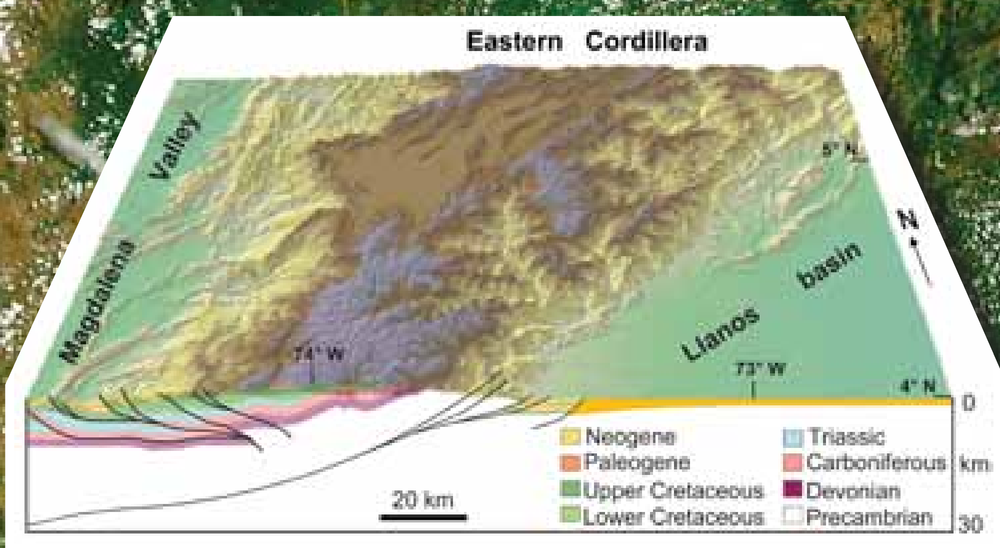
# GSA TODAY

VOL. 20, No. 7 A PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA JULY 2010


## Resolving uplift of the northern Andes using detrital zircon age signatures

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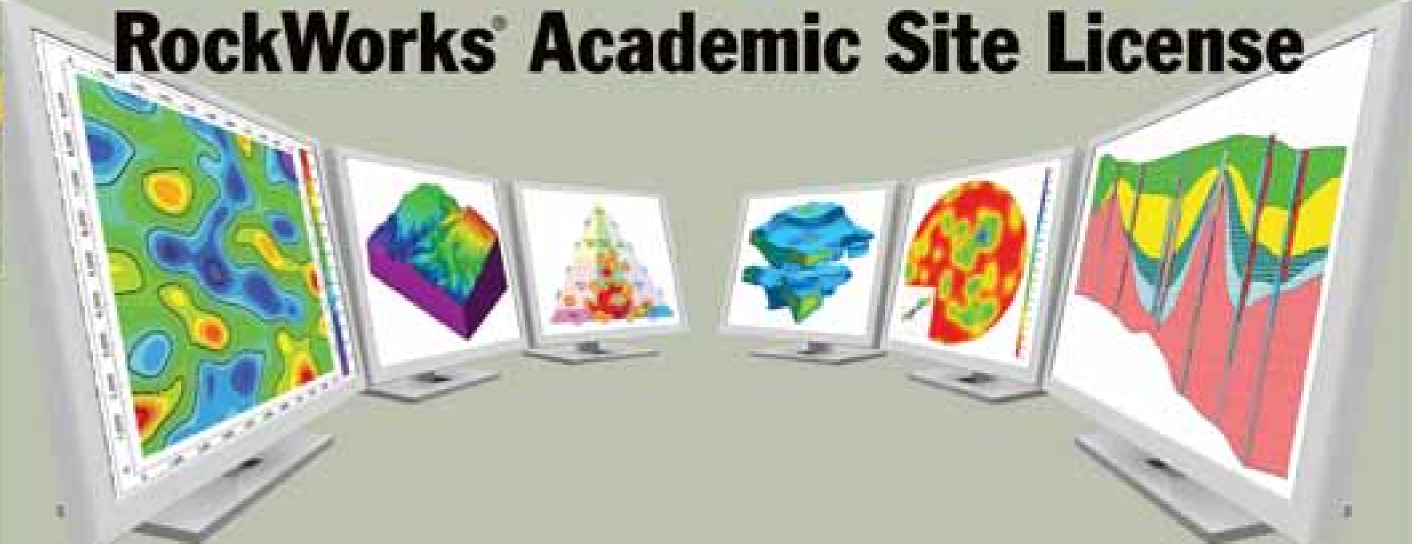

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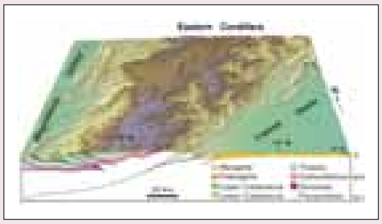
VOLUME 20, NUMBER 7 ▲ JULY 2010

## SCIENCE ARTICLE





**Cover:** View of the northern Andes of Colombia. Block diagram by Andrés Mora depicts modern topography and generalized subsurface structure of the Eastern Cordillera and bordering Magdalena Valley (left) and Llanos basin (right). Background image courtesy NASA. See "Resolving uplift of the northern Andes using detrital zircon age signatures" by B.K. Horton et al., p. 4–9.



**Corrections & Clarifications**
The receipt and acceptances dates for the Groundwork article in the June issue of *GSA Today* (v. 20, no. 6, p. 52–53) were inadvertently left out of the issue. The article, Innovations in the built environment for earth science, by M.A. Chan, was received 23 February 2010 and accepted 19 March 2010.

# Resolving uplift of the northern Andes using detrital zircon age signatures

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## ABSTRACT

Uplift of the Eastern Cordillera in the northern Andes has been linked to orographic climate change and genesis of South America's largest river systems. The timing of initial uplift remains poorly constrained, with most estimates ranging from ca. 60 to ca. 5 Ma. New detrital zircon U-Pb ages from proximal fill of the Llanos foreland basin in Colombia reveal a pronounced mid-Cenozoic shift in provenance from an Amazonian craton source to an Andean fold-thrust belt source. This shift corresponds with changes in detrital zircon (U-Th)/He ages, a conglomeratic unroofing sequence, and a sharp increase in foredeep accumulation rates. These nearly simultaneous changes in zircon age spectra, clast compositions, and sediment accumulation are attributable to latest Oligocene uplift of the eastern flank of the Eastern Cordillera. The timing relationships suggest an early activation of the frontal thrust system, implying a long-term (up to 25 m.y.) cessation of orogenic wedge advance, potentially driven by structural inheritance and/or climate change.

## INTRODUCTION

Surface uplift of the Eastern Cordillera in the northern Andes has had a profound effect on orographic climate change (Mora et al., 2008), growth of large continental drainage systems (Fig. 1) (Amazon, Orinoco, and Magdalena rivers; Hoorn et al., 1995; Díaz de Gamero, 1996), and biologic evolution of neotropical rainforests (Hooghiemstra and Van der Hammen, 1998; Jaramillo et al., 2006). Most estimates for the onset of uplift along the eastern flank of the Colombian Andes (Fig. 2) range from Paleocene to Pliocene time (Van der Hammen et al., 1973; Dengo and Covey, 1993; Cooper et al., 1995; Bayona et al., 2008; Parra et al., 2009a).

Initial uplift has proven difficult to constrain by conventional methods. First, recent zircon fission track data provide a minimum age but do not uniquely pinpoint the precise onset of earliest uplift-induced exhumation (Parra et al., 2009b). Second, insights from synorogenic growth strata are commonly limited by inadequate exposure, poor seismic resolution, and minimal variation in stratal dip (e.g., Toro et al., 2004). Third, clastic compositional records of erosional unroofing are hindered by the uniformly high-maturity (quartz-dominated) sand compositions imposed by intense tropical weathering (e.g., Johnsson et al., 1988).

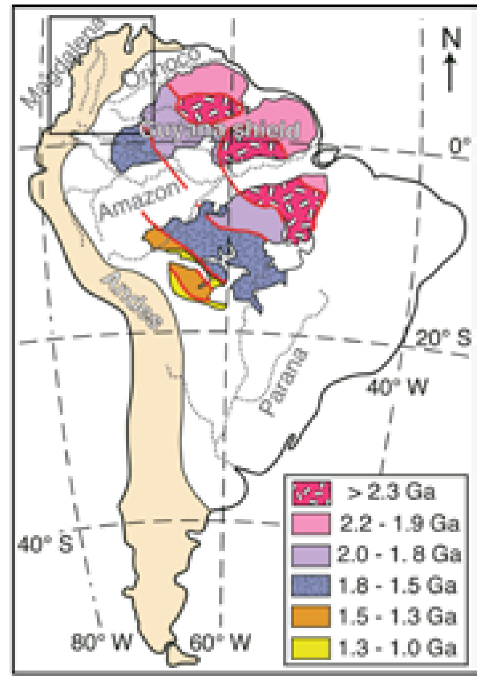


Figure 1. Map of South America showing main river systems (Magdalena, Orinoco, Amazon, and Parana) and Precambrian crustal provinces of the Amazonian craton (after Cordani et al., 2000; Chew et al., 2007).

In this study, we utilize U-Pb and (U-Th)/He ages of detrital zircon grains from the Colombian Andes to demonstrate that initial uplift-induced exhumation along the eastern flank of the fold-thrust belt had commenced by ca. 26–23 Ma. Timing relationships revealed by geochronological data coincide with shifts in conglomerate clast compositions and sediment accumulation rates and provide new insights into the pace of orogenic wedge advance.

## GEOLOGIC SETTING

The Eastern Cordillera of Colombia forms a 1–4-km-high orographic barrier separating the intermontane Magdalena Valley from the Llanos foreland basin (Fig. 2). The 100–200-km-wide range is bounded by a frontal thrust system consisting of inverted normal faults and newly formed fold-thrust structures (Cooper et al., 1995; Mora et al., 2006). Following Jurassic–Early Cretaceous rifting, Andean orogenesis began with latest Cretaceous–Paleocene shortening in the Central Cordillera and early foreland basin evolution in the present-day Magdalena

*GSA Today,* v. 20, no. 7, doi: 10.1130/GSATG76A.1


Figure 2. Shaded relief map showing tectonomorphic provinces of the northern Andes (after Mora et al., 2006) and 12 sample locations (white dots). CC—Central Cordillera; EC—Eastern Cordillera; MV—Magdalena Valley; WC—Western Cordillera.

Valley and Eastern Cordillera (Cooper et al., 1995; Gómez et al., 2003). The locus of deformation advanced eastward, reaching the western edge of the Eastern Cordillera by middle Eocene–Oligocene time (Restrepo-Pace et al., 2004; Gómez et al., 2005a; Montes et al., 2005; Parra et al., 2009b; Nie et al., 2010).

The Eastern Cordillera consists of Cretaceous quartzose sandstone and mudrock with subordinate Cenozoic, Jurassic, and Paleozoic clastic units capping localized occurrences of crystalline basement. Phanerozoic clastic units are quartz rich (Villamil, 1999), rendering sandstone petrography less effective in addressing provenance history (Johnsson et al., 1988). Prior to Andean uplift, terrigenous clastic sediment was derived from basement exposures to the east, in the Guyana shield of the northern Amazonian craton (Fig. 1) (Cooper et al., 1995). A reversal in sediment transport was triggered by uplift of principally magmatic-arc rocks in the Central Cordillera (Villamil, 1999; Gómez et al., 2005b) followed by uplift and erosional recycling of sedimentary rocks in the Eastern Cordillera (Cooper et al., 1995; Bayona et al., 2008).

The Cretaceous-Cenozoic stratigraphic successions of the Eastern Cordillera and Llanos basin (Fig. 3) consist of clastic units assigned to synrift, postrift, and foreland basin deposition (Cooper et al., 1995). Principally marine facies characterize the 3–8-km-thick Cretaceous succession, including diagnostic glauconitic sandstones in the Une, Chipaque, and Guadalupe units. The overlying 2–3-km-thick Paleogene section contains a range of nonmarine sandstone units that can be correlated from the interior of the Eastern Cordillera into the Llanos basin (e.g., Cacho, Barco, Regadera, and Mirador Formations). The youngest basin fill includes an upward coarsening, 3–5-km-thick Neogene section composed of mudstone, sandstone, and conglomerate of the Carbonera, León, and Guayabo Formations (Fig. 3).

## U-Pb GEOCHRONOLOGY

### Methods

Zircon grains from 12 samples of Cenozoic sandstones were separated by standard heavy liquid techniques, selected randomly, and analyzed by laser-ablation–inductively coupled plasma–mass spectrometry. Analyses and associated age calculations followed methods outlined by Chang et al. (2006), utilizing results for zircon standards Peixe (564 ± 4 Ma) and Temora (416.8 ± 1.1 Ma).

We report a total of 1107 U-Pb ages (see supplemental data Table DR1[1]) obtained by analyses that generally yielded <10% discordance, <5% reverse discordance, and <10% uncertainty. Interpreted ages represent $^{206}Pb/^{238}U$ ages for grains younger than 900 Ma and $^{207}Pb/^{206}Pb$ ages for grains older than 900 Ma. Results are plotted on relative age probability diagrams (Fig. 4) and normalized such that age-distribution curves for all

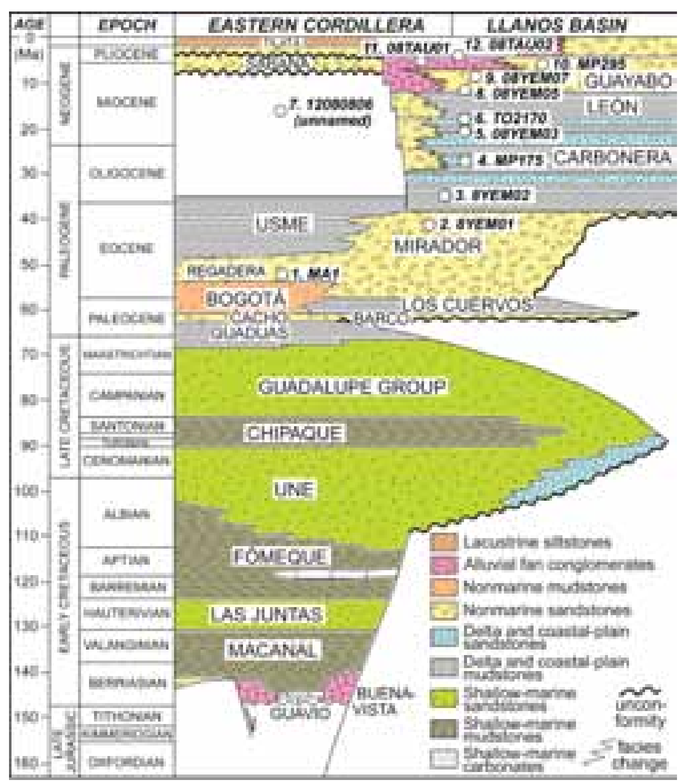


Figure 3. Generalized Mesozoic-Cenozoic stratigraphy of the Eastern Cordillera and Llanos basin, Colombia (after Parra et al., 2009a), showing approximate stratigraphic levels of 12 samples (circles).

[1]GSA Data Repository item 2010140, Table DR1, U-Pb geochronologic analyses, and Table DR2, (U-Th)/He results, is available at www.geosociety.org/pubs/ft2010.htm; copies can also be obtained by e-mail to gsatoday@geosociety.org.

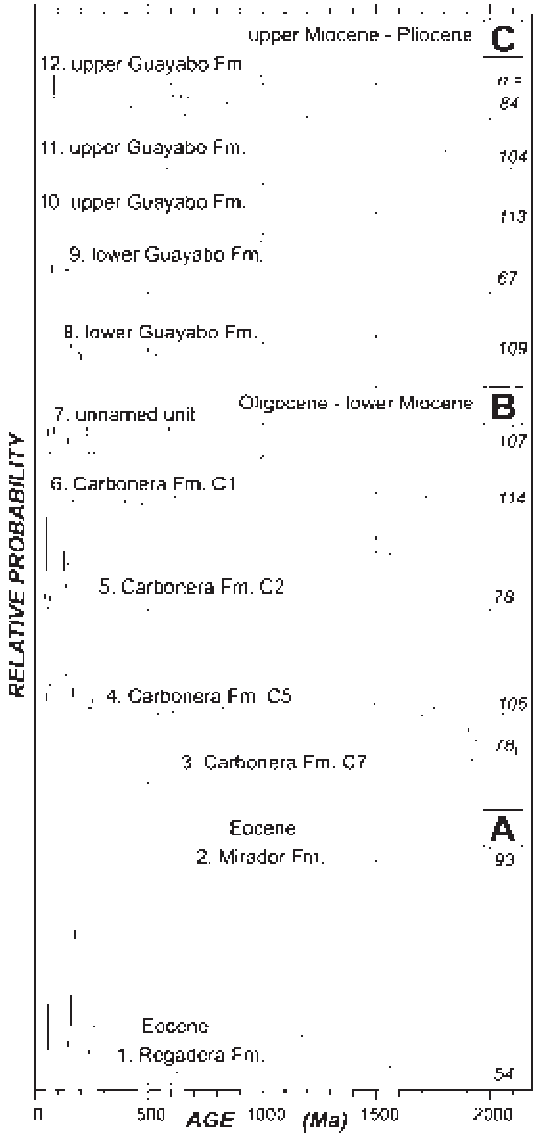


Figure 4. Detrital zircon U-Pb ages for Cenozoic strata in the proximal Llanos basin (samples 2–6 and 8–12) and axial Eastern Cordillera (samples 1 and 7). Age probability plots arranged in stratigraphic order.

samples contain the same area. Interpretations are based on age peaks defined by three or more grains.

### Results and Interpretations

An Eocene sample from the upper Mirador Formation (Fig. 3) in the proximal Llanos basin is characterized by Precambrian age peaks of 1850–1350 Ma (Fig. 4A). In contrast, a sample from the Mirador-equivalent Regadera Formation in the axial Eastern Cordillera shows principally Phanerozoic ages, with peaks at 85–75, 65–55, and 190–170 Ma (Fig. 4A). We ascribe the Llanos age distributions to a dominant eastern source of Proterozoic rocks in the Guyana shield, consistent with previous studies (Cooper et al., 1995; Villamil, 1999; Roure et al., 2003). Age spectra for the axial Eastern Cordillera, however, signify exhumation of Jurassic-Paleogene magmatic-arc rocks from a western source region in the Central Cordillera or Magdalena Valley region (Fig. 2). During Paleocene to Oligocene time, the Eastern Cordillera and proximal Llanos basin likely formed a single integrated basin with sediment supplied from the east and west (Dengo and Covey, 1993; Cooper et al., 1995; Villamil, 1999) and potentially from localized structural highs (Gómez et al., 2005a; Bayona et al., 2008).

Five Oligocene to lower Miocene samples (Fig. 4B) reveal a major provenance shift. A basal sample of the Oligocene C7 member of the Carbonera Formation (Fig. 3) shows exclusively Precambrian age peaks older than 1500 Ma, indicating a cratonic signature. Upsection, the four lower Miocene samples from the C5, C2, and C1 members and an unnamed equivalent unit in the Eastern Cordillera exhibit Precambrian age peaks (1850–1300, 1050–950 Ma) and a collection of Phanerozoic ages (65–45, 90–80, 155–135, 175–170 Ma) that include the first appearance in the Llanos basin of Jurassic-Paleogene zircons, grains that must originate in the west. Although such Phanerozoic zircons could be first-cycle grains from magmatic-arc rocks of the Central Cordillera and Magdalena Valley, the presence of a Grenville age peak at 1050–950 Ma and Paleoproterozoic to Mesoproterozoic grain ages at 1850–1300 Ma (Fig. 4B) suggests recycling of sediments originally derived from the easternmost Andes and/or Guyana shield (e.g., Horton et al., 2010). We attribute the U-Pb ages to initial unroofing of the Upper Cretaceous–Paleogene stratigraphic succession along the axis and eastern flank of the Eastern Cordillera during latest Oligocene–early Miocene time. Unroofing of this cover section produced composite age spectra reflecting recycled contributions from arc-derived Paleogene strata (e.g., Regadera; Fig. 4A), craton-derived Paleogene strata (e.g., Mirador; Fig. 4A), and craton-derived Cretaceous strata.

