial and completed, respectively, rifting of Baltica from east Greenland. There are also paleomagnetic indications, although the age control is poor, that Baltica rotated clockwise relative to Laurentia before the Sveconorwegian collision of Baltica with Laurentia and/or any other plate at ca. 1.0 Ga. The collision resulted in extensive folding of the Sveconorwegian province of southwest Baltica, crustal thickening, and shearing. In addition, it can be noted that synkinematic, juvenile magmatism is more or less lacking along the Baltica margin, although late Sveconorwegian postcompressional granitoids are common in southwest Baltica. The subsequent stretching and final separation of Baltica from Laurentia, followed by opening of the Iapetus Ocean, are recognized in dike swarms in the Scandinavian Caledonide foreland at 0.61 Ga but also as sheeted dike complexes in the Caledonides.

(References are available from the authors.)

Sven Åke Larson, sal@geo.gu.se
Jimmy Stigh
Göteborg University
SE-405 30 Göteborg, Sweden

Karl-Inge Åhall and Karl E. Karlstrom reply:

A major point of our paper was the recognition of a long-lived (1.8–1.0 Ga) "Cordilleran"-type orogen along southern Laurentia that also extended to Baltica (east) and Australia (west). Our emphasis was on Laurentia-Australia linkage, with less emphasis on Laurentia-Baltica evolution. Unfortunately, in both cases, paleomagnetic and geologic data are still inadequate to allow unambiguous reconstructions of Rodinia.

There is general consensus that Laurentia and Baltica looked roughly as shown in our Figure 2 until the ca 1.20–0.90 Ga Sveconorwegian (Grenvillian) orogeny. As pointed out by Larson and Stigh, many models have invoked a pre-Sveconorwegian break-up, followed by ca. 80 degrees clockwise rotation of Baltica and their collision, possibly with a third continent involved. However, evidence is still inconclusive whether such rifting and rotation commenced at ca. 1.25 Ga (e.g., Park, R. G., 1992, Plate kinematic history of Baltica during the Middle to Late Proterozoic: A model: Geology, v. 20, p. 725–728.) or later during the Sveconorwegian evolution, as is suggested by subduction-related magmatism as late as 1.05 Ga in western Baltica (Bingen, B., and van Breemen, O., 1998, Tectonic regimes and terrane boundaries in the high-grade Sveconorwegian belt of SW Norway, inferred from U-Pb zircon geochronology and geochemical signature of augen gneiss suites: Geological Society [London] Journal, v. 155, p. 143–154). Also, it is unclear whether Baltica and Laurentia were part of opposing "Grenville" sides when amalgamated with a third continent (likely Amazonia and/or Rio de la Plata) into Rodinia. Thus, we left our Figure 2 "open" for different models, and in particular for a three-continent assembly in the North Atlantic region. However, we agree with Larson and Stigh that it may be more appropriate to show Baltica in a rotated position in Figure 2C (at ca. 0.90 Ga).

Karl E. Karlstrom
University of New Mexico
Albuquerque, NM 87131

Karl-Inge Åhall
Göteborg University
SE-405 30 Göteborg, Sweden

Late Paleocene–Early Eocene Climatic and Biotic Events in the Marine and Terrestrial Records. *Edited by M.-P. Aubry, S. G. Lucas, and W. A. Beggren. Columbia University Press, New York, 1999, 513 p., $125.*

Edited theme volumes, such as this one, run the risk of being dominated by esoteric "data dump" papers with limited relevance to the larger audience. True, many of these papers deserve publication because they contain valuable data, worthy of widespread dissemination. This book, with its focus on the enigmatic and highly relevant Paleocene-Eocene transition and its content of mini-monograph papers, is a valuable addition to earth science publications. The volume contains an impressive collection of mostly paleontological and stratigraphical papers centered on the paleoclimatic and biologic events that are the Paleocene-Eocene transition. This episode of Earth history is of great interest because it documents a well-preserved, acute global-warming event, with obvious extrapolation to present-day climate-change scenarios. The paleontology papers span topics from deep marine microfossils to terrestrial vertebrates. High points are papers that present well-thought-out compilations of specific databases, such as Wing's effort to place the numerous Big Horn Basin paleobotanical assemblages in a stratigraphic and paleoclimatic context, Gunnell's excellent mammalian biostratigraphical compilation, and the magnetostratigraphical compilation by Flynn and Tauxe. Other noteworthy works include Aubry's exhaustive nannoplankton compilation and the paleoclimate review and model by Sloan and Thomas with their contrast of a "background" Paleocene climate and the now famous Late Paleocene Thermal Maximum. Hutchison's paper at first glance appears to fall into the "esoteric" category; however, the point is well made that turtles are an important indicator species of this global warming event, because they were able to migrate through, and into, high-latitude and continental interior areas. The carbon and oxygen isotope paper by Corfield and Norris seems a bit dated; a 1999 *Science* paper by the same group on the same time period has much finer data resolution.

In summary, this is a good compilation of data and ideas concerning an important time slice of Earth history. Some notable gems in this volume should make an impact on future thinking about climate-related biotic change.

Erick A. Bestland
Flinders University,
Adelaide 5001, Australia

Melting the Earth: The History of Ideas on Volcanic Eruptions. *By Haraldur Sigurdsson, Oxford University Press, 1999, 260 p., $30.*

This new text addresses a generally ignored and societally important thread of scientific progress—our understanding of where magma comes from and why it erupts. It is well illustrated; the reproductions, many from the author's personal collection, help integrate a richly detailed text and heighten the interest and delight of the reader.

The text generally pursues a chronological sequence beginning with Stone Age Africans and continuing up into our present age of plate tectonics. The potpourri of thinkers leading to our current view of volcanoes includes natural philosophers, poets, engineers, chemists and alchemists, biologists, and physicists. A memorable message of this book is introduced by Sigurdsson in his preface (p. viii): "I have ... learned ... that most scientists are guilty of arrogance toward early researchers—an arrogance that is built on ignorance." Some studies, discredited because of age (i.e., more than a few years old) may contain clues to resolving current paradoxes. Moreover, our present outlook might easily be prejudiced by the arcane, false conclusions of much older work, about which we may be little aware. This is why scientific history is important. It shows us how we think, for better or worse. Sigurdsson properly calls pursuit of this history a professional "responsibility."