Five upper Miocene–Pliocene samples from the lower and upper Guayabo Formation (Fig. 3) exhibit age spectra (1850–1300, 1050–950 Ma) comparable to Proterozoic basement in the Guyana shield, with limited Phanerozoic and few Jurassic-Paleogene ages (Fig. 4C). Paleocurrent data and conglomerate clast compositions show that these deposits were derived from western Andean sources rather than the Guyana shield in the east (Parra et al., 2010). We ascribe the U-Pb results to continued unroofing of the Eastern Cordillera, with recycling of principally Cretaceous strata originally sourced from the Guyana shield. Notably, for the upper Miocene–Pliocene upper Guayabo Formation, the conspicuous absence of Jurassic-Paleogene age populations that typified the underlying lower Miocene section (Fig. 4B) rules out the western magmatic arc as a potential source and suggests nearly complete erosional stripping of the arc-derived Paleogene section in the Eastern Cordillera (e.g., Regadera; Fig. 4A). Further, continued erosional recycling of craton-derived Cretaceous strata accounts for the upsection increase in Grenville-aged (1050–950 Ma) detritus at the expense of Jurassic-Paleogene ages (compare Figs. 4B and 4C). Removal of most of the ~2–3-km-thick Paleogene section during early to middle Miocene time suggests an average one-dimensional exhumation rate of ~0.2–0.3 mm/yr, a rate comparable to values estimated from low-temperature thermochronometry (Parra et al., 2009b).

## (U-Th)/He THERMOCHRONOMETRY

Zircon (U-Th)/He thermochronometry is an established technique involving a closure temperature of ~180–200 °C (e.g.,

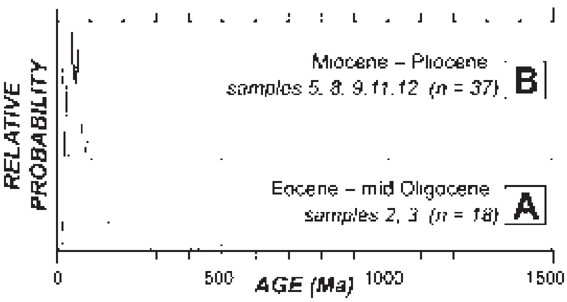


Figure 5. Detrital zircon (U-Th)/He ages for Cenozoic strata in the proximal Llanos basin. Age probability plots arranged in stratigraphic order.

Reiners, 2005) and a partial retention zone of ~120–180 °C (Stockli, 2005). Detrital (U-Th)/He age determinations were carried out following laboratory procedures described in Biswas et al. (2007). All ages were calculated using Fish Canyon and Durango zircon age standards and alpha-ejection corrections based on morphometric analyses (Farley et al., 1996). Reported age uncertainties reflect the reproducibility of replicate analyses of the two standards, with estimated analytical uncertainties of ~8% (2σ) for zircon (U-Th)/He ages (Reiners, 2005; Biswas et al., 2007).

We report 55 (U-Th)/He ages from seven of the aforementioned samples (see supplemental data Table DR2 [footnote 1]). Results are plotted on normalized relative age probability diagrams (Fig. 5). Detrital zircon (U-Th)/He ages for Eocene to mid-Oligocene sandstones of the Mirador and lowermost Carbonera Formations show a strong component of Neoproterozoic ages (11 of 18 grains in the 850–550 Ma range) with subordinate Paleozoic and Jurassic ages (Fig. 5A). In sharp contrast, Miocene-Pliocene sandstones of the middle-upper Carbonera and Guayabo Formations are dominated by Cretaceous-Cenozoic age signatures (28 of 37 grains younger than 150 Ma), with a minor 1000–850 Ma subpopulation of possible Grenville origin (Fig. 5B).

The (U-Th)/He results indicate a substantial shift in detrital age signatures during lower Carbonera deposition that coincides with the provenance shift expressed in the U-Pb data. However, rather than crystallization ages, the detrital zircon (U-Th)/He results provide insight into the integrated cooling history of the sediment source areas. In this case, we interpret the dominantly Precambrian cooling signatures of the Eocene to mid-Oligocene sandstones as the product of extremely long residence time at shallow burial depths (<5–10 km) in the stable cratonic interior of the Guyana shield. The significantly younger (U-Th)/He ages identified in the Miocene-Pliocene sandstones are considered to be the product of Cretaceous-Cenozoic exhumation in the Andean orogenic belt and/or possible contribution from igneous sources. Similar to the U-Pb data, these (U-Th)/He results reveal a pronounced shift in provenance from the ancient Guyana shield in the east to the Andean orogenic belt in the west.

## CLAST COMPOSITIONS AND ACCUMULATION RATES

The new detrital zircon data are compatible with the unroofing record suggested by conglomerate clast compositions and sediment accumulation rates in the proximal Llanos basin. Clast composition data for the Eocene to upper Miocene succession (Fig. 6A) record the first appearance of large proportions of sandstone clasts followed by increased amounts of distinctive clasts of glauconite-bearing quartzose sandstones (Fig. 6B). Reworked microfossils (pollen, dinoflagellates, and foraminifera; Bayona et al., 2008) suggest a Paleocene or older age for these sandstone clasts. This history indicates late Oligocene–early Miocene unroofing of Paleocene-Eocene sandstones and widespread middle to late Miocene exposure of glauconitic sandstones that are diagnostic of specific mid- to Upper Cretaceous units (Une, Chipaque, and Guadalupe units).

An Eocene to late Miocene sediment accumulation history (Fig. 6C) for the proximal Llanos basin has been constructed on the basis of stratigraphic sections temporally calibrated by detailed palynological assemblages (Parra et al., 2010). The data show a major increase in accumulation rates, starting ca. 26–23 Ma, from ~100 to ~460 m/m.y. Although this stratigraphic transition shows only modest changes in lithofacies or paleocurrents, it corresponds with the abrupt change in detrital zircon age signatures (Figs. 4 and 5) discussed in previous sections.

## DISCUSSION AND IMPLICATIONS

Coeval shifts in U-Pb and (U-Th)/He zircon age spectra, clast composition, and sediment accumulation rates in the Llanos

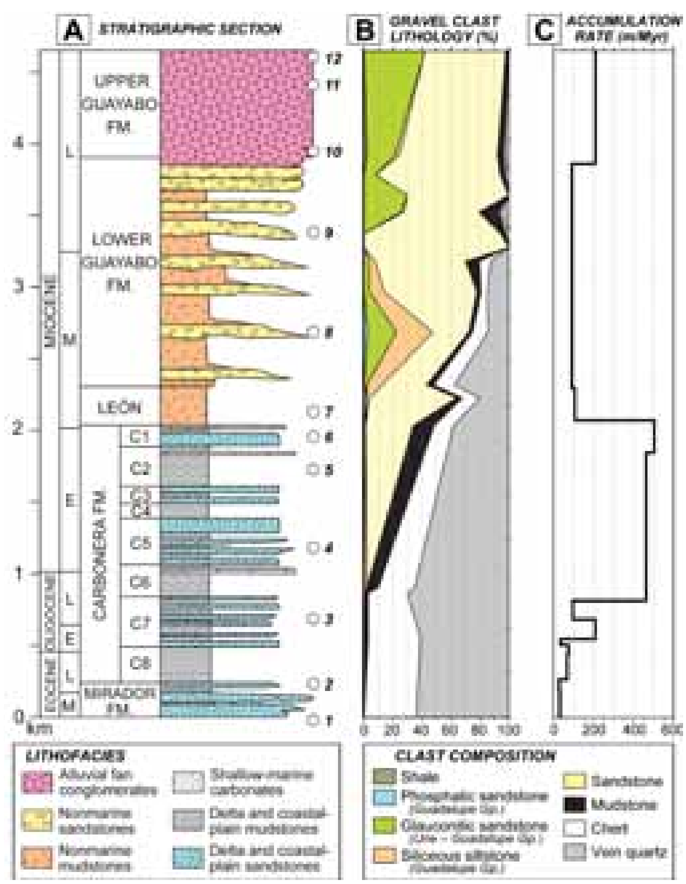


Figure 6. (A) Stratigraphic log of ~4.7-km succession showing approximate levels of 12 samples (circles); (B) corresponding conglomerate clast compositions; and (C) sediment accumulation rates derived from one-dimensional decompacted thicknesses for Eocene-Miocene deposits of the proximal Llanos basin at ~5°N (after Parra et al., 2009a, 2010).

foreland basin can be attributed to initial uplift of the eastern flank of the Eastern Cordillera (Fig. 2) during latest Oligocene time, consistent with zircon fission-track cooling histories (Parra et al., 2009b). Eastern Cordillera uplift is considered fundamental to the genesis and/or reorganization of the largest drainages in northern South America (Fig. 1). Therefore, initial deformation by ca. 26–23 Ma suggests that precursors of the Amazon, Orinoco, and Magdalena river systems may have originated >10–20 m.y. earlier than envisioned (e.g., Hoorn et al., 1995; Díaz de Gamero, 1996; Campbell et al., 2006). Evidence for protracted drainage histories should be preserved in the depositional records of the respective river deltas and submarine fans (e.g., Dobson et al., 2001; Harris and Mix, 2002), recognizing that changes in sediment accumulation rates could also be the product of climatic effects (Molnar, 2004). We speculate that reduced sediment accumulation rates in the Amazon fan during the early and middle Miocene (Dobson et al., 2001) may be the product of enhanced loading during Eastern Cordillera uplift and a corresponding increase in flexural accommodation and proximal storage of sediment in the Llanos foreland basin (e.g., Bayona et al., 2008; Parra et al., 2009a).

As the principal orographic barrier to easterly air masses, surface uplift of the Eastern Cordillera has influenced the paleogeography and biodiversity of South America's neotropical rainforests (e.g., Hooghiemstra and Van der Hammen, 1998; Albert et al., 2006). We hypothesize that aridification in the intermontane Magdalena Valley of Colombia (Fig. 2) represents the leeward orographic response to Eastern Cordillera uplift (e.g., Strecker et al., 2007). Although critical threshold elevations were likely reached in late Miocene to Pliocene time (Mora et al., 2008), paleoprecipitation estimates based on mammal faunal assemblages (Kay and Madden, 1997) are consistent with a sediment provenance reversal (Guerrero, 1997) suggesting that initial aridification due to an emerging orographic barrier may have been under way by middle Miocene time.

A further intriguing implication of latest Oligocene uplift along the eastern flank of the Eastern Cordillera is an apparent long-term reduction in the average rate of thrust front advance over the past ~25 m.y., the period of maximum shortening and surface uplift. This seeming contradiction underscores the potential importance of precipitation-driven erosion and inherited mechanical properties on structural evolution of the orogenic wedge in the humid northern Andes.

## ACKNOWLEDGMENTS

Funding was provided by Ecopetrol's Instituto Colombiano del Petróleo as part of a collaborative research agreement with the University of Texas at Austin. M. Parra, A. Mora, and M.R. Strecker also acknowledge funding from the German Academic Exchange Service and Deutsche Forschungsgemeinschaft. The manuscript benefited from discussions with many Ecopetrol employees and Colombian researchers along with reviews by Isabelle Coutand, James Mortensen, and Stephen Johnston.

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*Manuscript received 12 Aug. 2009; accepted 6 Jan. 2010.*



# 2010 MEDAL & AWARD RECIPIENTS

GSA PUBLIC SERVICE AWARD

**Jonathan G. Price,** University of Nevada and Nevada Bureau of Mines & Geology

GSA DISTINGUISHED SERVICE AWARD

**David A. Stephenson,** The Geological Society of America Foundation

AGI MEDAL IN MEMORY OF IAN CAMPBELL

**Vicki Cowart,** Colorado Geological Survey and Planned Parenthood of the Rocky Mountains (PPRM)

PENROSE MEDAL

**Eric J. Essene*,** University of Michigan

ARTHUR L. DAY MEDAL

**George E. Gehrels,** University of Arizona

YOUNG SCIENTIST AWARD (DONATH MEDAL)

**Dana L. Royer,** Wesleyan University

PRESIDENT'S MEDAL OF THE GEOLOGICAL SOCIETY OF AMERICA

**Keyhole Inc.** founders **John Hanke, Chikai Ohazama, Mark Aubin, Phil Keslin,** and **Avi Bar-Zeev**; and advisory founders **Brian McClendon, Michael Jones, Chris Tanner,** and **Remi Arnaud** (developers of Earth Viewer, now Google Earth).

RANDOLPH W. "BILL" AND CECILE T. BROMERY AWARD FOR THE MINORITIES

**Marilyn J. Suiter,** National Science Foundation

SUBARU OUTSTANDING WOMAN IN SCIENCE AWARD

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**Kateryna Klochko,** Carnegie Institution for Science

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

**William R. Lund, Tyler R. Knudsen, Garrett S. Vice, and Lucas M. Shaw,** 2008, Geologic hazards and adverse construction conditions, St. George–Hurricane Metropolitan Area, Washington County, Utah: Utah Geological Survey Special Study 127.

**Awardees to Be Honored at 2010 GSA Annual Meeting & Exposition**

The 2010 GSA Medals & Awards will be presented at the **Presidential Address & Awards Ceremony** on Saturday, 30 Oct., from 7–9 p.m. at the Colorado Convention Center in Denver, Colorado, USA. The 2010 Penrose, Day, and Donath medalists will present the second annual **GSA Gold Medal Lectures** on Sunday, 31 Oct.—three half-hour talks, each reflecting on their scientific careers. GSA's awardees will also be highlighted in the annual Hall of Fame.

*deceased (20 May 2010)

# 2010 GSA DIVISION NAMED AWARDS

RIP RAPP ARCHAEOLOGICAL GEOLOGY AWARD
*Archaeological Geology Division*
**Ervan G. Garrison,** University of Georgia

GILBERT H. CADY AWARD
*Coal Geology Division*
**Colin R. Ward,** University of New South Wales

E.B. BURWELL, JR., AWARD
*Engineering Geology Division*
**William L. Bilodeau, Sally W. Bilodeau, Eldon M. Gath, Mark Oborne, and Richard J. Proctor,** 2007, Geology of Los Angeles, California, United States of America: Environmental & Engineering Geoscience, v. XIII, no. 2, p. 99–160.

GEORGE P. WOOLLARD AWARD
*Geophysics Division*
**Timothy H. Dixon,** University of Miami

BIGGS AWARD FOR EXCELLENCE IN EARTH SCIENCE TEACHING
*Geoscience Education Division*
**Michael C. Rygel**
SUNY College at Potsdam

MARY C. RABBITT HISTORY OF GEOLOGY AWARD
*History of Geology Division*
**Gabriel Gohau,** Lycée Janson de Sailly, Paris (emeritus)

O.E. MEINZER AWARD
*Hydrogeology Division*
**Mary Jo Baedecker,** U.S. Geological Survey–Reston, for Baedecker, M.J., Cozzarelli, I.M., Eganhouse, R.P., Siegel, D.I., and Bennett, P.C., 1993, Crude oil in a shallow sand and gravel aquifer—III. Biogeochemical reactions and mass balance modeling in anoxic groundwater: Applied Geochemistry, v. 8, p. 569–586.

DISTINGUISHED CAREER AWARD
*International Division*
**W. Gary Ernst,** Stanford University (emeritus)

ISRAEL C. RUSSELL AWARD
*Limnogeology Division*
**William M. Last,** University of Manitoba

G.K. GILBERT AWARD
*Planetary Geology Division*
**Carle M. Pieters,** Brown University

KIRK BRYAN AWARD
*Quaternary Geology and Geomorphology Division*
**Rolfe D. Mandel,** Kansas Geological Survey, University of Kansas, 2008, Buried paleoindian-age landscapes in stream valleys of the central plains, USA": Geomorphology, v. 101, p. 342–361.

LAURENCE L. SLOSS AWARD
*Sedimentary Geology Division*
**Hugh Jenkyns,** University of Oxford

CAREER CONTRIBUTION AWARD
*Structural Geology and Tectonics Division*
**George H. Davis,** University of Arizona

# 2010 GSA FELLOWS

## Elected by Council 17 April 2010

The following GSA Fellows, elected by GSA Council on 17 April 2010, will be recognized at the 2010 GSA Annual Meeting Presidential Address & Awards Ceremony on Saturday, 30 Oct., at the Colorado Convention Center in Denver. Brief citations for each Fellow are posted at **www .geosociety.org/members/newFellows.htm.**

**David J. Anastasio,** Lehigh University. GSA Affiliations: Northeastern Section; Structural Geology and Tectonics Division. **Nominator:** Kenneth P. Kodama.

**Hassan A. Babaie,** Georgia State University. GSA Affiliations: Southeastern Section; International Section; Structural Geology and Tectonics Division; Geoinformatics Division. **Nominator:** W. Crawford Elliott.

**Andrew P. Barth,** Indiana University–Purdue University-Indianapolis. GSA Affiliations: Cordilleran Section; Mineralogy, Geochemistry, Petrology, and Volcanology Division; Structural Geology and Tectonics Division. **Nominator:** Eric H. Christiansen.

**Sydney L. Brown,** California Dept. of Parks & Recreation. GSA Affiliations: Cordilleran Section; Engineering Geology Division; Quaternary Geology and Geomorphology Division; Geology and Society Division. **Nominator:** J. David Rogers.

**Steven C. Cande,** Scripps Institute Oceanography. GSA Affiliations: Cordilleran Section; Geophysics Division. **Nominator:** Peter H. Molnar.

**Michael A. Clynne,** U.S. Geological Society. GSA Affiliations: Cordilleran Section. **Nominator:** Charles R. Bacon.

**Michele L. Cooke,** University of Massachusetts–Amherst. GSA Affiliations: Northeastern Section; Structural Geology and Tectonics Division; Geoscience Education Division. **Nominator:** Michael L. Williams.

**Larry S. Crumpler,** New Mexico Museum of Natural History & Science. GSA Affiliations: Rocky Mountain Section; Planetary Geology Division. **Nominator:** James R. Zimbelman.

**John H. Cushman,** Purdue University. GSA Affiliations: North-Central Section. **Nominator:** Stephen W. Wheatcraft.

**Zhenxue Dai,** Los Alamos National Laboratory. GSA Affiliations: Rocky Mountain Section; Hydrogeology Division. **Nominator:** Robert W. Ritzi.

**P. Thompson (Thom) Davis,** Bentley University. GSA Affiliations: Northeastern Section; Quaternary Geology and Geomorphology Division. **Nominator:** John T. Andrews.

**W. Mike Edmunds,** Oxford Centre for Water Research. GSA Affiliations: International Section; Hydrogeology Division. **Elevated to Fellowship** as the 2009 Meinzer awardee.

**Maya Elrick,** University of New Mexico. GSA Affiliations: Rocky Mountain Section; Sedimentary Geology Division. **Nominator:** John W. Geissman.

**Robert W. Embley,** National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory. GSA Affiliations: Cordilleran Section. **Nominator:** Robert J. Stern.