It is increasingly apparent that we must occasionally step across disciplinary boundaries to fulfill our potentials and improve an increasingly complicated world. So, it is inspiring to see a broadly experienced, multicultured scientist apply himself to history. The few historical errors in this book are forgivable: e.g., Octavian would roll over in his grave to read that Julius Caesar was an earlier Roman emperor. Significantly, however, the book suffers from a slight lack of organization. Mentions of many new personalities and developments in thinking are thrown at the reader; as a consequence, it is challenging to see quite how one scientific world-view emerged from another. In detail, the chronology of events, and even the distinctiveness of subject matter, jumps about with noticeable repetition of some material. Tighter editing and further discussion of the significance of new insights would have helped. Nonscientists, for whom this book is a suitable read, would also benefit from a glossary including such terms as "subduction."

Chapters three and five, concerning the eruptions of Minoan Thera, Lake Monoun, and the destruction of Pompeii, are thrilling. The letters of Pliny the Younger to Tacitus are all the more riveting because Sigurdsson weaves them into the deductions of his own research at Vesuvius. Many texts and articles have been written regarding the A.D. 79 eruption in particular. Still in print, many convey glaring misimpressions or inaccuracies to students of this event. Although quite general, the account in this book represents a new level of understanding that ought to supersede older "final words." The whole of these chapters is worthy of student reading in introductory geology courses as well as the attention of professionals. They are superb.

Despite its subtitle, this book does not deal with many ideas on volcanic eruptions, including, for example, our current understanding of pyroclastic deposits and processes. But it tackles the two really big fundamentals—how our modern views of igneous rocks and magma genesis emerged. The shortcomings mentioned above ought not deter any reader intrigued by the title. This is an important and welcome contribution. I hope that it stimulates further such work in the future.

Richard W. Hazlett
Pomona College
Claremont, CA 91711

Groundwater in Geologic Processes. *By Steven E. Ingebritsen and Ward E. Sanford, Cambridge University Press, Cambridge, UK, 1998, 341 p., hardback $69.95; paperback $32.95.*

Groundwater in Geologic Processes should be of interest to a wide, interdisciplinary audience because it reaches well beyond the standard assumptions of isothermal and nondeforming mediums common to most hydrogeologic investigations. Groundwater, as defined in the book is "any subsurface, aqueous fluid, including those of meteoric, connate, and magmatic origin." The result is work that covers a shared interest of geologists and hydrogeologists—the role of subsurface fluids in sedimentary basin evolution, ore deposition, tectonism, and diagenesis. The sciences of hydrogeology, physics, and chemistry are brought to bear on geologic processes, using field examples from around the world and representing numerous geologic environments. Topics include ore deposition, petroleum migration, upper-crustal heat transfer, earthquakes, diagenesis, and metamorphism. Many subsets of the broader topics are developed, such as the relationship of boiling-point-depth curves and gold deposition, or pore-fluid pressures that facilitate imbricate thrust faulting within accre-

Book Reviews *continued on p. 23*

Reminder: Call for Nominations

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

To be awarded for an outstanding paper on environmental geology published by GSA or by one of the state geological surveys during the preceding three full calendar years. The award is a $1000 cash prize presented in cooperation with the Association of American State Geologists (AASG). Nominated papers must establish an environmental problem or need; provide substantive information on the basic geology or geologic process and relate it to the problem or need; suggest solutions, provide appropriate land-use recommendations, or resolve the problem or need based on the geology; and present the information in a manner that is understandable and directly usable by geologists. Nominator must include a paragraph stating the pertinence of the paper.

Nominations are due by March 31, 2000.

OFFICERS AND COUNCILORS

The GSA Committee on Nominations requests your help in compiling a list of GSA members qualified for service as officers and councilors of the Society. The committee requests that each nomination be accompanied by basic data and a description of the qualifications of the individual for the position recommended (vice-president, treasurer, and councilor). Nominations are due by February 15, 2000.

NATIONAL AWARDS

The deadline for the William T. Pecora Award, the National Medal of Science, the Vannevar Bush Award, and the Alan T. Waterman Award is April 30, 2000.

Materials and supporting information for any of the nominations may be sent to Administrative Offices, Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140. For more detailed information about the nomination procedures, refer to the October 1999 issue of *GSA Today*, or visit our Web site at www.geosociety.org/aboutus/admin/awards.htm.

Book Reviews *continued from p. 22*

tionary prisms. For all topics there are rich citations of literature for those who want to pursue a topic in more detail.

The organization of the book lends itself for use as a classroom text and as a reference for professionals. Basic theories of groundwater flow, solute transport, and heat transport are developed in the first section. In the following chapters, these theories are applied to the processes described above. At the end of each chapter is a set of problems. The mathematics used (calculus) is at a level understood by most professionals and students who would have an interest in the subjects covered. Thirty-three pages of references from many scientific disciplines represent a resource in itself. As a special bonus, the book is well written and well illustrated.

Darryll T. Pederson
University of Nebraska
Lincoln, NE 68510

Historical Perspectives on Climate Change. *By James Roger Fleming. Oxford University Press, New York, 1998, 194 p., $45.*

This remarkable book documents the history of ideas concerning climate change since the 17th century. The 10 chapters are arranged in historical sequence. The first two chapters describe the rise of climatic determinism, a hypothesis that developed in Europe in the 1600s. Climatic determinism asserts that changes in the climate have influenced culture and society and are responsible for the wealth and level of civilization of different regions. Through the 18th century it was commonly held that the changes being wrought through settlement of North America by Europeans would make it a more habitable, culturally significant, and ultimately wealthy region. Deforestation was regarded as essential to creation of a healthy environment.

Chapters 3 and 4 describe the development of instruments for measuring temperature and pressure, and how observation gradually replaced anecdotal evidence as the collection of weather data became increasingly systematic through the establishment of meteorological offices in the late 18th and 19th centuries. Chapters 5 and 6 are devoted to history of the greenhouse concept through the work of Fourier, Tyndall, and Arrhenius. Chapter 7 discusses T. C. Chamberlin's application of ideas of climate change to the geological record. Chapter 8 describes the revival of climatic determinism by Ellsworth Huntington in the United States in the first half of this century. Chapters 9 and 10 are devoted to the changing ideas concerning global warming during this century.

Of particular interest to me was the discussion of ideas concerning the effect of carbon dioxide, much of which has been forgotten in the present arguments over its role in climate change. The importance of CO_2 as a greenhouse gas has been alternately in and out of fashion over the past century and a half. The discussion is remarkably prescient in anticipating the current debate over the role of carbon dioxide as the major agent responsible for the Cenozoic climate change toward cooler polar temperatures.

One of the most important features of this book is that it discusses who said and did what. It becomes clear that a considerable mythology has developed over the years as a result of the popular practice of attributing advanced ideas to early investigators. Fleming cites many cases of misquotation of older investigators and of disregard for placing statements in the context of scientific knowledge. This book is a must for anyone who teaches about climate change and the possibility of human influence on climate. It provides a sobering historical perspective. It deserves to be read and reread, especially before discussing our changing ideas about climate change with students and colleagues.

William W. Hay
GEOMAR
24148 Kiel, Germany ■

Geologists Probe Hominid Environments

Gail M. Ashley*, Department of Geological Sciences, Rutgers University, New Brunswick, NJ 08903, USA, gmashley@rci.rutgers.edu*

ABSTRACT

The study of an early Pleistocene "time slice" in Olduvai Gorge, Tanzania, provides a successful example of a reconstructed paleolandscape that is rich in detail and adds a small piece to the puzzle of hominid evolution in Africa. The reconstruction required multidisciplinary interaction of sedimentologists, paleoanthropologists, paleoecologists, and geochronologists. Geology plays an increasingly important role in unraveling the record of hominid evolution. Key questions regarding paleoclimate, paleoenvironment, and perhaps even hominid land use are answered by geology, and these answers provide a basis for multidisciplinary work. Landscape paleoanthropology integrates these data from several disciplines to interpret the ecological context of hominids during a narrow window of time. The multidisciplinary approach creates a "snapshot" with the highest temporal resolution possible. Inevitable limitations remain because of spatial variability of erosion and deposition and because of intrinsic time averaging of the sediment record.

INTRODUCTION

The questions of how and where humans evolved capture our attention and spark our curiosity. Recent applications of a variety of precise dating tools and the use of DNA typing have provided a strong case for Africa being the site of hominid evolution during the Pliocene, with waves of migration out of Africa as early as 1.8 Ma. However, primate populations are naturally small and their fossil record meager. Luckily, rifting has been active on the African continent since at least the Miocene. Rifting creates low areas that commonly contain the rivers and lakes so critical to life. Rifts also are sites of active volcanism and focused sedimentation and thus make ideal natural tombs.

There seem to be as many hominid family trees as there are anthropologists. Figure 1 illustrates three important aspects of hominid evolution about which there may be the most consensus (Wood, 1994). First, there was a common ancestor to humans and chimps ~5–7 million years ago. Second, *Australopithecus* (the earliest hominid group) evolved into two major lines, one *(Paranthropus)* dying out and the other leading to *Later Homo.* Third, the fossil record indicates that two and perhaps three or more species were living at one time.

In the early years of discovery, the study of hominid evolution was carried out by archaeologists and anthropologists. Geologists were usually relegated to answering the question, How old is the fossil? Few other data were collected from the geologic record that could be used to interpret paleoenvironments or paleoclimate. How the animals lived was often left to the imagination. Most scientists now agree that humans evolved with other primates in Africa. The important questions being asked about their evolution are: What were the climate and environment like? Did climate fluctuate or show trends? Were hominids vegetarians or omnivorous scavengers? Did they hunt or were they hunted?

We can focus the expertise of sciences such as geology, chemistry, biology, and hydrology on the same problems. The challenging areas of research often lie at artificially imposed discipline boundaries. Here lies the potential for synergy and perhaps even the generation of a new science (Fig. 2). However, integrating sciences is not as easy as it might first appear. It requires people to learn language, theories, methodologies, and a bit about the "culture" of the other science and to continually walk in the other person's shoes. Simply having lots of scientists with different backgrounds working in parallel on the same project doesn't produce the same end result as integrative science.

This paper describes a study at Olduvai Gorge, Tanzania (Fig. 3), using a relatively new approach, landscape paleoanthropology, that attempts to interpret the landscape during a geologic instant in time. The project is the Olduvai Landscape Paleoanthropology Project (OLAPP), involving a multidisciplinary team. Teamwork is needed to determine the environmental context, to flesh out the details of topography, hydrology, and biota, and to provide insights into hominid land use (Peters and Blumenschine, 1995).

LANDSCAPE PALEOANTHROPOLOGY

Landscape paleoanthropology depends on experts applying to the problem the major sciences like geology, biology, anthropology, and hydrology in concert. At least 12 disciplines have been used to answer key questions about hominid evolution and to interpret the paleolandscape (Table 1).

The rich fossil and cultural records at Olduvai were made world famous by Louis and Mary Leakey, starting in the late 1930s. Most of the systematic excavation and publication of the Olduvai record was carried out by Mary (Leakey, 1971). The Leakeys' pioneering work helped put branches on the hominid family tree and gather important data on the evolution of tool making. Their approach to studying paleoanthropology, typical of the time period, was to make a "space slice" through time by looking at temporal changes in relatively small areas (square meters) (Fig. 4). In landscape paleoanthropology, data are collected over a large area (square kilometers) representing very little time, in order to answer some of the questions about the nature of the environment in which hominids lived and how they might have interacted with it.

GEOLOGIC SETTING

Olduvai Gorge is located just south of the equator in northern Tanzania. It lies in a shallow basin just west of a large Pliocene-Pleistocene volcanic complex (Ngorongoro) that occurs at a point of bifurcation in the East African Rift (Hay, 1976). The gorge was incised into the eastern edge of the Serengeti Plain during the late Pleistocene. Figure 3 shows photos of the modern Gorge.

Olduvai Gorge exposes ~100 m at its deepest section (Fig. 3B). It is floored by basalts and comprises interbedded volcanic tuffs and reworked volcaniclastic sediments. It is a record of the past 2 m.y. At first glance it looks like a simple layer cake with ideal sequences for correlation over great distances. However, a detailed study of the geology of Olduvai Gorge revealed that the

TABLE 1. SUBDISCIPLINES USED TO ANSWER QUESTIONS IN OLDUVAI LANDSCAPE PALEOANTHROPOLOGY PROJECT

Fundamental questions being asked	Subdiscipline
What was the paleolandscape like?	Geomorphology, sedimentology, clay mineralogy
What are the age and duration of the time slice?	Geochronology, volcanology, paleontology
What were the climate and vegetation like? Did they vary through time?	Paleobotany, geochemistry, soil science
What were the fauna like?	Paleontology, archaeology, paleoanthropology
Were hominids present?	Paleontology, archaeology, paleoanthropology

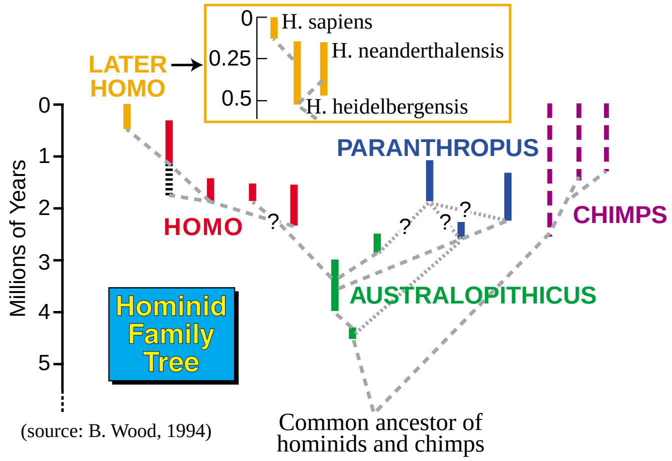


Figure 1. Hominid family tree suggests that hominid and chimpanzee clades diverged ~4–5 Ma and that a major hominid group *(Paranthropus)* died out, leaving *Homo* and *Later Homo* lines (modified from Wood, 1994).