**James P. Evans,** Utah State University. GSA Affiliations: Rocky Mountain Section; Cordilleran Section; Structural Geology and Tectonics Division. **Nominator:** Laurel B. Goodwin.

**C. Mark Fanning,** The Australian National University. GSA Affiliations: Rocky Mountain Section; Sedimentary Geology Division; Structural Geology and Tectonics Division. **Nominator:** John W. Goodge.

**Christopher M. Fedo,** University of Tennessee. GSA Affiliations: Cordilleran Section; Geobiology & Geomicrobiology Division; Sedimentary Geology Division; Structural Geology and Tectonics Division. **Nominator:** Robert D. Hatcher Jr.

**Ray E. Ferrell,** Louisiana State University. GSA Affiliations: South-Central Section; Geoscience Education Division. **Nominator:** Lynda B. Williams.

**Neil S. Fishman,** U.S. Geological Survey. GSA Affiliations: Rocky Mountain Section; Cordilleran Section; Northeastern Section; Southeastern Section; North-Central Section; South-Central Section; International Section; Sedimentary Geology Division. **Nominator:** Bart J. Kowallis.

**Gordon E. Grant,** USDA Forest Service. GSA Affiliations: Cordilleran Section; Quaternary Geology and Geomorphology Division; Mineralogy, Geochemistry, Petrology, and Volcanology Division. **Nominator:** Jon J. Major.

**Eric B. Grosfils,** Pomona College. GSA Affiliations: Cordilleran Section; Geoscience Education Division; Planetary Geology Division. **Nominator:** Vicki L. Hansen.

**Djordje Grujic,** Dalhousie University. GSA Affiliations: Northeastern Section. **Nominator:** Lincoln S. Hollister.

**Todd Halihan,** Oklahoma State University. GSA Affiliations: South-Central Section; Hydrogeology Division; Geology and Society Division. **Nominator:** F. Edwin Harvey.

**Joseph T. Hannibal,** Cleveland Museum Natural History. GSA Affiliations: North-Central Section. **Nominator:** Joanne Kluessendorf.

**T. Mark Harrison,** University of California–Los Angeles. GSA Affiliations: Cordilleran Section. **Elevated to Fellowship** as the 2009 Day Medalist.

**William K. Hart,** Miami University of Ohio. GSA Affiliations: Cordilleran Section; Geoscience Education Division. **Nominator:** Grant H. Heiken.

**Judson W. Harvey,** U.S. Geological Survey. GSA Affiliations: Northeastern Section. **Nominator:** George M. Hornberger.

**Darrell J. Henry,** Louisiana State University, GSA Affiliations: South-Central Section; Mineralogy, Geochemistry, Petrology, and Volcanology Division. **Nominator:** Sorena S. Sorensen.

**Robert S. Hildebrand,** Utah State University. GSA Affiliations: Cordilleran Section; Structural Geology and Tectonics Division. **Nominator:** Paul F. Hoffman.

**Mark R. Hudson,** U.S. Geological Survey. GSA Affiliations: Rocky Mountain Section. **Nominator:** V.J.S. (Tien) Grauch.

**Oldrich Hungr,** University of British Columbia. GSA Affiliations: Cordilleran Section; Engineering Geology Division. **Elevated to Fellowship** as the 2009 Burwell Awardee.

**Jiin-Shuh Jean,** National Cheng Kung University. GSA Affiliations: International Section; Geobiology & Geomicrobiology Division; Geology and Health Division; Hydrogeology Division. **Nominator:** Richard R. Parizek.

**Robert M. Joeckel,** University of Nebraska. GSA Affiliations: North-Central Section. **Nominator:** David B. Loope.

**Karl E. Karlstrom,** University of New Mexico. GSA Affiliations: Rocky Mountain Section; Structural Geology and Tectonics Division; Geoscience Education Division. **Elevated to Fellowship** as the 2009 GSA Distinguished Service Awardee.

**Richard A. Ketcham,** University of Texas. GSA Affiliations: Cordilleran Section. **Nominator:** William D. Carlson.

**Michal J. Kowalewski,** Virginia Tech. GSA Affiliations: Southeastern Section. **Nominator:** Karl W. Flessa.

**Cin-Ty Aeolus Lee,** Rice University. GSA Affiliations: South-Central Section. **Elevated to Fellowship** as the 2009 Donath Medalist.

**John T. Leftwich,** Halliburton Company. GSA Affiliations: South-Central Section. **Elevated to Fellowship** as the 2009 Bromery Awardee.

**Thomas E. Lisle,** Redwood Sciences Laboratory. GSA Affiliations: Cordilleran Section; Quaternary Geology and Geomorphology Division. **Nominator:** Thomas C. Pierson.

**Richard I. Macphail,** University College London. GSA Affiliations: International Section; Quaternary Geology and Geomorphology Division; Archeological Geology Division. **Elevated to Fellowship** as the 2009 Rip Rapp Awardee.

**Cathryn A. Manduca,** Carleton College. GSA Affiliations: North-Central Section. **Nominator:** Barbara L. Dutrow.

**Michael McCurry,** Idaho State University. GSA Affiliations: Rocky Mountain Section; Mineralogy, Geochemistry, Petrology, and Volcanology Division. **Nominator:** Paul K. Link.

**Joseph G. Meert,** University of Florida. GSA Affiliations: Southeastern Section; Structural Geology and Tectonics Division. **Nominator:** Neil D. Opdyke.

**Dorothy J. Merritts,** Franklin and Marshall College. GSA Affiliations: Northeastern Section. **Nominator:** Ellen E. Wohl.

**David W. Mogk,** Montana State University. GSA Affiliations: Rocky Mountain Section; Cordilleran Section; Structural Geology and Tectonics Division; Geology and Health Division; Geoscience Education Division. **Nominator:** Paul A. Mueller.

**Alessandro Montanari,** Osservatorio Geologico di Coldigioco. GSA Affiliations: International Section. **Nominator:** Walter Alvarez.

**Dante Moran-Zenteno,** Universidad Nacional Autónoma de México. GSA Affiliations: Cordilleran Section. **Nominator:** Luca Ferrari.

**Paul M. Myrow,** Colorado College. GSA Affiliations: Rocky Mountain Section. **Nominator:** John P. Grotzinger.

**Roseanna M. Neupauer,** University of Colorado. GSA Affiliations: Rocky Mountain Section. **Nominator:** Janet S. Herman.

**James G. Ogg,** Purdue University. GSA Affiliations: Cordilleran Section. **Nominator:** William J. Zinsmeister.

**Scott R. Paterson,** University of Southern California. GSA Affiliations: Cordilleran Section. **Nominator:** Robert B. Miller.

**Virginia L. Peterson,** Grand Valley State University. GSA Affiliations: Southeastern Section; Geoscience Education Division; Mineralogy, Geochemistry, Petrology, and Volcanology Division. **Nominator:** Laurie L. Brown.

**Kevin T. Pickering,** University College London. GSA Affiliations: International Section. **Nominator:** Michael B. Underwood.

**Kenneth D. Ridgway,** Purdue University. GSA Affiliations: Cordilleran Section; Sedimentary Geology Division; Structural Geology and Tectonics Division. **Nominator:** Terry R. West.

**Michael R. Rosen,** U.S. Geological Survey. GSA Affiliations: Cordilleran Section; Hydrogeology Division; Limnogeology Division. **Nominator:** Gail M. Ashley.

**Joseph G. Rosenbaum,** U.S. Geological Survey. GSA Affiliations: Rocky Mountain Section; Limnogeology Division; Quaternary Geology and Geomorphology Division. **Nominator:** Richard Lee Reynolds.

**Lisa A. Rossbacher,** Southern Polytechnic State University. GSA Affiliations: Southeastern Section. **Nominator:** Rex C. Buchanan.

**Christine S. Siddoway,** The Colorado College. GSA Affiliations: Rocky Mountain Section; Structural Geology and Tectonics Division. **Nominator:** Basil Tikoff.

**Robert G. Strom,** University of Arizona. GSA Affiliations: Rocky Mountain Section; Planetary Geology Division. **Elevated to Fellowship** as the 2009 Gilbert Awardee.

**Bonnie W. Styles,** Illinois State Museum Research. GSA Affiliations: North-Central Section; Archaeological Geology Division; Quaternary Geology and Geomorphology Division. **Nominator:** Rolfe D. Mandel.

**Keith A. Sverdrup,** University of Wisconsin. GSA Affiliations: North-Central Section; Geoscience Education Division. **Nominator:** Vincent S. Cronin.

**Margaret A. Townsend,** Kansas Geological Survey. GSA Affiliations: North-Central Section; Hydrogeology Division; Geology and Health Division. **Nominator:** Ralph K. Davis.

**Slawek M. Tulaczyk,** University of California–Santa Cruz. GSA Affiliations: Cordilleran Section; Quaternary Geology and Geomorphology Division. **Nominator:** Eli A. Silver.

**Jaime Urrutia-Fucugauchi,** Universidad Nacional Autónoma de México–Coyoacan. GSA Affiliations: Cordilleran Section. **Nominator:** Enrique Gómez de la Rosa.

**David W. Valentino,** SUNY-Oswego. GSA Affiliations: Northeastern Section. **Nominator:** Jeffrey R. Chiarenzelli.

**Michael L. Wells,** University of Nevada–Las Vegas. GSA Affiliations: Cordilleran Section; Structural Geology and Tectonics Division. **Nominator:** Richard W. Allmendinger.

**Kelin X. Whipple,** Arizona State University. GSA Affiliations: Cordilleran Section; Quaternary Geology and Geomorphology Division. **Nominator:** Frank J. Pazzaglia.

**Richard Wirth,** Helmholtz Centre Potsdam, GFZ Potsdam. GSA Affiliations: International Section. **Nominator:** Larissa Dorbrzhinetskaya.

**Tsanyao Frank Yang,** National Taiwan University. GSA Affiliations: International Section; Mineralogy, Geochemistry, Petrology, and Volcanology Division. **Nominator:** L. Lynn Chyi.

**Davis A. Young,** Calvin College (emeritus). GSA Affiliations: Cordilleran Section; History of Geology Division. **Elevated to Fellowship** as the 2009 Mary C. Rabbitt Awardee.

**Yan Zheng,** Queens College. GSA Affiliations: Northeastern Section; Hydrogeology Division. **Nominator:** Chunmiao Zheng.

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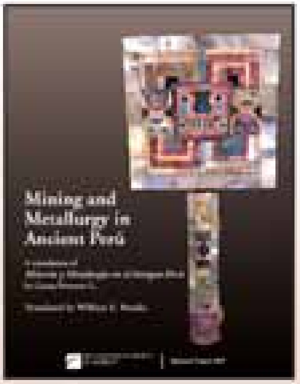


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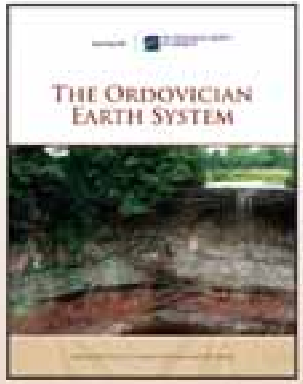


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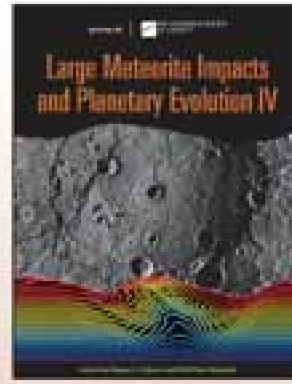


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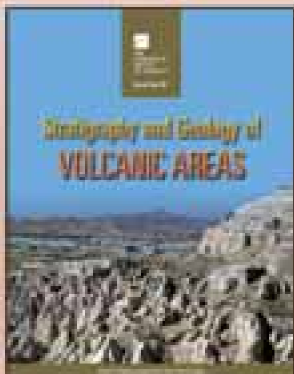


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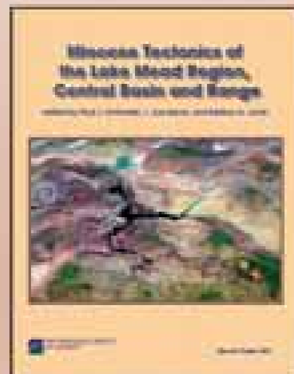


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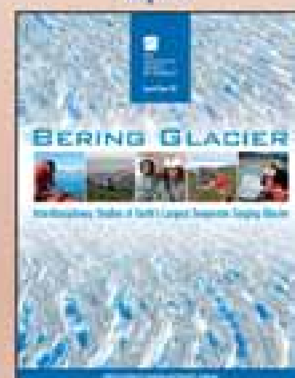
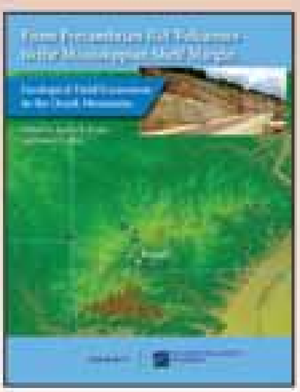
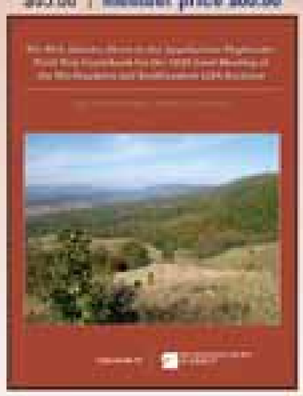
*edited by Paul J. Umhoefer, L. Sue Beard, and Melissa A. Lamb, 2010*
SPE463, 441 p. plus CD-ROM, plates, ISBN 9780813724638
$95.00 | **member price $66.00**



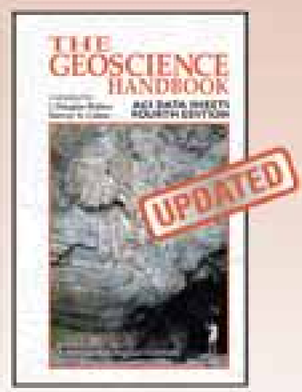

**Bering Glacier: Interdisciplinary Studies of Earth's Largest Temperate Surging Glacier**
*edited by Robert A. Shuchman*
*and Edward G. Josberger, 2010*
SPE462, 384 p., ISBN 9780813724621
$99.00 | **member price $70.00**



**From Precambrian Rift Volcanoes to the Mississippian Shelf Margin: Geological Field Excursions in the Ozark Mountains**
*edited by Kevin R. Evans and James S. Aber, 2010*
FLD017, 158 p., ISBN 9780813700175
$50.00 | **member price $35.00**



**The Mid-Atlantic Shore to the Appalachian Highlands: Field Trip Guidebook for the 2010 Joint Meeting of the Northeastern and Southeastern GSA Sections**
*edited by Gary M. Fleeger*
*and Steven J. Whitmeyer, 2010*
FLD016, 125 p., ISBN 9780813700168
$40.00 | **member price $28.00**




**The Geoscience Handbook, AGI Data Sheets, Fourth Edition**
*compiled by J. Douglas Walker*
*and Harvey A. Cohen, 2010*
DATASHEETS, 310 p., 5" × 8", spiral bound, ISBN 9780922152841
$49.95 | **member price $39.95**

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THE GEOLOGICAL SOCIETY OF AMERICA®

# GSA Celebrates 50-Year Member Anniversaries

## *Thanks for Your Membership!*

GSA salutes the following colleagues as they reach their 50-year anniversary of membership in GSA. We appreciate your dedication and loyalty to GSA for all these years!

Asterisks indicate those members who have not yet been elevated to Fellowship status. **GSA Fellows:** You can help maintain a dynamic, vibrant cohort by nominating deserving geoscience colleagues for Fellowship. Guidelines and nomination forms are online at www.geosociety.org/members/fellow.htm. If you have questions, please e-mail awards@geosociety.org or call +1-800-472-1988, ext. 1028, or +1-303-357-1028.

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Farouk El-Baz
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**Note:** This list shows only those members and Fellows who are celebrating their 50-year membership anniversary in 2010. Complete lists of members and Fellows who have surpassed the 50-year mark are online at http://rock.geosociety.org/membership/50YearMembers.asp and http://rock.geosociety.org/membership/50Yearfellows.asp, respectively.

# 2010 GSA Research Grant Recipients

**The GSA Committee on Research Grants has awarded US$612,042** to 276 of the 538 graduate students who applied (51%); the average grant was US$2,218. The committee also selected ten alternate candidates in the event that any grantees return all or part of their funds due to a change in their research project or receipt of funds from another source.

**Committee members:** Patricia Holroyd (Chair), Nan Crystal Arens, Julia A. Baldwin, David Borrok, Elizabeth Jones Crafford, Rupali Datta, Robert V. Demicco, James E. Evans, David P. Gillikin, Allen M. Gontz, Darren Grocke, Anita Grunder, Stephen S. Harlan, Antun Husinec, Oliver Korup, Jeffrey Lee, Tim Lowenstein, Michelle Markley, Susannah M. Porter, Michael F. Roden, Paul Tomascak, Julia Smith Wellner, Peter D. Wilf, and Kevin M. Yeager.

The GSA Graduate Student Research Grant Program is funded by The Geological Society of America, the GSA Foundation, GSA Divisions, and the National Science Foundation.

The following awards related to the research grant program will be presented at the 2010 GSA Annual Meeting in Denver, Colorado, USA: Outstanding Mentions, Specialized Awards, Diversity in the Geosciences Minority Research Grant Awards, Farouk El-Baz Student Grants, and The Maurice "Ric" Terman Fund.

## 2010 OUTSTANDING MENTIONS

The committee recognized 20 of the proposals to be of exceptionally high merit in conception and presentation.

**Alexis K. Ault,** University of Colorado–Boulder: "Tectonic connections to burial and unroofing of the Rae craton, Baffin Island: Evidence from apatite (U-Th)/He thermochronometry."

**Scott E.K. Bennett,** University of California–Davis: "Testing the role of obliquity in rupturing continental lithosphere: Dating rift-related transtensional structures in coastal Sonora."

**Chloe Bonamici,** University of Wisconsin–Madison: "Linking deformational and geochemical processes through intragrain oxygen-isotope diffusion profiles."

**Alvin J. Bonilla,** University of Kansas: "Paleoceanographic conditions of tropical oceans in the Caribbean region during the Cretaceous greenhouse world."

**Greg Brennecka,** Arizona State University: "Establishing $^{238}U/^{235}U$ as a new paleoredox proxy."

**Christopher F. Cassle,** Colorado State University: "Detailed sedimentological and stratigraphic analyses of organic rich successions within the Permian Phosphoria Formation of Idaho and Wyoming, USA."

**Rafael Cavalcanti de Albuquerque,** Simon Fraser University: "Hydrogeochemical assessment of arsenic occurrences in groundwaters in complex glaciomarine sediment aquifers."

**Laura Craig,** University of Nevada–Reno: "Developing locally based methods for controlling excess fluoride in drinking water in Ghana, West Africa."

**Brian J. Hanson,** Boise State University: "Evaluating the source and release mechanism of dissolved uranium in the Treasure Valley Aquifer, ID."

**Breanna L. Huff,** University of Kansas: "Microbial response in a $CO_2$-injected aquifer."

**Britta J.L. Jensen,** University of Alberta: "A chronostratigraphic framework for the middle Pleistocene in eastern Beringia."

**Caitlin Keating-Bitonti,** University of Wisconsin–Madison: "Deep-sea sedimentation as an archive and driver of the global climate system: The influence of North Atlantic deep water on carbon sequestration."

**Kirsten L. Kennedy,** Dalhousie University: "Sedimentology and paleobiological importance of the Campbellton Formation, New Brunswick."