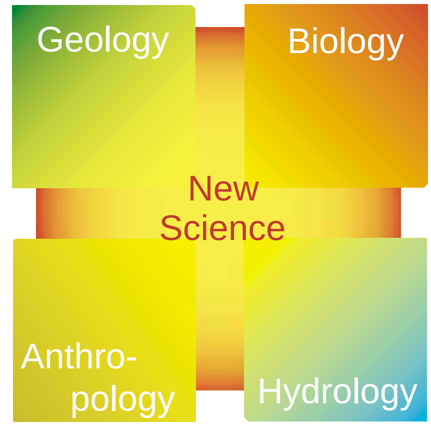


Figure 2. Interdisciplinary approach involving geology, biology, hydrology, and anthropology is needed to interpret early Pleistocene landscape and how hominids might have interacted with their environment. This approach may even lead to a new science. Figure by J. S. Delaney.

geology was anything but a "piece of cake"; the layers were chopped up by rift-parallel faults (Hay, 1976, 1990). Hay showed that the stratigraphy could be separated into four major chronologically based units. The time slice that we chose to study is early Pleistocene in the lowermost part of bed II. Our approach was to study the geologic record between two mappable tuffs (Fig. 5); 103 trenches, 4–6 m deep and 1–2 m wide, were excavated within a 20 x 20 km area. The section was meticulously excavated centimeter by centimeter, all sediment was sifted, and all bones and artifacts were collected. The step trenches created by this tedious process provided wonderful exposures for studying sedimentology, soil development, and the fossil record.

RESULTS AND DISCUSSION

We asked many fundamental questions about the chosen time slice and called on a range of specialties to help with the answers (Table 1).

What Was the Paleolandscape Like?

Hay's original interpretation of the landscape described a basin with streams flowing into it from the Serengeti on the west and an alluvial fan reworking the volcaniclastic sediments on the east (Hay, 1976). In general, we saw similar features, but the high-resolution study of the depositional environments revealed that surface runoff on the volcaniclastic fan was intermittent and that a large and persistent groundwater-fed spring system occurred at the eastern lake margin, freshening the lake (Fig. 6). Freshwater wetlands, several square kilometers in area, fringed the springs. We used both modern environments and sedimentary evidence from our time slice to visualize what the springs and wetlands were like. Carbonate spring tufa likely formed by carbonate precipitation when CO_2 degassed as groundwater disgorged (Fig. 7A). A highly siliceous earthy claystone contains abundant paleobotanical remains (Fig. 7B). We find from modern studies that springs can be relatively small, but highly reliable throughout the year, and can support hundreds (maybe thousands) of animals daily (Deocampo, 1997).

A synthesis of the 103 trenches revealed that the environments varied dramatically across the basin. Using modern analogs as a guide, we interpreted the sedimentary records found in our time slice to reconstruct a landscape dominated by a lake that expanded and contracted with time, by an active volcano that periodically disgorged sediment, and by a groundwater-fed spring system that seemed to persist despite short-term changes in climate (Fig. 8). The sedimentary sandwich contains the record of the large saline-alkaline lake in the center of the basin that had distinctly fresher water on the eastern margin. There were two major expansions of the lake. Unfortunately, the western part of the sedimentary record appears to have been subsequently eroded.

Hominid Environments *continued on p. 28*

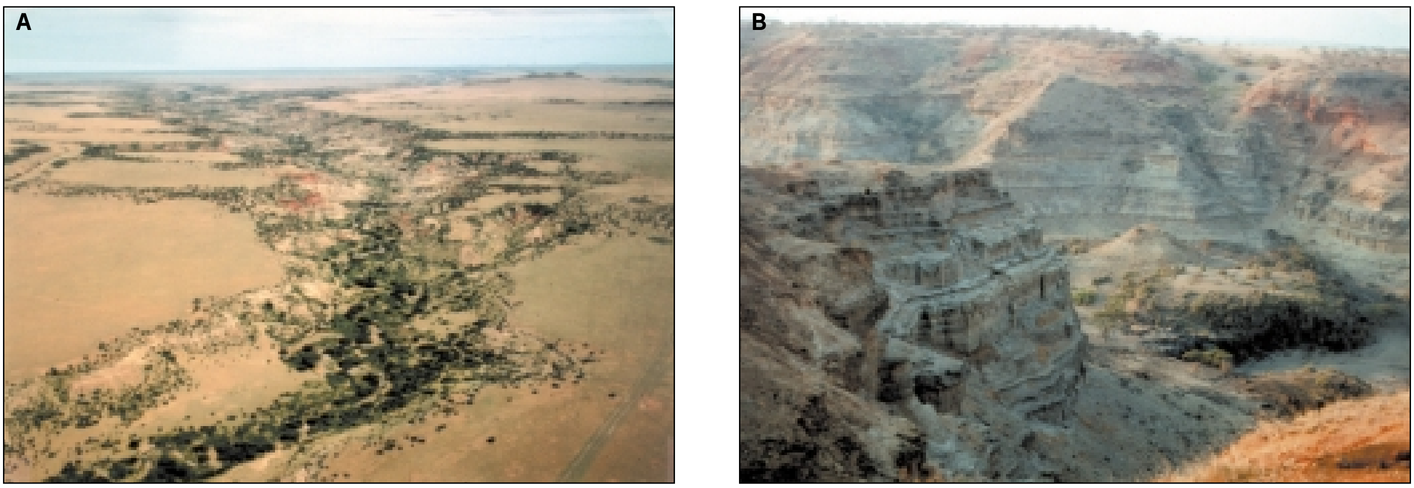


Figure 3. A: Olduvai Gorge, looking west toward Serengeti Plain away from rift valley (photo by R. J. Reeder). B: Two m.y. record of primary air-fall and reworked volcaniclastic sediments containing rich biological and cultural records are exposed in 100-m-high outcrops.