**Denise M. Levitan,** Virginia Tech: "Precipitation kinetics of autunite minerals: Implications for uranium immobilization."

**Jennifer Levy,** Columbia University: "Tree composition impact on the belowground carbon budget of a northeastern forest: A case study from a tree girdling experiment in Black Rock Forest."

**John Sommerfeld,** San Francisco State University: "Microstructural control on $^{40}Ar/^{39}Ar$ ages from a young leucogranite."

**Mindi Summers,** Scripps Institute of Oceanography: "aDNA extraction from sediments: Training in techniques and study of community changes over the past glacial."

**Ryan J. Thress,** University of Washington: "Structural and stratigraphic analyses of Messinian chaotic mass-flow deposits in the Sicilian foredeep basin."

**Sarah H. Vorhies,** Yale University: "Using intracrystalline diffusion to quantify timescales of metamorphism in the Barrovian zones, Scotland."

**David Weinstein,** University of Miami: "Rates of coral substrate bioerosion across the depth range of modern Caribbean reefs: Implications on past and future reef structures."

# 2010 SPECIALIZED AWARDS, SPONSORED BY THE GSA FOUNDATION

The committee selected the following recipients for specialized awards named in honor of Foundation donors or as memorials to former Society members.

**Gretchen L. Blechschmidt Award**
***Carlie Pietsch,*** *University of Southern California*. This award supports research by women interested in achieving a Ph.D. in the geological sciences and a career in academic research, especially in the fields of biostratigraphy and/or paleoceanography, and who have an interest in sequence stratigraphy analysis, particularly in conjunction with research into deep-sea sedimentology.

**John T. Dillon Alaska Research Award**
***Casey J. Huff,*** *University of California–Davis*. John Dillon was particularly noted for his radiometric age-dating work in the Brooks Range of Alaska; this award supports research that addresses field-based studies dealing with the state's structural and tectonic development and/or those that include some aspect of geochronology (either paleontologic or radiometric) to provide new age control for significant rock units in Alaska.

**Robert K. Fahnestock Award**
***Erica Bigio,*** *University of Arizona*. This award honors the memory of Fahnestock, a former member of the GSA Committee on Research Grants who died as a result of service on the committee, and recognizes the best proposal in sediment transport or related aspects of fluvial geomorphology, Fahnestock's field.

**Lipman Research Award**
***Sarah A. Bromley,*** *Oregon State University*. Established in 1993, this award is supported by gifts from the Howard and Jean Lipman Foundation; the president of the Lipman Foundation, Peter W. Lipman, was the recipient of a GSA research grant in 1965. The fund's purpose is to promote and support student research grants in volcanology and petrology.

**Minority Award**
***Robert W. Boessenecker,*** *Montana State University*. This award was established to promote and support minority students in the geosciences.

**John Montagne Fund**
***Kerry Riley,*** *Boise State University*. Established in 2000, this award supports one recipient's research in the field of Quaternary geomorphology.

**Bruce L. "Biff" Reed Scholarship Award**
***Joel Unema,*** *Northern Arizona University*. This award provides research grants to graduate students pursuing studies primarily on the tectonic and magmatic evolution of Alaska but can also fund other geologic research.

**Charles A. & June R.P. Ross Research Fund**
***Michael D. D'Emic,*** *University of Michigan*. Established in 2002, this fund supports research in the fields of biostratigraphy, stratigraphy and stratigraphic correlation, paleogeography and paleobiogeography, interpreting past environments of deposition and their biological significance, and the integration of these research areas into better global understanding.

**Alexander Sisson Research Award**
***George Daly,*** *Miami University*. Family members of Alexander Sisson established a fund in his memory to promote and support research for students pursuing studies in Alaska and the Caribbean.

**Parke D. Snavely, Jr., Cascadia Research Award Fund**
***Pasquale Del Vecchio***, *University of Nevada–Las Vegas*. This award provides funds to support field-oriented graduate-student research that contributes to understanding the geologic processes and history of the Pacific Northwest convergent margin or to evaluation of its hazard or resource potential.

**Harold T. Stearns Fellowship Award**
***Kayla D. Holleman,*** *University of Hawaii–Manoa;* ***Sarah M. White,*** *University of California–Davis*. Established in 1973, this fellowship supports student research on aspects of the geology of the Pacific Islands and the circum-Pacific region.

**Alexander & Geraldine Wanek Fund**
***Jennifer R. Dierauer,*** *Southern Illinois University*. Established in 2002, the Wanek Fund supports research dealing with coal and petroleum resources, mapping, and engineering geology, marine resources, petroleum economics, appraisal, and evaluation, and the geology of phosphate resources.

# SPECIALIZED AWARDS

## DIVERSITY IN THE GEOSCIENCES MINORITY RESEARCH GRANT AWARDS

Two research grant applications, selected from minority graduate student submissions, were found to be of exceptionally high merit in conception and presentation by the GSA Diversity in the Geosciences Committee, and will be recognized with a cash award of US$500 each: **Yamira Adorno-Negron,** University of Nebraska, "Isotope geochemistry, petrography and diagenesis of Permian carbonates from the Yuzhno Kilchuyu (YK) field, Timan-Pechora Basin, Russia"; and **Orlando Teran,** Centro de Investigación Cientifica y de Educación Superior de Ensanada (CICESE), "Kinematics and tectonic evolution of the rifted margin of the Rio Grande rift, Culebra Range, Colorado."

## FAROUK EL-BAZ STUDENT RESEARCH GRANT

This fund was established to encourage and support desert studies by students worldwide who are either in their senior year of undergraduate studies, or at the master's or Ph.D. level. This year's two awardees will receive a cash award of US$2,500 each: **Justine R. Cullen,** University of the Fraser Valley–British Columbia, "Determining an optimal protocol for optically-stimulated luminescence of sand dunes in the drylands of central Canada"; and **Stefan T. Knopp**, University of Calgary–Alberta, "Near-surface diagenetic processes and their implication for landscape evolution in desert environments: An example from the Late Jurassic to Early Cretaceous of the western interior U.S.A."

## THE MAURICE "RIC" TERMAN FUND

This grant fund provides support for one year of Ph.D. and post-doctoral research for scientists from the following East Asian countries: Cambodia, China, Indonesia, Japan, Korea, Malaysia, Papua New Guinea, Thailand, and Vietnam. The recipients for 2009 were **Nguyen Thi Hai Van** of Vietnam and **Namphon Khampilang** of Thailand.

# ALL 2010 GSA RESEARCH GRANT RECIPIENTS

Hannah Aird
David Aldridge
Megan Arnold
Alexis Ault
Eric Avalos
Karen Aydinian
Jonathan Baker
Thomas Baltz
Bharat Banjade
Jane Barnes
Lee Barnett
Chandranath Basak
Samuel Beal Jr.
Rachel Beavins
Catherine Beck
Scott Bennett
Blair Benson
Thomas Bianchette
Erica Bigio
Timothy Blazina
Grant Boardman
Robert Boessenecker
Wendy Bohon
Chloe Bonamici
Alvin Bonilla
Michael Bonomo
Deblina Bose
Greg Brennecka
Kirstin Brink
Sarah Bromley
Christine Brown
Kenneth Brown
Lucy Brudnak
Daniel Burnham
Matthew Burton-Kelly
Jesse Carlucci
Alison Carter
Christopher Cassle
Richard Casteel
Rafael Cavalcanti de Albuquerque
Kuldeep Chaudhary
Ming-Chu Chen
Kenneth Christle
Christopher Clinkscales
Joseph Collette
Elise Conte
Jennifer Cotton
Laura Craig
Megan Crocker
Brandi Cron
Ryan Crow
Michael D'Emic
George Daly
Michael Darin
Stephanie Day
Maarten de Moor
Jacob Deitz
Tanya del Valle
Pasquale Del Vecchio
Kathryn Denommee
Michael DeVasto
Jennifer Dierauer
David Dixon
Thomas Donahoe
Daniel Doolittle
Emily Eastridge
Clint Edrington
Austin Elliott
Timmons Erickson
Elena Evans
Joseph Felix
Adam Forte
Herbert Fournier
Travis Foy
Sarah Friedman
Andrew Frierdich
Evan Frye
Juan Luis García
Yann Gavillot
Michael Giallorenzo
Kelly Gibson
Nick Graehl
Alison Graettinger
Lauren Greene
Danielle Grogan
William Guerra

(*continued on p. 20*)

## ALL 2010 GSA RESEARCH GRANT RECIPIENTS (continued from p. 19)

Alan F. Halfen
Brian Hanson
Austin Hart
Janet Harvey
Joern Hauer
Bretani Heron
Gordon Hicks III
Luke Hilchie
Shari Hilding-Kronforst
Jenna Hojnowski
Kayla Holleman
Forrest Horton
Breanna Huff
Casey Huff
Kenneth Hughes
Rachel Hunt
Andrew Hutto
Ethan Hyland
Kayla Ireland
Kelly L. Jackson
Kristin Jacob
Matt Jenkins
Brittany Jenner
Britta Jensen
Adam Johnson
Casey Jolley
Matthew Jungers
Lisa Kanner
Leif Karlstrom
Andrew Kay
Caitlin Keating-Bitonti
Christopher Kelley
Neil Kelley
Kirsten Kennedy
Emiko Kent
Rimma Khodjanyazova
Jonathon LaCarrubba
Daniel Lancaster
Charity Lander
Rachel Landman
John Lee
Sophie Lehmann
Denise Levitan
Jennifer Levy
Robert Lewis
Zachery Lifton
Philip Lindner
Brad Lipovsky
MaryEllen Loan
Sandra Londono
David Lovelace
Christopher Lowery
Jason Loxton
Michael Lucas
Daniel Luna
Keith Ma
Robert Mahon
Guadalupe Maldonado Sanchez
Ahmadreza Malekpour Alamdarie
Richard Malizia
Thomas Malizia
Nobuaki Masutsubo
Malyssa Maurer
Aaron Mayfield
Windy Jo McBride
Bree McClenning
Sophie McCoy
B. Rex McLachlin
Michael Meyer
Melanie Michalak
Lauren Michel
Christen Miller
Diana Miller
Joseph Miller
Jason Mintz
Kristen Mitchell
Robin Moore
Beau Morris
Jesse Mosolf
Sarah Nagorsen
Pauline Paul Nesaraja
Laura Neser
Ghanashyam Neupane
Kathryn Nold
Andy Nunnery
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Joseph Perkins
Jared Peters
Carlie Pietsch
Jean-Luc Pilote
Zachary Ploskey
Zachary Poland
Lina Polvi
Vladislav Powerman
Jeremy Prouhet
Jonathan Prouty
Thejashwini Ramarao
John Ramirez-Avila
Christine Rasoazanamparany
Joanna Redwine
Melanie Reed
Christine Regalla
David Reioux
Francis Rengers
Paul Richardson
Leigh Anne Riedman
Kerry Riley
Nicholas Rosenau
Roxana Safipour
Esteban Sagredo
Morgan Salisbury
Carlos Sanchez
Aaron Sappenfield
Amanda Savrda
Nicole Schoolmeesters
Thomas Schramm
Eric Seeger
Jacob Selander
Steven Shaw
Xuhua Shi
Owen Shufeldt
Ashley Shuler
Karri Sicard
Marion Sikora
Maciej Sliwinski
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Jonathan Snatic
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Eleanor Spangler
Molly Staats
Edward Starns
Justin Starr
Gary Stinchcomb
Elizabeth Stock
Ashley Streig
Ciprian Stremtan
Justin Stroup
Debra Stults
Richard Styron
Mindi Summers
Kurt Sundell
Elizabeth Swanner
Dawn Sweeney
Rafferty Sweeney
Jordan-Leigh Taylor
Orlando Teran
Susanna Theroux
Jennifer Thompson
Ryan Thress
Justin Tiffany
Jessica Till
Tobgay Tobgay
Lauren Toth
Kaori Tsukui
Michael Tuite
Joel Unema
Morgan Unrast
Alexander Van Plantinga
Sarah Vorhies
Alina Walcek
Victoria Walker
Zackary Wall
Zachary Wallace
Talor Walsh
David Weinstein
Sarah White
Martha Whitney
Andrew Wickert
Inoka Widanagamage
Eric Wilcox Freeburg
Karen Williams
Matthew Winnick
Corinne Wong
John Wood
Ryan Wood
William Woodruff
Teresa Wriston
Tao Wu
Tracy Wulf
Lindsey Yann
Hongjiao Yu
Adam Zeiza
Ashley Zung

**2010 Alternates**

Jordan Armstrong
Christian Christofferson
Evan Kochelek
John Kroon
Ryan Mills
Reed Myers
Nathan Peters
Jeanne Roningen
Tabitha Trosper
Kathryn Warren

# 2010 GSA DIVISION & SECTION STUDENT RESEARCH AWARDS

## DIVISION AWARDS

Five GSA Divisions have recognized the following graduate student research grant recipients for submitting proposals of exceptionally high merit in conception and presentation in their fields. These students will be honored by these Divisions at the 2010 GSA Annual Meeting in Denver.

### GEOPHYSICS DIVISION

**Allan V. Cox Student Research Grant**
**Sarah Friedman,** Southern Illinois University

**Geophysics Student Research Grant Award**
**Deblina Bose,** Auburn University

### HYDROGEOLOGY DIVISION

**Student Research Grant Awards**
**Kuldeep Chaudhary,** The University of Texas at Austin–Jackson School of Earth Sciences;
**Jennifer Dierauer,** Southern Illinois University;
**Emily Eastridge,** University of Kentucky;
**Marcie Occhi,** University of Maryland

### QUATERNARY GEOLOGY AND GEOMORPHOLOGY DIVISION

**J. Hoover Mackin Student Research Award**
**Juan Luis Garcia,** University of Maine

**J. Hoover Mackin Student Research Award Honorary Mention**
**Matthew C. Jungers,** Arizona State University

**Arthur D. Howard Student Research Award**
**Ryan W. Wood,** San José State University

**Arthur D. Howard Student Research Award Honorary Mention**
**Serin Duplantis,** Portland State University

**Marie Morisawa Student Research Award**
**Britta J.L. Jensen,** University of Alberta

**Marie Morisawa Student Research Award Honorary Mention**
**Erica Bigio,** University of Arizona

### SEDIMENTARY GEOLOGY DIVISION

**Sedimentary Geology Division Student Research Grant Award**
**Jennifer Cotton,** University of Michigan

### STRUCTURAL GEOLOGY AND TECTONICS DIVISION

**Student Research Grant Awards**
**Adam Forte,** University of California–Davis;
**Janet C. Harvey,** California Institute of Technology;
**Melanie Michalak,** University of California–Santa Cruz;
**Richard H. Styron,** University of Kansas;
**Justin M. Tiffany,** University of Missouri–Columbia

## SECTION AWARDS

Two GSA Sections have recognized exceptional students within their geographic region.

### SOUTHEASTERN SECTION

The following graduate students from universities within the geographic boundaries of GSA's Southeastern Section were recognized by the Section for submitting research grant proposals of exceptionally high merit in conception and presentation:

**Max Christie,** University of Georgia;
**Tina L. Colbert,** Georgia Institute of Technology;
**Kristin M. Dorfler,** Virginia Polytechnic and State University;
**Subhadip Mandal,** University of Alabama;
**Adeola Oyewumi,** Virginia Polytechnic and State University;
**Oluyinka Oyewumi,** Virginia Polytechnic and State University;
**Dalene Smith,** Western Kentucky University.

### NORTHEASTERN SECTION

GSA's Northeastern Section offers student research grant awards to support research by sophomore or junior undergraduates attending universities within the geographic boundaries of the Section:

**Daniel J. Arcadi,** SUNY Potsdam;
**Matthew Dunlop,** SUNY Potsdam;
**Caitlin Herbert,** Lesley University;
**Elizabeth Petsios,** Cornell University;
**Chelsea L. Richard,** SUNY Potsdam;
**Allen J. Schaen,** Bridgewater State College;
**Marissa Tremblay,** Barnard College.

# 2010 Cole Award Recipients

*The 2010 Cole Awards for postdoctoral research are funded by the GSA Foundation.*

### GLADYS W. COLE MEMORIAL RESEARCH AWARD

**Kathleen Nicoll,** University of Utah, was awarded US$6,500 from the Gladys W. Cole Fund for research in geomorphology of semi-arid and arid terrains for her research project "Revisiting G.K. Gilbert's 'Great Bar at Stockton, Utah'—documenting a site in peril." The award will be presented at the Quaternary Geology and Geomorphology Division Awards Ceremony at the 2010 GSA Annual Meeting.

### W. STORRS COLE MEMORIAL RESEARCH AWARD

**Richard H. Fluegeman**, Ball State University, was awarded US$6,000 from the W. Storrs Cole Fund for research in invertebrate micropaleontology for his research project "Eocene planktonic foraminiferal biostratigraphy and the timing of ophiolite obduction, New Caledonia, southwest Pacific." The award will be presented at the Cushman Foundation for Foraminiferal Research Awards Ceremony at the 2010 GSA Annual Meeting.

GSA LIMNOGEOLOGY DIVISION

# Kerry Kelts Student Research Award

**Application deadline:** 2 August 2010

GSA's Limnogeology Division is offering an award of US$1,000 for research related to limnogeology, limnology, or paleolimnology. To apply, send a summary in PDF format (include your name in the PDF file name) of the proposed research, its significance, and how the award will be used (five-page max.) along with a short (two-page max.) CV to the chair of the Limnogeology Division, Michael Rosen, mrosen@usgs.gov. For more information, go to http://rock.geosociety.org/limno/Kelts%20Award%202010%20announcement.htm.

The award recipient will be announced at the Limnogeology Division Business Meeting and Reception at the 2010 GSA Annual Meeting.

If you are interested in supporting this program to help increase the number of awards given, please send your donations designated for the Kerry Kelts Research Awards of the Limnogeology Division to GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

# ABOUT PEOPLE

GSA Fellow **William F. Ruddiman,** professor emeritus at the University of Virginia, has been awarded the 2010 Lyell Medal by the Geological Society (London) for his "significant contribution to 'soft rock' geology by means of a substantial body of research."

GSA Fellow **Barbara K. Bekken** was honored with two awards from Virginia Tech this spring—the 2010 Edward S. Diggs Teaching Scholars Award and the 2010 Alumni Award for Excellence in Teaching—recognizing her exceptional contributions to the Virginia Tech teaching program and learning environment.

The National Academy of Sciences (NAS) has named its new members and "foreign associates," elected "in recognition of their distinguished and continuing achievements in original research." Congratulations to GSA Fellow **Douglas W. Burbank** of the University of California–Santa Barbara and GSA Fellow **Roberta L. Rudnick** of the University of Maryland–College Park for their election to NAS membership and to GSA Honorary Fellow **Víctor A. Ramos** of Universidad de Buenos Aires for his election as an NAS foreign associate.

GSA Fellow and Foundation Trustee **Farouk El-Baz** has been appointed chair of the steering committee of the 2010 National Academies Keck *Futures Initiative* (NAKFI) on imaging science. The Futures Initiative is a 15-year effort to stimulate interdisciplinary inquiry and to enhance communication among researchers, funding agencies, universities, and the general public.

GSA Member **Rebecca Flowers** of the University of Colorado at Boulder has received an NSF CAREER Award for her work studying the southern African Plateau.

GSA Member **Kenneth H. Nealson** has been selected the 2010 D.C. White Research and Mentoring Award laureate by the American Society of Microbiology in recognition of his scientific research and mentoring activities.

In March, GSA Fellow **Richard Alley** presented the 2010 George Gamow Memorial Lecture, "Learning while burning: Peak (whale) oil, climate change, and our future," at the University of Colorado at Boulder, where physicist George Gamow taught from 1956 to 1968.

You'll find more news about GSA members at **www.geosociety.org/news/memberNews.htm.** Keep your colleagues up to date and help to honor excellence among the GSA membership by sending your member news to GSAToday@geosociety.org.

# Last Call for 2010 Officers and Councilor Nominations

Nominations accepted through 15 July

The GSA Committee on Nominations requests nominations for GSA Officers (vice president and treasurer) and Councilors to serve beginning in 2011.

Each nomination should be accompanied by basic data and a description of the qualifications of the individual for the position recommended.

You can access the online nomination form at **www.geosociety.org/aboutus/officers.htm,** or you many send nomination materials to Pamela Fistell, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA, pfistell@geosociety.org.

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# In Memoriam

GSA regretfully reports the death of the following members (notifications received between 1 Feb. 2010 and 30 Apr. 2010).

**George O. Bachman**
Centennial, Colorado, USA
Notified 16 February 2010

**Saleh M. Billo**
Riyadh, Saudi Arabia
1 April 2010

**Charles A. Boland**
Rock Hill, South Carolina, USA
Notified 18 March 2010

**Eric Lloyd Cohen**
East Hampton, New York, USA
Notified 22 March 2010

**Anthony B. Gibbons**
Wheat Ridge, Colorado, USA
Notified 28 April 2010

**Leland H. Gile**
Las Cruces, New Mexico, USA
16 November 2009

**Nikki T. Hemmesch**
Paynesville, Minnesota, USA
10 July 2009

**Albert C. Holler**
Saint Paul, Minnesota, USA
Notified 1 February 2010

**Walden P. Pratt**
Arvada, Colorado, USA
30 August 2008

**William S. Shaw**
Antigonish, Nova Scotia, Canada
1 August 2009

**Jeffrey D. Spooner**
Rolla, Missouri, USA
19 January 2010

**George C. Stephens**
Washington, D.C., USA
Notified 8 April 2010

**Edgar L. Weinberg**
Austinville, Virginia, USA
Notified 2 March 2010

**Stuart S. Wilson**
Boulder, Colorado, USA
Notified 10 March 2010

**M. Gordon Wolman**
Baltimore, Maryland, USA
24 February 2010

**Richard A. Zimmermann**
Heidelberg, Germany
28 February 2010

Each year, GSA publishes a memorial volume dedicated to deceased GSA members. The memorials are written by associates, friends, or relatives of those who have passed away and are priceless, indispensable records of the fascinating individuals who have been part of GSA. To honor one of the colleagues listed here with a memorial, please go to **www.geosociety.org/pubs/memorials/index.asp.** This page also lists completed memorials, some of which are available for download.

If you would like to contribute to the GSA Memorial Fund, please contact the GSA Foundation, drussell@geosociety.org, +1-303-357-1054, www.gsafweb.org.

## Call for GSA Committee Service

# *Impact the Future of Geoscience—*
# Serve on a GSA Committee!

**2011–2012 COMMITTEE VACANCIES**

**Deadline to apply or submit nominations:** 15 July 2010

GSA invites you to volunteer or nominate one of your fellow GSA Members to serve on Society committees or as a GSA representative to other organizations. Learn more about each committee and access the nomination form at **www.geosociety.org/aboutus/committees/.** You can also download the form and send a hardcopy nomination to Pamela Fistell, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA; fax: +1-303-357-1074; phone +1-303-357-1044 or +1-800-472-1988, ext. 1044; pfistell@geosociety.org. **Terms begin 1 July 2011** (unless otherwise indicated).

**COMMITTEE, SECTION, AND DIVISION VOLUNTEERS:**

## COUNCIL THANKS YOU!

GSA Council acknowledges the many member-volunteers who, over the years, have contributed to the Society and to our science through involvement in the affairs of the GSA. Your time, talent, and expertise help build a solid and lasting Society.

**COMMITTEES REQUIRING VOLUNTEERS/NOMINEES:**

| COMMITTEE | NO. OF VACANCIES | LENGTH OF TERM |
|---|---|---|
| **Academic and Applied Geoscience Relations (AM, T/E)** | one | 3 years |
| **Annual Program (AM, B/E)** | one | 2 years |
| | one | 4 years |
| **Arthur L. Day Medal Award (T/E)** | two | 3 years |
| **Diversity in the Geosciences (AM, T/E)** | three | 3 years |
| **Education (AM, B/E, T/E)** | one | 2 years |
| | two | 4 years |
| **Geology and Public Policy (AM, B/E, T/E)** | two | 3 years |
| **Joint Technical Program (T/E)** | one | 3 years, starts 1 Jan. 2011 |
| **Membership (B/E)** | three | 3 years |
| **Nominations (B/E, T/E)** | one | 3 years |
| **Penrose Conferences and Field Forums (T/E)** | one | 3 years |
| **Penrose Medal Award (T/E)** | two | 3 years |
| **Professional Development (T/E)** | two | 3 years |
| **GSA Public Service Award (T/E)** | one | 3 years |
| **Publications (AM, B/E, T/E)** | one | 4 years |
| **Research Grants (B/E, C)** | eleven | 3 years |
| **Young Scientist Award (Donath Medal) (T/E)** | two | 3 years |

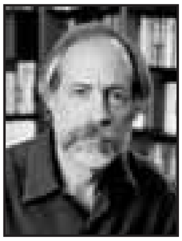
**GSA REPRESENTATIVES TO OTHER ORGANIZATIONS**

| COMMITTEE | NO. OF VACANCIES | LENGTH OF TERM |
|---|---|---|
| **GSA Conferee to the AAPG Publication Pipeline Committee (B/E, T/E)** | one | 3 years |
| **North American Commission on Stratigraphic Nomenclature (NACSN) (AM, possibly B/E)** | one | 3 years, starts Nov. 2011 |

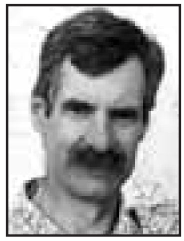
**AM—Meets at the Annual Meeting • B/E—Meets in Boulder or elsewhere**
**C—Extensive time commitment required during application review period (15 Feb.–15 Apr. 2012) • T/E—Communicates by phone or electronically**

# Meet Your NEW 2010 Officers and Councilors

## GSA OFFICERS (July 2010–June 2011)



**PRESIDENT**
**Joaquin Ruiz**
University of Arizona
Tucson, Arizona, USA



**VICE PRESIDENT**
**John W. Geissman**
University of New Mexico
Albuquerque, New Mexico, USA

**TREASURER**
**Jonathan G. Price**
Nevada Bureau
of Mines & Geology
Reno, Nevada, USA

PAST PRESIDENT
**Jean M. Bahr**
University of Wisconsin
Madison, Wisconsin, USA

## GSA COUNCILORS

**NEWLY ELECTED GSA COUNCILORS**
**Term: July 2010–June 2014**

**Bruce R. Clark**
The Leighton Group, Inc.
Irvine, California, USA

**Barbara L. Dutrow**
Louisiana State University
Baton Rouge, Louisiana, USA

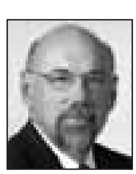
**Daniel Larsen**
University of Memphis
Memphis, Tennessee, USA

**CURRENT GSA COUNCILORS**

**Term: July 2007–June 2011**

**Monica E. Gowan**
University of Canterbury
Christchurch, New Zealand

**Jacqueline E. Huntoon**
Michigan Technological University
Houghton, Michigan, USA



**G. Randy Keller**
University of Oklahoma
Norman, Oklahoma, USA

**Term: July 2008–June 2012**

**Brian R. Pratt**
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

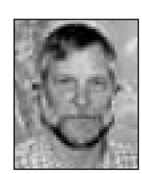
**Murray W. Hitzman**
Colorado School of Mines
Golden, Colorado, USA

**Claudia I. Mora**
Los Alamos National Laboratory
Los Alamos, New Mexico, USA

**Term: July 2009–June 2013**

**Lisa D. White**
San Francisco State University
San Francisco, California, USA

**Ricardo A. Astini**
Universidad Nacional de Córdoba
Córdoba, Argentina



**J. Douglas Walker**
University of Kansas
Lawrence, Kansas, USA

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE • STEWARDSHIP • SERVICE

The following 2,515 new GSA members, who joined GSA between Sept. 2009 and Feb. 2010, were elected to membership by GSA Council at its spring 2010 meeting.

# ***New Members:*** *GSA Welcomes You!*

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Stephen R. Alcorn
Allison R. Aldous
Ahmad Al-Dousari
Julien Marius Allaz
Richard M. Allen
Steve Alm
Bader Khezam Al-Mahri
Sadraddin Amini
Hiroyoshi Arai
Rosemary A. Askin
Russell Blaik Axelrod
Brad Bacon
Elizabeth A. Baker
Kathleen Baker
Julian Tucker Barksdale
Paul M. Barlow
Constanza H. Jara Barra
Richard Lester Bartels
David Bary
Behrooz Bashokooh
Douglas L. Bates Sr.
Christopher Behnke
Claire M. Belcher
Claudia Benitez-Nelson
D. Wayne Berman
Claudio Berti
Rick A. Bieber
Justin Edward Birdwell
Sean Bistoff
Steven C. Bjornstad
James Joel Blair
James Luke Blair
Alberto Blanco Piñón
Sergio Blanco
Bhaskar Bondada
Michael G. Bostock
William V. Bour III
Dana Bove
Darren Box
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Benjamin John Brady
Michael J. Brayton
Larry D. Brisendine
Grant Bromhal
Jennifer Jo Brown
Eric Buer
Shondricka Burrell
Walter Burt
Rob Butler
Kenneth Paul Cannon
Richard Walter Carlson
Simon Anthony Carn
Daniel Glenn Carpenter
Lauren Gee Carroll
Lisa G. Carter
Bruce Richard Cassem
Michael Andrew Casso
Renee Cataneo
Kurt E. Cato
Anne Marie Chaka
Helder I. Chaminé
Sze-Ling Chan
Renee Chantrill
Clark R. Chapman
Chang-Hwa Chen
Jui-Sheng Chen
John Alan Chermak
Andrei Chitalin
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Robert W. Clayton
Richard Lee Coffman
James W. Cole
Jamus Collier
Anna Colvin
Curtis A. Cooper
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Chris Cottingham
Vincent E. Courtillot
Brian C. Crooks
Michael A. Danahy
Amy Daniell
Melinda Dawn Daniels
Dana Maurice D'Aria
Stephanie Davidson
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Robert Dedoes
Seth Dee
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Rui M.S. Dias
Rose Difley
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James Farquhar
Neal Farrar
James L. Fastook
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Katherina Fiege
Harry F. Filkorn
Ilya Reuben Fischhoff
David Fischman
Miguel Franco-Rubio
Julia Frazier
Corey R. Froese
John Gale
Miguel Gallardo Sr.
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Aude Gebelin
Ady Geda
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William J. Gibbons
Jan Gillespie
S. Dianne Gillespie
Helge Gonnermann
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Michael T. Gottler
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Alfred Herman Guhl
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Robert B. Hawman
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Franklin T. Heitmuller
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Md. Sakawat Hossain
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Hai Huang
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David Hulslander
Oldrich Hungr
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Danny Itkin
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Kandy Sue Jarvis
Calvin Johnson
Gwynn R. Johnson
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Zhen Li
Francesca Liberi
Sebastian Lindhorst
Liliana Lizarraga Mendiola
Dion R. Lobreau
Andrew Love
Zhiming Lu
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Ann Maest
Joseph Zebulon Maharrey
Cornel-Dorel Manecan
Jingdong Mao
Danny Marks
Roger Eugene Marlin
Ronald L. Martin
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Sara E. Mason
Hans-Joachim Massonne
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Reed Maxwell
Ronald Mayerle
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Ryan Joseph McAleer
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John Charles Menzies
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Kevin M. Meyer
Enrico Miccadei
Peter Michael
Phyllis Midkiff
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Santanu Misra
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Shinya Nakamura
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Jodi Norris
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Matthias Ohr
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Tina Ornduff
Tim Orr
Holger Ott
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Jessica Ann Palmer
Selena T. Pang
Samuel Vincent Panno
Cathy Pappas-Maenz
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Steven Michael Pawley
Joshua H. Payne
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Sally J. Pehrsson
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Fabrizio Piana
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Monica Pondrelli
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David P. Powell
Matthew D. Powers
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Stacey Priestley
Doug Prose
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Bern J. Qualheim
Kristin J. Quell-Garguilo

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Peter Burland Read
Michele L. Reba
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Janet Marian Riddell
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Charles L. Saunders III
Thomas Patrick Schmidt
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Martin Simmons
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Donald Singer
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John McGregor Skinner
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Robert Smit
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Paul A. Smith
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Rob Striegl
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Mark Sturgess
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Robert F. Swenson
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Tokichiro Tani
Yuri Taran
Christopher N.A. Taylor
Mark Teague
David Terry
Garrett Michael Thornton
Andy Tiedeman
Brian Paul Tillquist
Hengmao Tong
Rex Roger Torrez
Theofilos B. Toulkeridis
Shashank S.P. Tripathi
Frank Urban
Lara Lanyon Urizar
Peter Kent Van de Water
Simon E. van der Wielen
Nick Varnum
Carol Bolam Verrier
Nathan Voorhies
Heidi M. Wadman
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Fengqin Wang
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Eric Wannamaker
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Eileen Weppner
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Jason Woodcock
Jennifer Wright
Andrew Trevor Wurst
Shangping Xu
Tatsuhiko Yamaguchi
Yoseph Yechieli
David R. Yesner
Yusuke Yokoyama
Zhenlei Yuan
Victor Zabielski
Yannick Zaczek
Zoltan Zajacz
Thomas Zdeb
Lifei Zhang
Manjiang Zhang
John Zutman

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Susan M. Avre
Jacob Baggerman
Iestyn Barr
Cheila Benavides
Jeremy Bergeron
Eros Antoine Bilyeu
Thomas Michael Bone Jr.
Caitlin Borbely
Lindsay Bourgoine
Clinton Brickner
Anthony Brillante
Eileen Capitoli
Kenneth Cooper Carroll
Mandy Jo Charles
Peipei Chen
Scott Conrad
Clay Corbin
Milton Cortez III
Fiona K. Couperthwaite
Stephen Ellis Cox
Scott Craig
Andrew M. D’Agostine
Audrey Dakan
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Maia C. Davis
Samuel L. Dayton
Marleiah Denka
Corinne R. Disenhof
Ian P. Donovan
David Dow
Jenna Ellis
Hossam E.M. El-Sayed
Meaghan Emery
Jennifer K. Evans
Ake Fagereng
Anthony Fair
Reid C. Fenning
Alex James Ferguson
Matteo Ferrucci
Brian Peter Ferwerda
Nathaniel Jon Fischer
Steven Fisk
Kaitlin Brookes Fleming
Thomas L. Fowke II
Megan Lynn Foye
Elizabeth Mari Francisco
Thomas Garrett Freeman
Ben Friedman
Samuel Galenty
Seth Goad
Amit Kumar Guru
Manuel Vargas Gutierrez
Ryan James Haupt
Kathryn Ann Hazlehurst
Brett E. Heist
David Ryan Hickey
Nazim Hodzic
Ruth Indrick
Joseph Michael Ivanowski
Rob Jaecks
James Robert Jahnz
Michelle James
Scott H. Jewell
Matthew B. Johnson
Devin Michael Justman
Jennifer D. Keese
Dana Marie Kitchell
Denise Kay Kulhanek
Robert George Lee
Selina S. Lee
Chu-Ching Lin
Maren Lindow
David M. Livingston
David Lugo
Leigh Colby Mastin
Charles A. McCaffree
Tiffany Dawn McClennen
Leisa Meitl
Frederick Marc Michel
James Jeffrey Miller
Marc Miller
Stuart J. Mills
Josh Mohler
Megan M. Montgomery
Maureen Nancy Moore
Adrian Morales
Vince Morton
Matthew Mrozek
Marcus R. Muccianti
Rachel Helen Murray
Andrew Lloyd Myers
Lisa Navarro
Jeremy David Nicoletti
Jasin Olsen
Onisobuana R. M. Osuamkpe
Joseph F. Oszuscik
Andrea Pain
Kaustubh Patwardhan
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Rachael Simon Peavler
Mark E. Poindexter
Veronica Poteat
Matthew Ryan Prusinski
Gina René Raymond
Clarence William Reece
Anna Marie Reimer
Wil Reyes
Ursula Rick
Jed Roberts
Anthony Romanoski
Michael Rupright
Marissa A. Saccente
Vincent J. Schlageter
Andrew Schneider
Gregory A. Schrader
Jacob Tyler Schwenk
Matthew Scullin
Andrea M. Seymour
Terri Lynn Shattuck
Steven J. Shaw
Andrew D. Shireman
Daniel R. Simpson
Drexel Siok
Brittany Smith
Alexander Snyder
Daniel E. Soda
Patrick I. Spurgeon
Andrew A. Starland
Alex Strugatskiy
Summer Joy Sturhan
Katelyn Sutcliffe
Gary Swan
Carl D. Swanson II
Paul Brett Talmage
Alicia Thompson
Mathew Arvid Tilman
Colby D.H. Tisdale
Nicholas Tranter
Joshua Troyer
Michael Tutt
Heather Van Strydonk
Casey Nicholas Varnum
Ryan Foster Vazquez
Nicole Velasco
Camilla Jane Watts
Daniel Paul White
Nicholas Wieclaw
Carsten Wieczorrek
Stephanie Ann Woicik
Steven Randall Woodley
Reid Isao Yano
Janet Marie Yates
Stephen A. Zdan

**STUDENTS**

Christa Abatemarco
Hasan Abdeljawad
Ashley Adams
John Kendall Adams
Sharon Ann Adams
Christina D. Adkins
Jonathan Adkins
Rebecca Abigail Adler
Yamira Adorno-Negron
Sofia Agopian
LaOde Ahdyar
Madeeha Ahmed
David Aaron Ahumada
Hannah Mary Aird
Kathryn Helene Akerman
Sara J. Akin
Eric A. Akoko
Itohowo Akpabio
Austin Elihu Akridge
Ahmadreza M. Alamdarie
Md. Iftekhar Alam
Seyed Matin Alavi
Meredith Albers
Henio Danilson Alberto
Andrew M. Alderman
David Aldridge
Joseph C.R. Alejandro
Meghan E. Alesce
Aaron M. Alexander
Kathryn Alexander
Andrew Wayne Allen
Kent C. Allen
Marsha Allen
Ashley Erin Almon
Omar M. Al-Qudah
Yaqoub Yousef Alrefaei
Christopher D. Althoff
Kathryn Marie Altman
Hehewutei Amakali
Caroline Mary Amelse
Reda Amer
Daniel B. Amoakoh
Erin L. Anderson
Leif Stefan Anderson
Péter András
Michael Paul Andrew

## *New Members: GSA Welcomes You!*

Alexandra Andrews
Derrick O'Neal Andrews
Eric Andruk
Conrad Anker
Suzanne M. Ankerstjerne
David Charles Annis
James Ansley
Teryila Apera
Ravi Appana
Kimberly Aquino
Daniel J. Arcadi
Ryan M. Archer
Meesha M. Ard
Jacob Edward Ardner
Asefu G. Aregawi
Mohd. Hariri Arifin
Takahiko Arima
Mary Ruth Armbruster
Jordan T. Armstrong
Michael L. Armstrong
Taylor Armstrong
William H. Armstrong Jr.
Summer L. Arrowood
Jennifer Lynn Artman
Elizabeth F. Asbury
Anthony Amor Asher
Biniam B. Asmerom
Timothy Ian Astrop
Ali Atef
Victor O. Attah
Amanda Kay Attick
Clemens Augenstein
Karen E. Austin
Constantinos Avgoustou
Oladotun Awosemo
Karen Aydinian
Kacie Baak
Margaret Baber
Kira Joy Baca
Timothy Badger
Kirsten Bahr
Mike Baierlipp
Amanda L. Bailey
Bevin L. Bailey
Vincent Bailly-Comte
Suraj Kumar Bajgain
Brad Jonathan Baker
Emily Hewitt Baker
Jonathan Lloyd Baker
Patrick Baker
Gregory Patrick Balch
Dylan Baldwin
Carolyn Elizabeth Ball
Michael Ball
Ted Jeffrey Balling
Lerin Marie Baltzly
Phil W. Bambach
Sikhar Banerjee
Bharat Banjade
Rachel Anna Bankus
Milo Barham
Alex Gregory Barker
John David Barker
Theodore Basile Barnhart
Gregory John Baron
Bridgette A. Barr
Heather A. Barrett
Sarah Anne Barrett
Joshua David Bartley
Jamie L. Bartling
Ashley Barton
Ashley Marie Barton
Tapati Barui
Chandranath Basak
Lamuail Bashir
Hridaya Bastola
Benjamin W. Bates
Thomas R. Battenhouse Jr.
Joseph C. Bauman
Andarge Yitbarek Baye
Matthew William Beachly
Jessica A. Bean
James Andrew Beard
Ernest W. Beasley IV
Robert Beauford
Blaire Beavers
Rachel Beavins
Miki Annette Beavis
Lori Bebinger
Andrew William Becker
Richard Albert Becker
Natalie D. Beckman
Chloe Brett Beddingfield
Leah Bedoian
Stephanie Beebe
Adam D.B. Behlke
Hannah Beker
Kevin Gregory Bellamy
Nicole Bellino
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John Benedict
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Ariana Garcia-Trejo
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Max Gardner
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Monica Hanson
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Ross Raynor Hartwick
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Jeremy M. Henning
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Bretani Heron
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Rachael Alyce Hines
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Maya Ishikawa
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Jue Jiang
Batbaatar Jigjidsuren
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Jacques Johnson
John J. Johnson
Kathleen Burke Johnson
Nancy Leigh Johnson
Sarah Elizabeth Johnson
Casey Gibson Jolley
Michael Edward Jonas
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# Leadership Change in the Foundation

David A. Stephenson

After six years, **David A. Stephenson** stepped down as president of the Geological Society of America Foundation on 30 June 2010.