STUDENT NEWS AND VIEWS

Kyoko Ohashi, *State University of New York at Stony Brook*

Student News and Views provides GSA membership with commentary on matters relating to undergraduate and graduate students in the geosciences. The correspondent for Student News and Views welcomes comments and suggestions, sent to stumatts@geosociety.org.

Leaping

"What is the sound of a bell ringing 00 times?" This (or some variant thereof) was often asked between students when I was an undergraduate at Bryn Mawr College. The bell was that of Taylor Hall in the center of our campus. We had a tradition in which seniors, after completing their very last finals, rang the bell the same number of times as their graduation year (e.g. 95 times in my case). So what was the class of '00 to do? Ring the bell 2,000 times? Good luck—my friends and I nearly burned the skin off the palms of our hands trying to pull the bell rope. In the end, the five of us were clinging to the rope as one big mass, feeling the rope slowly moving (or was it just us sliding down?). We will never know whether we managed to ring the bell or not, and if so, how many times. A person inside Taylor Hall cannot hear the sound from the bell tower. So it wouldn't make a difference to this year's seniors whether they decide to ring the bell zero times or 2,000; they won't hear it anyway. It was something we should have expected from a school like Bryn Mawr—to give us a humbling experience to top off four grueling years.

Although it seemed like a distant prospect at the time, graduation of the class of 2000 is nearing. To me, a 1995 alumna, this can mean only one thing; my first reunion is coming up. Recognizing an excuse to visit the campus, I volunteered for the reunion organizational committee. With a vested interest, I asked a few friends over the summer if they were coming to the reunion. While the response "I don't know, are you?" was typical, another was "I'm not going. I'm not where I want to be in life." (Maybe she said "yet" at the end of that sentence.) Where does she want to be in life, then? I did not ask, but I know she is in the final stages of completing her Ph.D. dissertation. So being a Ph.D. is her answer, at least if you ask her now. If you ask me while I'm trying to put together my dissertation proposal, hers is an enviable position. She is where *I* want to be. Further, where both of us probably want to be is ... to have a career that is challenging, rewarding, and fulfilling, a beautiful child or garden or spouse ... and a big dog or house or book budget. None of us will ever make it to the reunion if we adhere to such a mentality. We know how easily one can fall into the trap of thinking this way, as the movie "Romy and Michelle's High School Reunion" hilariously illustrated. Yet if people feel they are not where they want to be now, will they ever feel that way?

A political science professor in college once gave this example to illustrate two kinds of enjoyment: "Take mystery novels. Do I read 10 mystery novels and feel enjoyment only after finishing them, or do I enjoy myself while reading them?" The two types of fun are often present in a single situation, but I still think about his words often, especially when I am studying. I am then reminded of another friend from college, who is about to receive her Ph.D. in physics. She has always loved and excelled in physics. She has thrived especially on solving problems. Yet, she says, the prospect of spending the rest of her life in a physics career did not appeal to her. She has taken some business classes, and plans to start working in finance when she receives her degree.

Hearing her story, I was left with the impression that physics could not provide her the second type of enjoyment the professor talked about—the thrill of being in the midst of something, even if it more often than not triggers headaches. Experiencing this is crucial to any serious undertaking. The first kind, which arises from a sense of accomplishment, can only take us so far. At the same time, it is easy to forego looking for the second ("What if, heaven forbid, I make the wrong choice and jump into something that is all drudgery and no fun?") I suspect this is partly why I tend to read and mull over ideas concerning my research, as opposed to actually putting something down on paper. As a result, when I finally turned in the first draft of my proposal, it was to me the best work I've ever done—despite its being just three pages long and consisting mostly of background information—just by virtue of it having materialized.

Katharine Hepburn, an alumna of Bryn Mawr, wrote this of her alma mater:

> It was my springboard into adult life.
> Slowly you work your way to the end of the board.
> You begin to get your balance. You're getting set
> for the spring—the leap—the ...
> Good bye ... I've got it ... I've got my balance ...
> Here I go.
> And you jump. With some hope of landing on your feet.*

The mix of anticipation and fear (and the faintly tragi-comic nature of that state, when seen from another's point of view) is something, I'm sure, known to many people, especially students. Maybe that is why the Mr. Bean episode about his fear of jumping from the springboard is such a classic among fans. With that in mind, I should resume jumping off the board and work on my proposal. Now, if I can only find that paper I wanted to read first....

* Hepburn, K. H., To Leap, *in* Labalme, P. H., ed., A century recalled: Essays in honor of Bryn Mawr College, Bryn Mawr College Library, 1987.

Call for Applications and Nominations for GSA *Bulletin* Editor

The GSA *Bulletin* seeks a co-editor, beginning January 1, 2001. The new editor will replace the editor whose term ends in 2000 and will serve a four-year term. A phased transition should begin in the summer of 2000.

The GSA *Bulletin* has a 112-year history of excellence in publication of definitive works related to all aspects of geoscience. Part of GSA's mission is to bring together different earth sciences in a forum for scientific inquiry and discussion, and the *Bulletin* editors will be charged with continuing this tradition while helping Society staff find the best ways to provide comprehensive manuscripts in the electronic environment.

Editor Duties

1. Continue to maintain excellence of journal content through active solicitation of diverse and definitive manuscripts.
2. Ensure stringent peer review and expeditious processing of manuscripts.
3. Make final acceptance or rejection decisions after consideration of recommendations of reviewers and Associate Editors.
4. Correspond with authors regarding revisions and expeditious return of final manuscripts. Maintain active correspondence with current and potential contributors.
5. Select contents for each issue that will interest the broadest audience possible.
6. Select and maintain an active board of Associate Editors.
7. Report to the Committee on Publications on manuscript topic trends and issues specific to the *Bulletin*.

Editor Qualities

1. Broad personal background and active research in the geological sciences. Broad knowledge of geological research activities of scientists both nationally and internationally.
2. Interest in electronic publishing and in maximizing *Bulletin* content for print and electronic media.
3. Willingness to try new techniques to enhance author and reader satisfaction (e.g., theme issues).
4. Excellent organizational skills and ability to manage significant manuscript flow to ensure timely publication of papers. Ability to supervise editorial assistant to ensure that schedules are maintained.
5. Ability to remain tactful and helpful to authors, yet create and maintain stringent acceptance and rejection policies.
6. Willingness and capability to coordinate working schedules with a co-editor.
7. Willingness to invest about one day per week on *Bulletin*-related activities.
8. Objectivity and scientific maturity.

To Apply or Nominate

If you are interested in this opportunity to help guide the *Bulletin*, one of the premier geoscience journals, submit a resume and a brief letter describing relevant qualifications, experience, and objectives. If you are nominating someone, include a letter of nomination and the nominee's written permission and resume. Send nominations and applications to Peggy S. Lehr, Chief Operating Officer/Director of Publications, Geological Society of America, P.O. Box 9140, Boulder, CO 80301 by May 15, 2000. ■

Hominid Environments *continued from p. <None>*

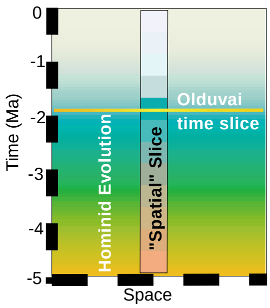


Figure 4. Traditional approach to studying hominid evolution was a "space slice" that examined representative sites (small excavations of fossils and artifacts) and studied the change of record with time. New approach, a "time slice," attempts to interpret a paleolandscape as a snapshot in time to highest resolution possible, given limitations of time averaging of sediment record. Olduvai time slice is at ~1.75 Ma.

Figure 5. Archaeological step trench placed between two isochrono-stratigraphic tuff beds, Tuff IF (lower arrow) and Tuff IIA (upper arrow). The 103 trenches that were excavated in sediments (between these tuffs) likely represent ~50,000 yr period.

What Are the Age and Duration of the Time Slice?

We take advantage of the bracketing volcanic tuffs (which were deposited in an instant of geologic time) to define ages. Feldspar crystals from the lower tuff (which is a trachyandesite deposit) were analyzed by argon-argon single-crystal laser dating technique (by Alan Deino at Berkeley Geochonology Center). Dating revealed an age slightly older than 1.75 Ma. (A. Deino, personal communication) for the lower tuff. The upper tuff appears to have been mixed and contaminated by surficial processes, and at present we do not have reliable dates on it. The vertebrate fossil record, which is useful for paleoenvironmental information, cannot be used for high-resolution time analysis. However, the evidence for major expansions of the lake can be used as a tentative means of estimating time. The dominant Milankovitch signal recorded in the world's marine records during this early Pleistocene time is ~41,000 yr (deMenocal and Bloemendal, 1995). Research with eolian dust levels in marine cores off the coast of Africa suggest that wet-dry cycles at low latitudes may occur in sympathy with the 41 k.y. cold-warm cycles seen at higher latitudes. If that is true, then the one major lake cycle within our time slice would represent the 41 k.y. cycle and our time slice would be ~50,000 yr long.

What Were the Climate and Vegetation Like? Did They Vary Through Time?

The lake margin was a key area for recording climate. The lake periodically flooded the margin and the groundwater exited at the base of the slope. The fossil evidence for grasses and sedges is abundant, but woody plant preservation is sparse. Some root casts and remains of fossilized wood up to 6 cm in diameter are preserved.

An impressive red soil developed on the lake margin (Fig. 8). Steven Driese (University of Tennessee) and I have determined that the red soil records a major fluctuation in the water table during the early part of our time slice; it went from wet to dry to wet, creating the strong red coloration. Subsequently the climate became quite arid. Soil-forming processes at the top of the red soil were dominated by alkaline conditions and zeolite formation. Geochemical profiles through the soil detected three volcanic eruptions, suggesting that new material was frequently added to the surface during its formation.

What Were the Fauna Like? Were Hominids Present?

Several thousand bones were collected and identified during the excavation of the 103 trenches. A large proportion can be identified, and a story of the animals that lived there is gradually emerging. One hominid tooth, probably belonging to the extinct *Paranthropus* branch of the hominid family tree, was found. Additional evidence for hominids on the landscape is clear. Thousands of stone tools representing Oldowan culture were collected and are being analyzed. These tools are similar to the thousands collected by Mary Leakey (1971).

About 10%–15% of the long bones showed evidence of cut marks made by hominids with stone tools. About 40% of the bones either had carnivore tooth marks or the bone ends showed ravaging by carnivores. Bone and artifact density is plotted as a function of depositional environment in Figure 9. The highest concentrations are associated with potable water sources. The highest density of bones and stones occured in a river draining the Serengeti. This is not surprising, but the previously unrecognized presence and importance of springs and the groundwater-fed wetlands as a focus of hominid activity on the eastern shore of the lake were not anticipated. Apparently hominids were attracted to this freshwater habitat for water, root stocks, and fruits, and to scavenge carcasses (Bunn, 1981; Blumenschine, 1995).

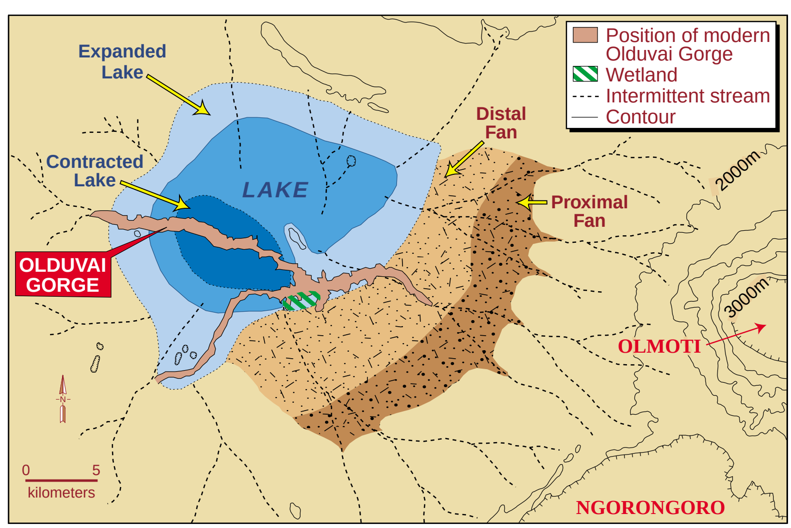
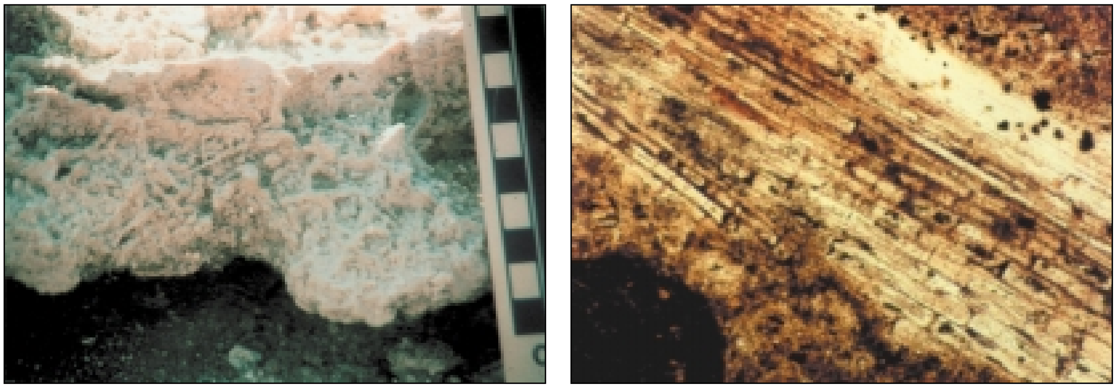