Stephenson has served GSA unselfishly for more than four decades—as an associate editor of the *GSA Bulletin* from 1979–1984; chair of the Hydrogeology Division in 1983; member of GSA Council from 1989–1991; and president of GSA in 1995. In 2001, Stephenson took on the role of acting executive director for GSA, and he assumed the presidency of the GSA Foundation in 2004. He has served on numerous committees and lent his wisdom and effort to many of the Society's activities. Stephenson's extraordinary record of service will be recognized by the Society at the 2010 Annual Meeting in Denver with the Society's Distinguished Service Award.

Stephenson received his AB in geology from Augustana College in 1958, his M.S. in geology from Washington State in 1961, and his Ph.D. in hydrogeology from the University of Illinois in 1965. He taught at the University of Wisconsin for a decade and directed the Water Resources Management Program there. Stephenson then moved into the applied geology sector for nearly 25 years, holding senior leadership positions with Woodward-Clyde Consultants, Dames & Moore, South Pass Resources, and S.S. Papadopulos & Associates. Stephenson was also president of the American Geological Institute in 1999. He is now planning to resume his hydrogeology consulting career.

During his tenure as GSA Foundation president, Stephenson has seen the Foundation's annual donations rise by nearly 20% and a substantial increase in bequests. He has worked tirelessly to expand and diversify the Foundation's Board of Trustees so that members now come from a wide range of academic and applied backgrounds. Under his leadership, a new Development Committee, consisting of current and past board members, former GSA leaders, and major supporters of the Foundation, has been formed and is in the process of developing a set of ambitious goals for the Foundation's future.

Geoff Feiss

**Geoff Feiss** began as Stephenson's successor on 1 July 2010. He has been a member of the Foundation Board of Trustees since 2006, serving as vice-chair for the past two years.

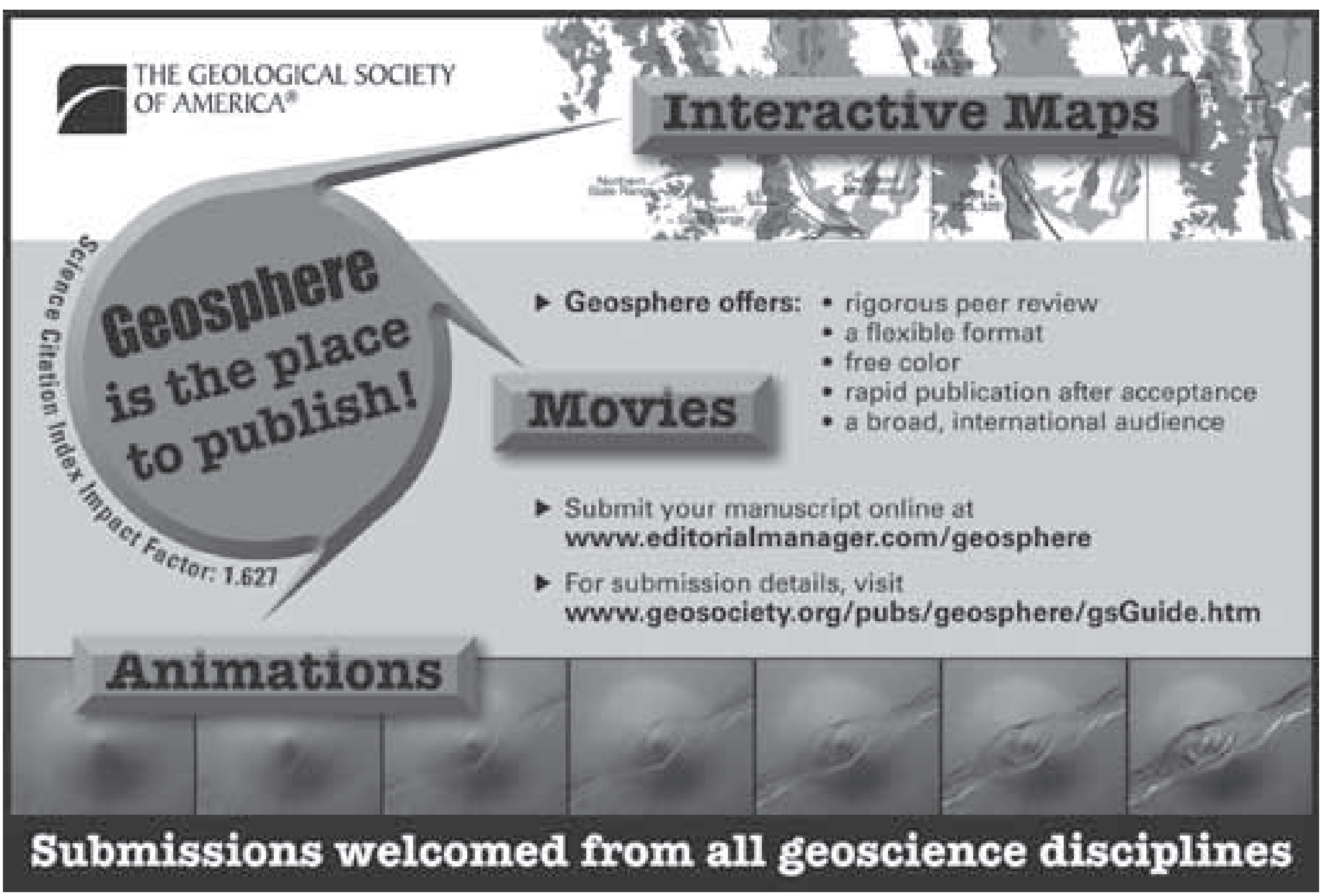
Feiss retired as provost emeritus and professor emeritus at the College of William and Mary in Virginia in 2009 and moved to Fort Collins, Colorado, USA. In his capacity as provost, he was an ex officio member of the college's Board of Visitors and the Board of Directors of the William & Mary Foundation. He also was on the Board of Directors of the Williamsburg Community Foundation.

Feiss served as William and Mary's provost for six years, and before that served as Dean of the Faculty of Arts and Sciences for six years. Prior to moving to William & Mary, he was a member of the geology faculty at Albion College from 1970 to 1975 and at the University of North Carolina at Chapel Hill from 1975 to 1997, where he also served as chair of the Department of Geological Sciences and as senior associate dean. He was the chair of the Board of the Southeastern Universities Research Association and president of both the Council of Colleges of Arts and Sciences and the National Association of Geoscience Teachers. From 1999 to 2002, Feiss was a member of the NAS/NRC Committee on Mineral Resources. He has chaired the GSA Committee on Public Policy and the GSA-USGS Congressional Science Fellowship Selection Committee. An economic geologist, Feiss received his AB in geology from Princeton University in 1965 and his Ph.D. from Harvard University in 1970.

Feiss takes on the presidency as the Foundation moves into its thirtieth anniversary. At the time of this writing, a search for a chief development officer is on-going; we hope to have the new development officer on board in advance of the 2010 Annual Meeting. Among the first priorities of business for Feiss and the new development officer will be implementation of the Development Committee's recommendations after its year-long review of GSA Foundation activities so as to advance GSA's priorities and fill its unmet needs.

> Feiss: "I can imagine no more rewarding work than joining forces with the GSAF Board and GSA leadership and members to obtain the critical resources to support GSA. Such worthy activities as student research and travel grants, GeoCorps, awards and recognitions, increasing the international presence of GSA, and the many public education and outreach efforts of the Society are among GSA's priorities deserving all of our support in the years to come."





# Sustaining the Global Environment through the Foreign Assistance Act

*Mark G. Little*

More than fifteen African nations, including Nigeria and the Democratic Republic of Congo, won their independence from European nations in 1960. Construction of the Berlin Wall began in the middle of 1961, just months after the failed Bay of Pigs invasion. President John F. Kennedy signed the Foreign Assistance Act (FAA) into law in September of 1961 and subsequently created the United States Agency for International Development (USAID). The Foreign Assistance Act, crafted in a Cold War crucible of bipolar, Soviet-American antagonism, was based on a belief that American security required international cooperation "to use wisely the world's limited resources" and that the "traditional humanitarian ideals of the American people … to assist people in developing countries to eliminate hunger, poverty, illness, and ignorance" should be affirmed. The five major goals were poverty alleviation, independent economic growth, individual rights, economic integration into global markets, and good governance.

Today, we live in a much-changed world: Sub-Saharan Africa is experiencing economic growth after years of stagnation; the United States and Russia have cordial relations; and Brazil, China, India, and South Africa are surging ahead, joining the community of nations fueled by natural resources, often at the expense of the natural environment. These momentous political and economic changes have also created a more complex diplomatic world while placing further demands on our collective resources.

In the intervening decades, the Foreign Assistance Act has been amended; however, it is the judgment of many involved in development work—including the Chair of the House Committee on Foreign Affairs—that this patchwork of fixes has led to a bureaucratically fragmented foreign aid system that is inadequate to address contemporary development problems, including those related to earth systems and the environment. For example, the five original major goals of the bill make no mention of natural resources or the environment. Little thought was given to the finite nature of fossil fuels and mineral resources. Clean air, water, and soil were not given the appropriate level of importance.

Many of the omissions are quite understandable given that the first substantial federal acknowledgement of and commitment to environmental stewardship was not passed until 1970, in the form of the Clean Air Act. A requirement that any federal agency perform assessments of the environmental impacts of their own domestic projects was not in place until the 1970 National Environmental Policy Act (NEPA). And the watershed political moment for recognition of climate change, the United Nations Framework Convention on Climate Change, did not come to pass until 1992. There have been many subsequent amendments to address these gaps—debt-for-nature swaps to encourage conservation, mandatory environmental impact assessments, and modest funds for climate change adaptation assistance; however, the time has come for a comprehensive rewrite.

As a Congressional Science Fellow, I have been dumbfounded by the often circuitous process of crafting legislation but encouraged by a professional staff able to navigate this world without losing sight of their objectives. The diversity of concerns within the U.S. government as it relates to Foreign Assistance Act reform is also impressive. Before coming to the Hill, I was unaware of the significance of the separation amongst Congress and each of the numerous executive branch agencies. Agencies have their own viewpoints and expertise, and we have sought input from groups as diverse as the State Department and the U.S. Geological Survey. Moreover, there are foreign governments, nongovernmental organizations, and civil society groups who all have a direct interest in our work. Through this process of reaching out to the various stakeholders, we are working out such questions as how best to encourage developing economies to mitigate emissions of greenhouse gases and how we can help poorer nations balance adaptation to substantial climatic changes, future development, and the conservation of natural resources.

In the proposed new structure of the Foreign Assistance Act, the goal of "Sustaining the Global Environment" will be elevated in importance to the level of other major goals, including poverty reduction and anti-terrorism. Within this environmental title, grand efforts will be made to broaden conservation to include fragile natural ecosystems like coral reefs, wetlands, and grasslands. Along with these efforts is a desire to make sure that there are connections between conservation and long-term economic development; between health and the environment; and between water and climate. On the horizon is a new approach to international development that understands that a peaceful world requires not only cooperation among nations, but among human beings and the earth systems in which we live.

*This manuscript is submitted for publication by Mark G. Little, 2009–2010 GSA-USGS Congressional Science Fellow, with the understanding that the U.S. government is authorized to reproduce and distribute reprints for governmental use. The one-year fellowship is supported by GSA and by the U.S. Geological Survey, Department of the Interior, under Assistance Award No. G09AP00158. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government. Little can be reached at MarkGabriel.Little@mail.house.gov.*

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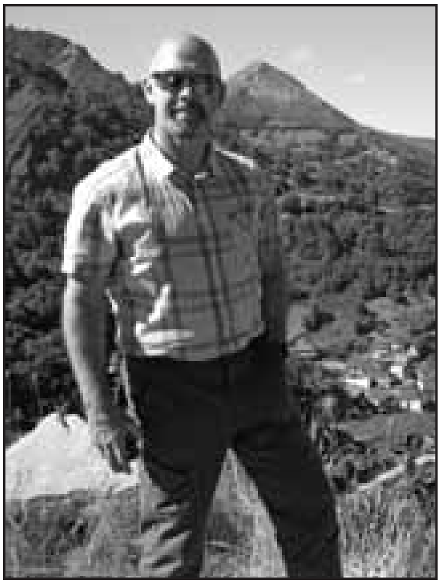
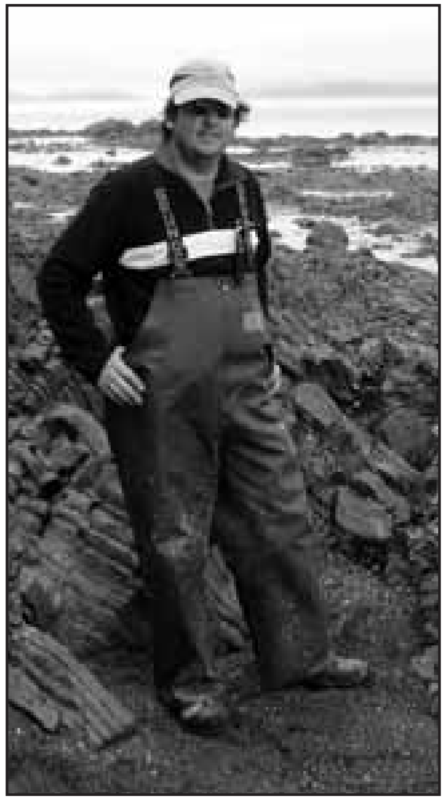
# *GSA Today* Science Editor Changes



Science co-editor **Stephen T. Johnston** has come to the end of his four-and-a half–year term with *GSA Today*. In 2006, Johnston set as his goal for *GSA Today* to “bring forward high-quality articles that appeal to as broad an audience as possible and that spark debate within our community regarding the major societal and scientific questions facing the earth sciences.” This he has achieved. As well, under Johnston’s stewardship, the processing of *GSA Today* science articles from receipt to acceptance has grown to such an order of efficiency that instead of scheduling from month to month, we now have a steady stream of papers accepted through 2011.

Johnston’s plan now is to continue his search for “terrane wrecks” the world over. This summer, his “quixotic quest” will, ironically, see him back in the land of Cervantes, trekking from the brown hills and plains of La Mancha north to the green slopes of Asturias and Galicia. His focus, when not enjoying pulpo, vino blanco, and the odd chupito, will be to try and understand the geometry, origin, and tectonic significance of oroclines affecting the Paleozoic Variscan orogen of the Iberian massif.

Johnston is a professor in the School of Earth and Ocean Sciences at the University of Victoria. Learn more at http://web.uvic.ca/~stj/.



Taking over for Johnston as of 1 July is Western Washington University (WWU) professor **Bernard (Bernie) Housen.** Housen is chair of the geology department at WWU, and his main research focus is on Cordilleran tectonics and structure. Learn more at http://myweb.facstaff.wwu.edu/bernieh/.

As science co-editor, Housen says his primary goal will be to ensure that *GSA Today* remains an interesting venue for the presentation of new research and synopses of important topics in the geosciences. He hopes to draw on his interdisciplinary background to encourage articles and other content that will be valuable to specialists and interesting and educational to the general *GSA Today* readership, such that this may translate to an increase in the visibility and appeal of *GSA Today,* and GSA as a whole, to professional geologists and educators.

**David Fastovsky,** who stepped in as a *GSA Today* science co-editor in July 2007, remains on the job through January 2011. Fastovsky is a GSA Fellow and the 2006 recipient of GSA’s Distinguished Service Award, in recognition of his work as *Geology* editor from 1999 to 2005, service on numerous GSA committees, and his time as associate editor for *GSA Bulletin* (1996–2000). He is a vertebrate paleontologist and professor in the department of geosciences at the University of Rhode Island. Learn more at www.uri.edu/cels/geo/GEO_Dfastovsky.html.

*GSA Today* science editors are charged with obtaining first-class, focused articles that collectively reflect and summarize current topics and discoveries in the earth sciences. Science editors also solicit “Groundwork” articles, which are meant to further the influence of earth science on education, policy, planning, and funding. All submissions, whether solicited or volunteered, are peer reviewed. To submit a science or Groundwork article to *GSA Today,* please go to www.geosociety.org/pubs/gsatguid.htm for instructions and a link to our online manuscript tracking system.

# COMMENTARY

# GSA Position Statement on Climate Change

***William F. Ruddiman,*** *University of Virginia (emeritus), rudds2@ntelos.net*

GSA recently released its new position statement on climate change. Because this issue has been highly controversial in recent years, this article is written to provide information on the history of developing the statement and its scientific basis. I write this in my former capacity as chair of the panel that assembled the early draft statement, and as a GSA member since 1966 and Fellow since 1971.

In 2007, I was invited to become a member of the Critical Issues Caucus (CIC), a group of about two-dozen GSA scientists who exchange opinions about emerging environmental issues with the goal of suggesting new initiatives to the GSA, and specifically to the GSA Geology and Public Policy Committee (GPPC). In spring 2008, I concluded that the next GSA position statement on climate change needed to reflect the many recent advances in scientific understanding occurring in that field. I wrote a draft of a possible future statement, circulated it within the CIC, and received suggestions for improvements. In June 2008, a draft position was approved without dissent by the CIC and sent forward in July to the GPPC, chaired at that time by Dick Berg. The GPPC considered the draft during its October 2008 meeting and concluded that a revision to the existing statement was timely. The GPPC wrote a proposal recommending appointment of an expert panel, chaired by me, to develop a draft revised statement. The proposal was forwarded to and approved by Council in January 2009.