Figure 6. Paleogeographic reconstruction of landscape at 1.75 Ma. Lake in center of basin expanded and contracted with climate. Pyroclastic fan built from the east, and small groundwater-fed wetland occurred on lake margin.

Figure 7. Left: Tufa. Fenestral carbonate-encrusted roots and stems in localized deposits (1–2 m^2). Interpretation is that tufa represents precipitation of $CaCo_3$ at spring heads resulting from degassing of CO_2 at spring orifice. Right: Paleobotanical remains. Thin section of silicified plants in earthy claystones thought to represent sedimentary record of lake margin wetlands. Micrograph width is 1.9 mm.



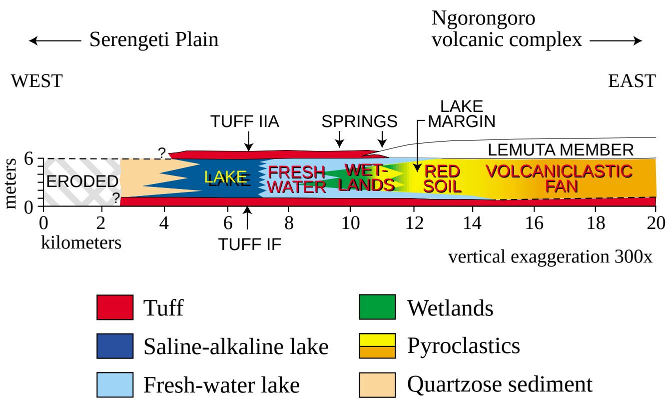


Figure 8. Time slice of Lowermost Bed II is 20 km wide and 6 m high. Sedimentary facies analysis reveals a volcaniclastic fan building from east into saline-alkaline lake that was freshened slightly in vicinity of the wetlands. Streams drained into western part of lake from Serengeti.

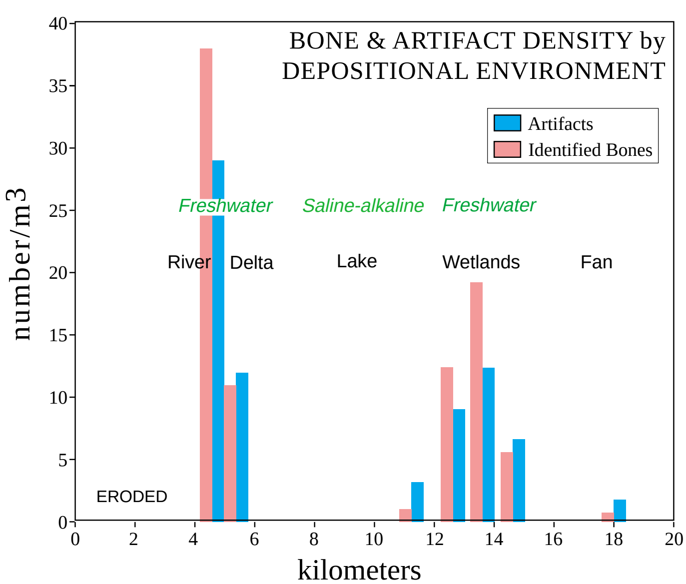


Figure 9. Preliminary results of density of identified bone and artifacts as a function of depositional environment. Greatest density is in a river draining from Serengeti, but a surprisingly large concentration was found in spring-fed wetlands located on eastern lake margin. This suggests focus of hominid activity that had not been recognized before.

CONCLUSIONS

This example from East Africa demonstrates that multidisciplinary approaches and integrative science are absolutely critical to answering the many questions of paleoenvironmental reconstruction. The high density of bones and artifacts in the wetland environment strongly suggests a focus of hominid activity at the lake margin directly related to the appeal of the wetland rather than the presence of the saline and alkaline lake. The importance of wetlands to the ecology of hominids at Olduvai was not recognized before. This linkage might not have been noticed by geologists or archaeologists or anthropologists working alone.

ACKNOWLEDGMENTS

The Olduvai Landscape Paleoanthropology Project involves about 25 scientists from Tanzania, the United States, South Africa, the United Kingdom, and Canada, and an equal number of support staff from Tanzania. Principal investigators are Robert J. Blumenschine (Rutgers University) and Fidelis T. Masao (Dar es Salaam). I am indebted to all OLAPP scientists for their generosity in discussing ideas and data. I am particularly grateful to Richard Hay for his valuable insights into the complicated geology of Olduvai, his continued moral support, and the unpublished data that he shared with me. Research was sponsored by the U.S. National Science Foundation (Archaeology BNS 9000099 and SBR 961065, Geosciences 9903258).

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Graduate Student Support Opportunities in Earth Sciences, Lehigh University —The Department of Earth and Environmental Sciences of Lehigh University has Graduate Student Fellowships for highly qualified individuals. The department has active research programs in tectonic studies (geochronology, stable isotope geochemisty, low temperature geochemistry, seismology, high resolution geophysics, structural geology, paleomagnetism) and surficial processes (low temperature geochemistry, fluvial and tectonic geomorphology, glacial geology, hydrology, and limnology). Please contact Prof. D. Morris, Dept. of Earth and Environmental Sciences (dpm2@lehigh.edu) or see our Web page for more details (http://www.ees.lehigh.edu).