Early in 2009, the GPPC and I assembled the panel (see sidebar). We sought highly respected scientists who had international reputations and were recognized leaders in the disciplines and subdisciplines involved in the climate issue. The eight panel members, who have worked for decades in the climate/paleoclimate area, have a total of nearly 900 published papers. Three are members of the National Academy of Science, many are AGU or GSA Fellows (or both), and several have won prestigious medals from major scientific societies. Thure Cerling provided continuity to the panel that had produced the 2006 climate statement. Hydrogeologist Jean Bahr (then GSA president-elect) volunteered as a liaison to the GPPC, and Don Paul served because of his industry perspective and his interest in the climate problem. The panel members have not been outspoken advocates on either side of the global warming issue. I have spoken out against exaggerations on the climate issue in a trade book for Princeton University Press and invited contributions to the AGI publication, *EARTH*, but I have criticized both extremes.

Working by e-mail starting in early March 2009, the panel produced a draft statement by May and sent it to the GPPC. The GPPC refined the draft and approved it in June 2009. The statement was then sent to GSA members via the e-news magazine, *GSA Connection*, on 17 August and via *GSA Today* in early September for a comment period. Because of delays some members experience in receiving their *GSA Today* issues, the comment period was extended to the end of the month.

Those GSA members who submitted statements were assured of anonymity so that they would feel free to speak out regardless of possible workplace constraints. Rex Buchanan, the new chair of GPPC, and I were charged with reading the comments and deciding on appropriate response(s). We received comments from ~60 members, or just under 0.3% of GSA's 22,000 members. The responses fell into three categories: (1) generally favorable comments, some of which suggested changes or additions to improve the statement; (2) more neutral or moderately unfavorable (but still constructive) responses that in many cases suggested changes or clarifications on various issues; and (3) responses that were critical of the entire process and in many cases dismissive of the motives of anyone who had taken part.

Faced with these highly divergent reactions from GSA members, mindful of the very controversial nature of this issue, and holding to the guarantee of anonymity for those who had commented, I proposed in late August 2009 that the panel respond to those major criticisms that we chose not to incorporate into the revised statement. I tabulated the criticisms and condensed them to a short list of seven, which I sent to the panel (with no member names attached), and we produced the response printed at the end of this article. Those GSA members who remain unsure about the anthropogenic warming issue will find within this document arguments that counter many common misconceptions about (and objections to) anthropogenic warming, as well as references with which to check out the scientific basis of the counter-arguments. A few items in the Aug.–Sept. 2009 panel response have been updated in minor ways to reflect subsequent developments, including recent publications of relevance.

In October 2009, the GSA Executive Committee voted unanimously to forward a slightly amended draft of the position statement to GSA Council for a vote. Council discussed the statement during its October meeting, held shortly after receiving the draft from GPPC, but felt the need for additional review and comment prior to voting. The comments and suggested edits from Council were referred back to GPPC for consideration, including clarification on several scientific issues. Although the panel formally disbanded on 1 February 2010, individual members helped to supply the information requested by the GPPC as it prepared a revision of the draft statement and responses to GSA Council comments. The GPPC approved a new revision of the draft statement during its March 2010 meeting and forwarded the revised draft to Council. In April

2010, GSA Council voted on and approved that version of the revised statement without modification.

I add several personal perspectives about this process:

1. The operations of the panel were remarkably consensual throughout. We soon came to basic agreement on the major issues in the statement and spent most of our time refining the wording to make sure it accorded fully with the latest science. We agreed to characterize the large climatic changes currently projected for the future as "risky," but we did not think it was our role to try to choose among possible policy options.
2. Many members of the public and the media seem confused about which sources to trust on the subject of global warming. The members of this panel are not only highly respected but also typical of the large body of mainstream climate scientists who spend most of their time "doing the science" and rarely, if ever, speak out on policy issues. This position statement qualifies as a mainstream climate science document.
3. Given that *any* position statement on climate change was inevitably going to be seen as controversial by one part of the GSA membership or another, the GSA leadership showed excellent judgment and considerable courage in supporting this climate statement and thereby weighing in on the side of mainstream climate science.

## PANEL RESPONSES TO GSA MEMBER COMMENTS

(Oct. 2009; updated Apr. 2010)

### Is the panel qualified?

Cumulatively, the panel members have published ~900 peer-reviewed research papers on paleoclimate/climate, ranging across the Paleozoic, Mesozoic, and Cenozoic, and including the Pleistocene and Holocene. Barron was director of the National Center for Atmospheric Research and is now president of Florida State University. Cerling, Kutzbach, and Lean are members of the

## PANEL MEMBERS

**Jean M. Bahr:** Hydrogeology. Professor and past chair of the Dept. of Geoscience, Univ. of Wisconsin; 2009–2010 Geological Society of America president and panel liaison to the GPPC. Fellow: GSA. Learn more at www.geology.wisc.edu/people/display.html?id=4.

**Eric J. Barron:** Mesozoic climate. President, Florida State Univ. Former director, National Center for Atmospheric Research; former dean, Jackson School of Geosciences, Univ. of Texas at Austin. Recipient of the NASA Distinguished Public Service Medal. Fellow: AAAS, AGU, AMS, GSA. Learn more at http://president.fsu.edu/biography/index.html.

**Julie Brigham-Grette:** Cenozoic to Holocene climate. Geosciences Dept. professor, Univ. of Massachusetts. Past chair, PAGES Steering Committee; past president, American Quaternary Association. Member, National Academy of Sciences Polar Research Board. Learn more at www.geo.umass.edu/faculty/jbg.

**Thure Cerling:** Mesozoic to Quaternary climate. Distinguished professor, Dept. of Geology and Geophysics, Univ. of Utah. Member, National Academy of Sciences. Fellow: GSA, AAAS, and International Association of Geochemistry. Learn more at www.biology.utah.edu/faculty2.php?inum=55.

**Peter U. Clark:** Quaternary climate. Professor, Dept. of Geosciences, Oregon State Univ. Recipient of the Easterbrook Distinguished Scientist Award (GSA). Fellow: GSA, AGU. Learn more at geo.oregonstate.edu/people/faculty/clarkp.htm.

**John E. Kutzbach:** Paleozoic to Holocene climate. Associate Director, Univ. of Wisconsin–Madison Center for Climatic Research, Gaylord Nelson Institute for Environmental Studies. Member, National Academy of Sciences; recipient of the Roger Revelle Medal (AGU), the Milankovitch Medal (EGU), and the William Smith Award (Geological Society of London). Fellow: AGU, AMS. Learn more at http://ccr.aos.wisc.edu/contact/kutzbach_john.php.

**Judith Lean:** Historical to Recent climate and solar physics. Senior Scientist, Naval Research Laboratory. Member, National Academy of Sciences. Fellow: AGU. Learn more at http://eospso.gsfc.nasa.gov/ess20/docs/lean_bio.pdf.

**Donald L. Paul:** Exploration geologist. Director, Univ. of Southern California Energy Institute, William Keck Chair in Energy Resources. Past vice-president and chief technology officer, Chevron-Texaco Corporation. Learn more at www.usc.edu/schools/sppd/faculty/detail.php?id=74.

**William F. Ruddiman:** Cenozoic climate. Past professor and chair, Dept. of Environmental Science, Univ. of Virginia. Past associate director, Lamont-Doherty Earth Observatory; past director, CLIMAP project. Recipient of the Lyell Medal (Geological Society of London). Fellow: GSA, AGU. Learn more at www.evsc.virginia.edu/faculty/ruddiman-william-f.

**Cathy Whitlock:** Cenozoic climate. Professor, Dept. of Earth Sciences, Montana State Univ. Past geography dept. chair, Univ. of Oregon; past president, American Quaternary Association; chair, U.S. National Committee, International Quaternary Union. Learn more at www.montana.edu/wwwes/facstaff/whitlock.htm.

National Academy of Sciences. Ruddiman wrote the widely used college textbook, *Earth's Climate*. Seven are GSA members, and many are Fellows of the GSA, AGU, AMS, and past presidents of other organizations. The panel's four women and six men are distributed among eight states and the District of Columbia. None has been outspoken at either the alarmist or skeptic extreme of the spectrum of views on global warming.

### Was there an "inappropriate" IPCC influence?

Some critics claim that the 2007 IPCC process was flawed and that its conclusions were accepted uncritically by the members of the National Academy and the panel. In this view, recognized experts in the field appear for some reason ill-informed and easily misled on important issues that lie within their expertise. In contrast, the panel views the 2007 IPCC statement as a valid synthesis and assessment of current knowledge of global warming that received thorough and extensive review from many members of the scientific community (despite minor errors discovered recently).

### Could the last 125 years of warming be natural?

Because Earth's climate is always changing, some claim that the recent warming is natural, not anthropogenic. This criticism is refuted by a growing body of evidence closely scrutinized by panel members with a wide range of experience studying natural climate change on time scales ranging from tectonic to orbital to recent/instrumental. Given this experience, panel members took into account competing hypotheses in arriving at their conclusions. The warming of the last century is unusual in both speed and size, and it cannot be explained by natural factors, except for the modest solar contribution during the first half of the century.

### Was there a larger solar influence?

Some claim that the Sun is responsible for most twentieth-century climate change, including the net warming since 1980. Contrary to this claim, satellite measurements of solar radiation over the last 30 years find no significant persistent trend other than 11-year cycles. These cycles vary in amplitude by 0.1% (1 $W/m^2$) around a mean value of 1361 $W/m^2$, and empirically based studies indicate that global surface temperature responds with an amplitude of ~0.1 °C. Possible indirect effects of solar ultraviolet radiation on the stratosphere and troposphere are being investigated, with some recent studies indicating a small effect. In summary, Earth's response to solar variability during the satellite era is ~0.1 °C, much smaller than the projected warming of <2 °C to >5 °C in the next century from greenhouse gases.

Some have also claimed that solar variability over century to millennial time scales has influenced climate, but we lack direct solar irradiance observations to show how the Sun varied this far in the past. Two proposed proxies of solar forcing on centennial time scales are compromised by other factors tied to climate. The age difference between $^{14}C$ and tree-ring counts is affected by changes in ocean circulation and carbon reservoirs, and $^{10}Be$ variations in ice cores are affected by changes in snow accumulation rates. As a result, it is difficult to separate solar forcing from internal climate system responses. In addition, proxy measurements of climate during previous millennia are highly variable both from site to site and for multiple proxies at single sites. Circumstantial evidence points to a link between solar and climatic proxies at some sites, but widespread evidence of a strong link remains ambiguous.

### What is the significance of the recent cooling?

The 150-year instrumental record of global temperature shows an obvious long-term increase. Superimposed on this increase are shorter-term rises and falls caused by natural fluctuations due to ENSO (El Niño–Southern Oscillation; or decadal-scale atmosphere-ocean oscillations such as the Pacific Decadal Oscillation [PDO]), volcanic eruptions, the 11-year solar cycle, and perhaps other factors. A very small cooling occurred from 2005 to 2008, but 2009 was a warmer year. The last 10 years make up the warmest 10-year interval in the entire instrumental record, as are the averages for the last 15 years, 20 years, and longer. Every previous pause or dip in the long-term warming trend was followed by new record warmth.

### What about the urban heat-island effect?

Some claim that compilations of surface temperature are compromised by anomalous warmth at stations located in "heat islands" warmed by urban growth, but urban areas cover less than 2% of Earth's land surface. Station data from the Arctic demonstrate that this non-urbanized region has experienced a warming larger than the global average, a conclusion also supported by decreasing snow cover and sea ice trends measured by satellites and borehole temperature trends. In addition, many stations from other non-urbanized areas show warming trends larger than the global average. Early attempts to estimate global average temperature were compromised by the heat-island effect, but methods have now removed most of this overprint. Any such effect remaining in the observations is estimated to contribute <5% to the warming trend in hemispheric and global-average temperatures.

### Can models predict future climate?

Another criticism is that models are useless for predicting climate change far in the future. One part of this argument is that models can't even predict weather two weeks from now, so how can they predict the distant future? This criticism is based on a misunderstanding of how models are used.

Weather models start from initial observations of present weather conditions, and they rely on equations to anticipate how specific weather systems will develop in the near future. But the current "weather" is not known perfectly, and thus the model forecasts start out with small errors. As the model forecasts progress, non-linear processes inherent to the climate system cause actual weather to diverge from the model forecasts. After 10 days to two weeks, model predictions of features such as specifics storm at a particular time and place are no longer reliable.

The use of models for future climate forecasts is entirely different. Climate models rely on analogous equations, but not to predict day-to-day weather in the far-distant future, which is obviously impossible. Instead, they estimate *average* annual or seasonal changes expected when factors that determine modern-day climate—such as sun strength, greenhouse gases, and aerosols—change by specified amounts.

Climate models are initially evaluated by how well they reproduce the main characteristics of modern climate, such as temperature, precipitation, pressure, and wind direction and strength. On balance, they simulate these features well, although more successfully for temperature than for regional precipitation. One criticism is that these models are "tuned" to simulate modern climate. Although tuning is a part of the modeling process, it is not an unconstrained exercise. Models have to capture basic climatic characteristics both vertically and spatially at global, hemispheric, and regional scales, and over average annual and daily cycles. Simultaneously reproducing all these features reasonably well is a highly challenging test that cannot be met by simply tweaking a few "knobs."

In addition, climate models have been tested by their ability to simulate times in the past when the average climate was very different due to changes in well-constrained factors, such as orbital parameters (the mid-Holocene 6000 years ago) and ice sheets, carbon dioxide levels, and sea level (the last glacial maximum 20,000 years ago). This ongoing process of testing and successfully validating climate models against past observations is a major reason scientists feel confident in relying on them to predict average conditions in future centuries. Many scientists in GSA (including several panel members) have made important contributions to these scientific advances.

As the draft position statement notes, these projections of average future climate carry uncertainties tied to (1) the uncertain range of future gas emissions and atmospheric concentrations, and (2) climate feedbacks that are not yet tightly constrained. Over shorter intervals, such as the next decade or two, changes are difficult to predict because of natural variability in the climate system ("noise") and because models assign different strengths to key factors. Farther in the future (a century from now), these uncertainties will have become progressively less important as the response to growing $CO_2$ concentrations increasingly overwhelms natural variability.

In summary, the model capabilities noted above show that they provide a firm basis for assessing the plausible range of future climates that could result from greenhouse-gas forcing. Even the lower end of the projected range will bring a global warming of 1.5–2 °C (~3 times larger than that experienced to date). The middle-to-upper range of the estimates (4–6 °C) would make future climate on Earth as much warmer than it was colder during the peak of the last glacial maximum 20,000 years ago.

## FURTHER READING

Several scientific references that support key statements in the 2010 GSA position statement on climate change are listed with that document. The following additional references address common misconceptions about (and resulting criticisms of) mainstream scientific views on anthropogenic global warming.

### Solar Influence

Lockwood, M., 2008, Recent changes in solar outputs and global mean surface temperature. III. Analysis of contributions to global mean air surface temperature rise: Proceedings of the Royal Society A, v. 464, p. 1387–1404, doi: 10.1098/rspa.2007.0348.

Benestad, R.E., and Schmidt, G.A., 2009, Solar trends and global warming: Journal of Geophysical Research, v. 114, doi: 10.1029/2008JD011639.

### Urban Heat Island Effect

Peterson, T.C., 2003, Assessment of urban versus rural in situ temperature differences in the contiguous United States: No difference found: Journal of Climate, v. 16, p. 2941–2959.

Parker, D.E., 2006, A demonstration that large-scale warming is not urban: Journal of Climate, v. 19, p. 2882–2895.

### Recent Cooling

Peterson, T.C., Connolley, W.M., and Fleck, J., 2008, The myth of the 1970s global cooling scientific consensus: Bulletin of the American Meteorological Society, Sept., p. 1325–1337, doi: 10.1175/2008BAMS2370.

Easterling, D.R., and Whener, M.F., 2009, Is the climate warming or cooling?: Geophysical Research Letters, v. 36, L08706, doi: 10.1029/2009GLo37810.

Fawcett, R., 2007, Has the world cooled since 1998?: Bulletin of the Australian Meteorological and Oceanographic Society: v. 20, p. 141–148.

Murphy, D.M., Solomon, S., Portmann, R.W., Rosenlof, K.H.., Forster, P.M., and Wong, T., 2009, An observationally based energy balance for the Earth since 1950: Journal of Geophysical Research, v. 114, D17017, doi: 10.1029/2009JD012105.

von Shuckmann, K., Gaillard, F., and Le Traon, P.-Y., 2009, Global hydrographic variability patterns during 2003–2008: Journal of Geophysical Research, v. 114, C00907, doi: 10.1029/2008JC005237.

### Model Testing Based on Paleo Data

Ruddiman, W.F., 2007, Earth's Climate: Past and Future: New York, W.H. Freeman & Company, 465 p. (Note: Several chapters [and references therein] give examples of the interplay between geologic observations and modeling: Ch. 2: general use of models; Ch. 4: Supermonsoons on Pangaea; Ch. 5: Cretaceous greenhouse climate; Ch. 6: Cenozoic cooling; Ch. 8: insolation control of ice sheets; Ch. 11: orbital-scale interactions; Ch. 12: last glacial maximum; Ch. 13: last deglaciation and Holocene. Some of many studies not mentioned in the book follow.)

Lunt, D.J., Haywood, A.M., Schmidt, G.A., Salzmann, U., Valdes, P.J., and Dowsett, H.J., 2009, Earth system sensitivity inferred from Pliocene modelling and data: Nature Geoscience, v. 3, p. 60–64, doi: 10.1038/ngeo706.

DeConto, R.M., and Pollard, D., 2003, Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric $CO_2$: Nature, v. 421, p. 245–249, doi: 10.1038/nature01290.

Oto-Bleisner, B.L, Marshall, S.J., Overpeck, J.T., Miller, G.H., Hu, A., and CAPE Last Interglacial Project members, 2010, Simulating Arctic climate warmth and icefield retreat in the last interglaciation: Science, v. 311, p. 1751–1753, doi: 10.1126/science.1120808.

### Model Simulations of Recent/Future Warming

Meehl, G.A., Washington, W.M., Ammann, C.M, Arblaster, J.M., Wigley, T.M.L., and Tebaldi, C., 2004, Combinations of natural and anthropogenic forcings in twentieth-century climate: Journal of Climate, v. 17, p. 3721–3727.

2010 GSA Annual Meeting & Exposition
Reaching New Peaks in Geoscience

## Events & Deadlines

**10 August**
- Abstract Submission Deadline

**27 September**
- Early Registration Deadline
- Housing Deadline

**4 October**
- Registration Cancellation Deadline

**27–30 October**
- Premeeting Field Trips

**29–31 October**
- Short Courses & Workshops

**30 October**
- GSA Presidential Address & Awards Ceremony: 7–9 p.m.

**31 October**
- GSA Gold Medal Lectures
- Welcoming Party & Exhibits Opening: 6–8 p.m.

**31 October–3 November**
**Technical Program**
- Oral Sessions
- Posters: Hung all day with half-day sessions, authors present a.m. or p.m.