Master's/Ph.D. Fellowship Available, Baylor University. The Department of Geology at Baylor University is pleased to announce the creation of the Wendlandt Fellowship, available to an outstanding incoming graduate student in the fall of 2000. The fellowship is supported by an annual stipend of $14,000 plus full tuition. More detailed information on the fellowship and on available graduate programs can be obtained at: www. baylor.edu/~Geology/ studentinfo.html. In addition to the Wendlandt Fellowship, there are also a number of teaching assistantships available at $12,000/yr + tuition (Masters) or $15,000/yr + tuition (Ph.D.s). For information or application please contact Dr. Thomas Goforth, Baylor University Dept. of Geology, PO Box 97354, Waco, TX 76798-7354; (254) 710-2361; e-mail: tom_goforth@baylor.edu.

Graduate Assistantships available, University of Akron: The Department of Geology, University of Akron, has multiple graduate assistantships in our MS program available for Fall 2000. Students with a GPA of 3.0 or above are invited to apply for 9-month assistantships valued at $9,500 with a full remission of tuition and fees. Research interests of our twelve faculty range from the traditional areas of geology and geophysics to a specialization in Quaternary Research covering such topics as hydrogeology, paleoclimate reconstruction, glacial geology, ancient lake systems, surficial processes, karst systems, aqueous geochemistry, and GIS. Akron is undergoing a cultural resurgence marked by new construction across campus and the adjacent downtown area. The city is located adjacent to extensive green spaces in neighboring Cuyahoga Valley National Recreation Area. Prospective students can request an information package or learn more about the graduate program and current research opportunities by visiting the departmental Web site (http://www.uakron.edu/geology/) or can contact the Graduate Advisor, Department of Geology, University of Akron, Akron, OH 44325-4101 for additional information.

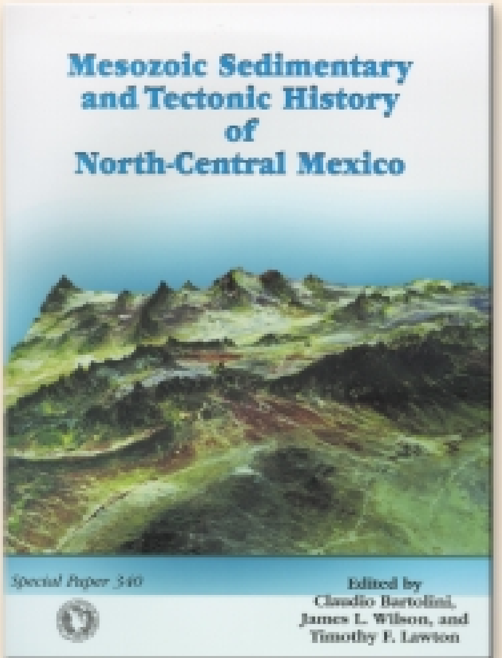
Graduate Student Research Grants, The Society for Organic Petrology (TSOP). TSOP invites applications for two graduate student research grants of up to $1000 each. The purpose of the grants is to foster research in organic petrology (which includes coal petrology, kerogen petrology, organic geochemistry and related disciplines) by providing support to graduate students who demonstrate the application of organic petrological concepts to research problems.

The Grant Program focuses on support of qualified candidates for masters or equivalent degrees. Qualified doctoral candidates with expenses beyond the usual scope of funding by other agencies are also encouraged to apply. Grants are to be applied to expenses directly related to the student's thesis work such as summer fieldwork, laboratory expenses, etc.

Grant application deadline is March 31, 2000. Grants will be awarded in September 2000. Detailed information and an application form are available on the TSOP Web page: http://www.tsop.org, or from C. L. Thompson- Rizer, Conoco Inc. PR 3072, P.O. Box 2197, Houston, TX 77252-2197 USA, phone (281) 298-3160, fax: 281-293-3833, or e-mail: carolyn.thompson-rizer@usa. conoco.com.

Center for Environmental Analysis – Centers for Research Excellence in Science and Technology (CEA-CREST) A major goal of CREST is to increase the number of underrepresented minorities with PhDs in science, mathematics, engineering, and technology. CEA-CREST provides generous financial support for students: $8,000/yr undergraduate research assistantships and $15,000/yr fellowships for master's degree students, plus funds for travel to national scientific meetings. Additional support for graduate students is available through teaching assistantships and numerous financial aid options. For more information please contact: CEA-CREST, California State University, Los Angeles, 5151 State University Dr., Los Angeles, CA, 90032-8970, (323) 343-5799, ceacrest@calstatela.edu, http://cea-crest.calstatela.edu. ■

Mesozoic Sedimentary and Tectonic History of North-Central Mexico



edited by
C. Bartolini,
J. Wilson, and
T. Lawton, 1999

Learn about the geology of north-central Mexico through 21 papers that span the assembly of Pangea in the Permian–Early Triassic, the Mesozoic opening of the Gulf of Mexico, and the evolution of the Mexican geosyncline. Topics include analysis of the Permian-Triassic magmatic arc from surface and well data; detailed stratigraphy and paleontology of red beds of Late Triassic and Middle Jurassic age along the Gulf of Mexico coast region; studies on the Jurassic-Cretaceous boundary in eastern Mexico, as well as a strong emphasis on the sequence stratigraphy, sedimentology, and microfacies of Upper Jurassic to Cretaceous successions of northeastern Mexico; selective studies in La Popa basin, and tectono-stratigraphic analyses of the lower Middle Jurassic geology in central Mexico. Gravity and paleomagnetic investigations in northern Mexico complement many of the tectonic and structural papers.

SPE340, 380 p., indexed, ISBN 0-8137-2340-X,
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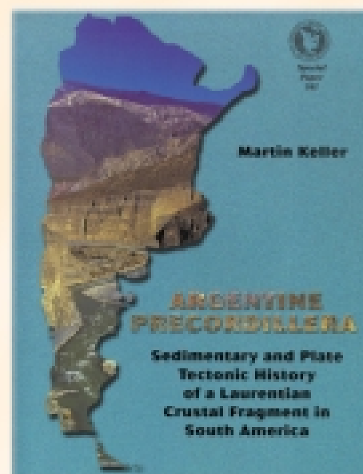
Argentine Precordillera
Sedimentary and Plate Tectonic History of a Laurentian Crustal Fragment in South America

Martin Keller, 1999



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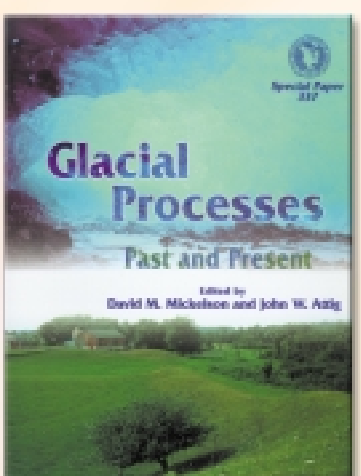

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