**31 October–3 November**
- Lunchtime Keynote Lectures: 12:15–1:15 p.m.

**1 November**
- Group Alumni Reception: 7–9:30 p.m.
- Private Alumni Receptions

**1–2 November**
- Exhibit Hall Open: 9 a.m.–6 p.m.

**3 November**
- Exhibit Hall Open: 9 a.m.–2 p.m.

**4–6 November**
- Postmeeting Field Trips

2010 GSA Annual Meeting & Exposition
Denver, Colorado, USA

# Lunchtime Lectures

Marcia McNutt

## GSA Lunchtime Lecture 1

### Marcia McNutt: *Reflections on My First Year as USGS Director*

Sunday, 31 Oct., 12:15–1:15 p.m.

GSA Fellow **Marcia McNutt** was confirmed by the U.S. Senate on 22 October 2009 to serve as Director of the United States Geological Survey (USGS) and Science Advisor to the Secretary of the Interior. As USGS Director, McNutt is responsible for leading the largest water, earth, biological science, and civilian mapping agency in the United States in its mission to provide the scientific data that enable decision makers to create sound policies for a changing world.

McNutt previously served as president and chief executive officer of the Monterey Bay Aquarium Research Institute (MBARI) in Moss Landing, California, USA. She has participated in 15 major oceanographic expeditions and served as chief scientist on more than half of those voyages. Her research includes studies of ocean island volcanism in French Polynesia, continental breakup in the Western United States, and uplift of the Tibet Plateau, and she has published 90 peer-reviewed scientific articles.

McNutt earned a bachelor's degree in physics from Colorado College and a doctorate in earth sciences from Scripps Institution of Oceanography. Along with being a GSA Fellow, McNutt is a member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences. She was awarded the Macelwane Medal by the American Geophysical Union (AGU) in 1988 for research accomplishments by a young scientist and AGU's Maurice Ewing Medal in 2007 for her significant contributions to deep-sea exploration.

THE GEOLOGICAL SOCIETY OF AMERICA®

**GSA's Lunchtime Lectures series** offers four one-hour presentations (one for each day of the meeting) by high-profile speakers on broad topics relevant to today's world. Bring your lunch and prepare to be challenged and inspired! Information on each speaker will appear in subsequent issues of *GSA Today* as well as on the meeting Web site, www.geosociety.org/meetings/2010/.

# 2010 GSA Annual Meeting & Exposition

# Call For Papers

**Abstract submission deadline:** 10 August

http://gsa.confex.com/gsa/2010AM/index.epl

1. **Determine the discipline category for your paper** (see www.geosociety.org/meetings/2010/jtpc.htm or p. 39 of the June *GSA Today*). This is an essential step, even if you are submitting to a topical session. This year's 156 topical sessions (see www.geosociety.org/meetings/2010/sessions/topical.asp) are designed to promote the exchange of interdisciplinary, state-of-the-art information; discipline sessions also add to a well-rounded meeting.
2. **Select your preferred mode of presentation:** Oral, poster, or no preference. The program organizers will do their best to fit your abstract into your preferred mode.
3. **Include a title, five keywords, and name** and contact information for each author; e-mail addresses must be provided for communication purposes. No more than 10 authors may be listed on a paper, and group names will not be accepted.
4. **Abstracts must be no longer than 2,000 characters** (not counting spaces). Do not repeat title and authors in the abstract.
6. **Please proofread** your abstract; we won't edit it before publication on the Web and in the abstract book.
7. **A non-refundable fee** of US$35 per abstract submission will be charged to professionals per submission; for students, it's US$20 per submission. Payment by credit card must be made when you submit your abstract.
8. **You may present two volunteered abstracts** *as long as one of these abstracts is a poster presentation.*
9. **The decision by the Joint Technical Program organizers** to place your paper in an oral or poster session is final.

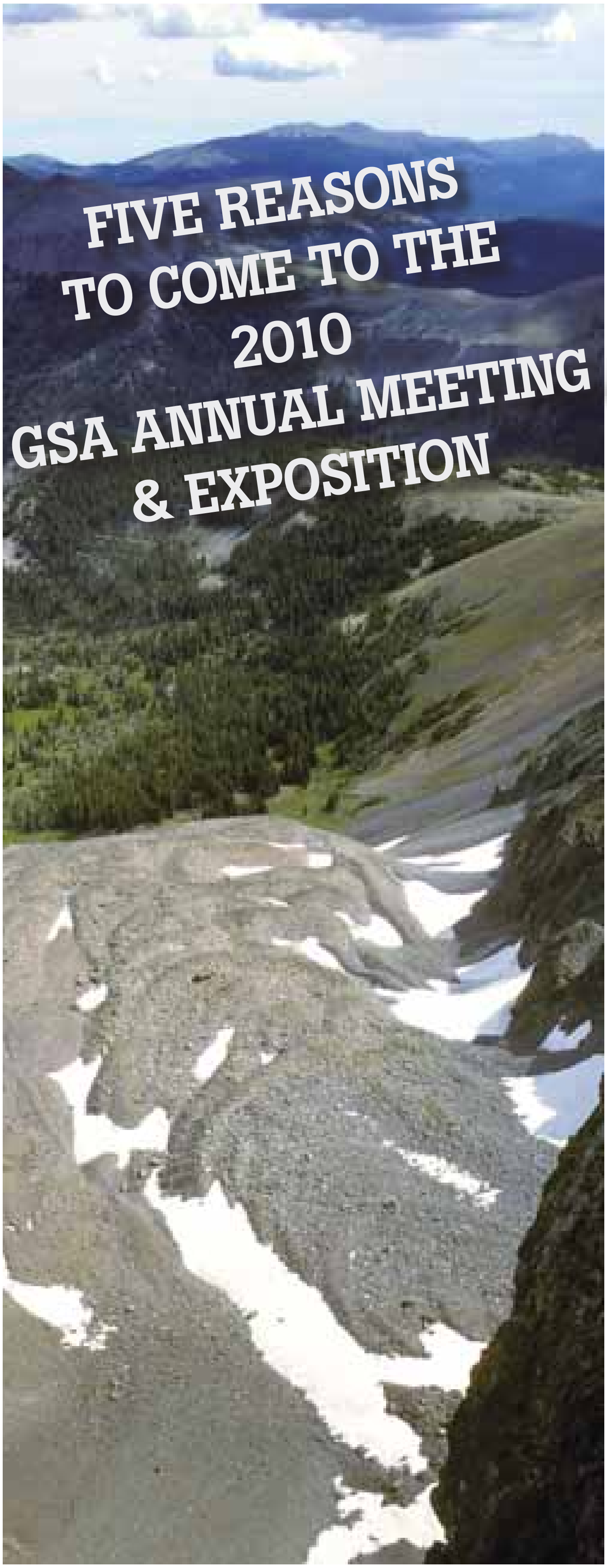
### Oral Presentations

- The normal length of an oral presentation is 12 minutes, plus three minutes for Q&A.
- You *must* visit the Speaker Ready Room at least 24 hours before your scheduled presentation.
- All technical session rooms are equipped with a PC.
- If your presentation was created on a Macintosh, you must save it to run on a PC. Please test it before coming to the meeting and again in the Speaker Ready Room. If you have any questions on this, please contact Nancy Wright, nwright@geosociety.org.
- If your presentation includes embedded video, please convert any .mov files to .avi format, or create a link in your slide show to an external .mov file. If you choose the latter, your animation will play in a separate QuickTime window, outside of your PowerPoint presentation.

### Poster Presentations

- You will be provided one horizontal, freestanding 8-ft-wide by 4-ft-high display board along with Velcro for hanging the poster, and each poster booth will share a 6-ft by 30-in table.
- Electricity will be available in the poster area at no charge.
- Posters will be on display 9 a.m.–6 p.m. Authors should be present either 9–11 a.m. *or* 2–4 p.m. and are encouraged to be at their posters during the 4:30–6 p.m. beer reception as well.

Standing 40 feet high, the big blue bear peers through the lobby of the Colorado Convention Center. Photo used with permission from the Denver Metro Convention & Visitors Bureau.




Rock glacier, northern Colorado. Photo by Marli Bryant Miller, University of Oregon, www.marlimillerphoto.com.

1. **Location, location, location.**

Centrally located just to the east of the U.S. Continental Divide and right on the edge of the Great Plains, Denver is easy to get to from just about anywhere. The city is familiar territory to those of you who have attended meetings here in the past, with just about everything you need within walking distance of the Colorado Convention Center.

2. **Opportunity.**

GSA meetings provide opportunities for valuable face-to-face interactions with mentors, colleagues, friends, and former students. GSA is also the perfect venue for meeting new people who can help advance your research—at Town Hall meetings, along NSF Street in the exhibit hall, and at the NSF booth, where you can meet with program officers as well as NSF Assistant Director for Geosciences, Timothy Killeen, who will be attending the Denver meeting.

3. **Be inspired and hear from the best.**

The 2010 Gold Medal Lectures will take place Sunday afternoon, 31 Oct. Learn more about the life and careers of these geoscience leaders:

**Eric J. Essene,** 2010 GSA Penrose Medalist

Essene was professor *emeritus* at the University of Michigan–Ann Arbor. His main focus of study was metamorphic petrology, and his interests spanned the fields of mineralogy, geochemistry, and general petrology.

**George E. Gehrels,** 2010 Arthur L. Day Medalist

As a professor of tectonics and geochronology at the University of Arizona, Gehrels has several research projects going, including stratigraphic, structural, and geochronologic analyses of Alaska's Coast Mountains, a detrital zircon provenance study of accreted terranes in the western U.S. and Canada, and analyses of the uplift and erosional history of the Tibet Plateau.

**Dana L. Royer,** 2010 Young Scientist Award–Donath Medalist

Dana Royer is an assistant professor at Wesleyan University who lists his general interests as "global change, paleoclimatology, carbon cycle, paleoecology, paleobotany, plant physiology, and light stable isotope geochemistry." His research explores how plants can be used to reconstruct ancient environments.

**Here's a sampling of what bloggers had to say about last year's meeting:**

"Meetings like this are a great opportunity for professional scientists to catch up on the latest ideas both inside and outside their specialties." — Callan Bentley

"It was a great conference. I had a fantastic time scientifically and socially … I'm looking forward to these events for years to come." — Brian Romans

"The annual GSA meeting is a large meeting if you measure by the number of scientific talks given. … The best part of

## 4. Live on the leading edge.

The Pardee Keynote Symposia, made possible by a grant from the Joseph T. Pardee Memorial Fund, are interdisciplinary sessions that address broad, fundamental issues in the geosciences. The following topics were selected on a competitive basis, and all speakers are invited.

**Seeing the True Shape of Earth's Surface: Applications of Airborne and Terrestrial LiDAR in the Geosciences** (session P6: Sun., 31 Oct., 8 a.m.–noon).

**Why Aren't Our Ideas Getting Attention? Finding a More Convincing Voice on Controversial Issues** (session P3: Sun., 31 Oct., 1:30–3:30 p.m.).

**Mineral Evolution: The Coevolution of the Geo- and Biospheres** (session P4: Mon., 1 Nov., 8 a.m.–noon).

**Evolving Moon: Recent Advances in Understanding Our Planetary Neighbor from NASA's Lunar Reconnaissance Orbiter and Other Missions** (session P2: Mon., 1 Nov., 1:30–5:30 p.m.).

**Symbiosis as a Driver of Global Change in Ancient and Modern Earth Systems** (session P1: Tues., 2 Nov., 8 a.m.–noon).

**Exploring for Life in the Cosmos: Celebrating Five Decades of Astrobiology** (session P8: Tues., 2 Nov., 1:30–5:30 p.m.).

**Rapid Environmental/Climate Change in the Cretaceous Greenhouse World** (session P5: Wed., 3 Nov., 8 a.m.–noon).

**Impacts of Ocean Acidification: The Other $CO_2$ Crisis** (session P7: Wed., 3 Nov., 1:30–5:30 p.m.).

## 5. Share your expertise.

If you don't, who will? GSA meetings are designed to serve your needs, but only if you participate. Technical sessions are built from the ground up. What this means is that your colleagues have created topical sessions in order to provide you an opportunity to submit abstracts to these sessions and represent your scientific area of expertise. You can review the list of topical sessions at http://gsa.confex.com/gsa/2010AM/cfp.epl. **Abstracts are due on or before 10 August.**

2010 GSA Annual Meeting & Exposition
Reaching New Peaks in Geoscience

meetings, though, is meeting people, which for me often involves seeing people I haven't seen in 10 to 20 years."
— Sandra Powers

"I come to meetings for several reasons:
1. To get better at teaching content.
2. To get better at teaching, period.
3. To give me ideas for my own research.
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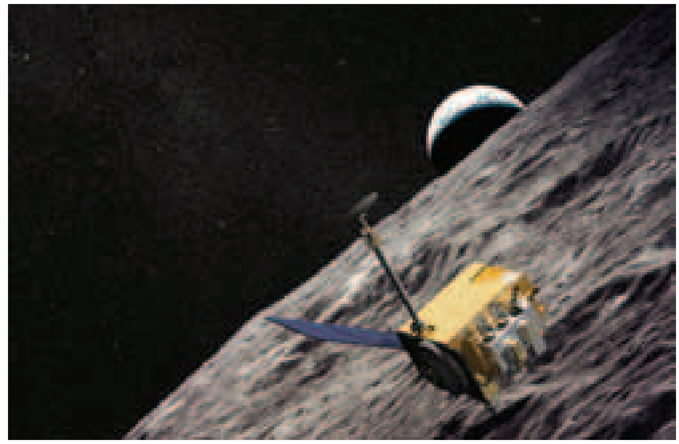

Artist concept (Chris Meaney, NASA) of the Lunar Reconnaissance Orbiter with Apollo mission imagery in the background, http://www.nasa.gov/mission_pages/LRO/multimedia/lroconcept2.html.

"Cave of Crystals," Naica mine, Chihuahua, Mexico. April 2007 *Geology* cover photo by Javier Trueba (Madrid Scientific Films).

Large primnoid coral loaded with brittle stars on Dickins Seamount, Gulf of Alaska. Credit: National Oceanic and Atmospheric Administration (NOAA) Gulf of Alaska Seamount Expedition (library image ID expl0125), http://www.photolib.noaa.gov/htmls/expl0125.htm.

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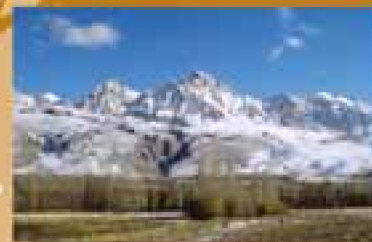

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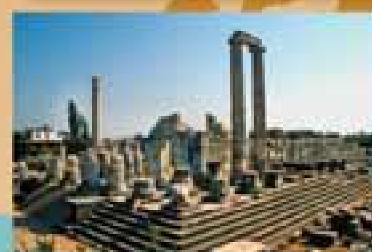

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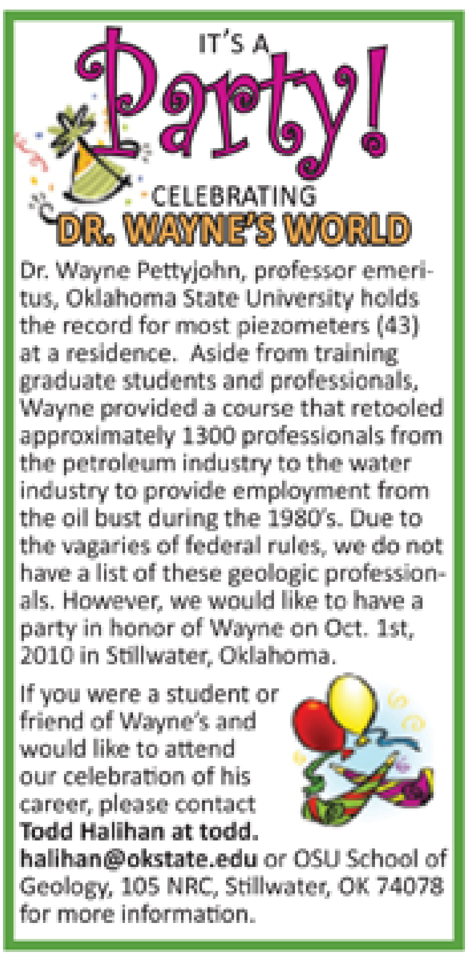


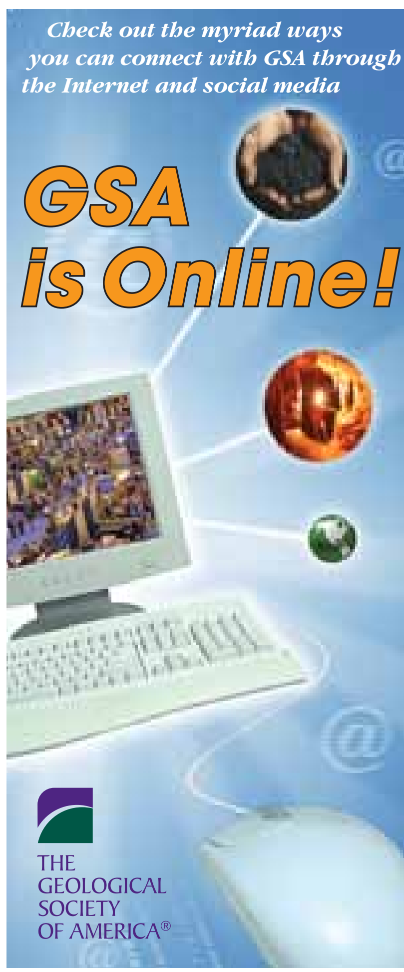

GROUNDWORK
Furthering the Influence of Earth Science

# Super-rotation of Earth's inner core and the structure of scientific reasoning

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## INTRODUCTION

Recent confirmation that Earth's inner core rotates with respect to the mantle (cf. Zhang et al., 2005) presents a good case to highlight important aspects of the structure of observation and reasoning in geophysics, geology, and the physical sciences in general. In particular, it can help to clarify the relationship between theory and evidence. Determining the rotation of the inner core is a solution to a so-called "inverse problem" (Jacobs, 1987, p. 2). The defining characteristic of an inverse problem is the challenge of determining properties of an unobserved cause based on observed properties of the effect. This provides an opportunity to raise some worthwhile methodological questions.

The first question is about confirmation. How is solving an inverse problem different from other forms of confirmation in science? A second question is about the difference between explanation and description. Is an inverse problem distinct from common patterns of explanation—in particular those that explain observed effects in terms of their unseen cause? What, if anything, has been explained by the discovery of super-rotation? Or, is this a case of describing an aspect of nature without explanation?

And then there is a question of the empirical status of super-rotation. Is the image of the rotating inner-core a matter of observation (with information moving from outside in, from the physical world into our minds), or inference (with information moving from inside out, from ideas to implied situations in the world)? Following the flow of information in the case of super-rotation will shed some light on this difference.

## SUPER-ROTATION

Earth's inner core is solid; it apparently also rotates a bit faster than the rest of the planet. Most recent evidence puts the super-rotation at 0.3° to 0.5° per year, or about one extra revolution each 900 years (Zhang et al., 2005).

The super-rotation was predicted by models that explain Earth's inherent magnetism (Glatzmaier and Roberts, 1996). Detecting the theorized rotation is an example of an inverse problem, in that it uses measured data of effects on the surface to draw inferences about the causes within. The problem has now been solved by analysis of seismic waveform doublets (Zhang et al., 2005). The super-rotation is said to be "confirmed by earthquake waveform doublets" (Zhang et al., 2005, p. 1357).

The evidence is in the recording of seismic waves from earthquakes that are more or less on the opposite side of Earth. Refraction of the waves at interfaces between mantle and core, and bending of the waves through material of varying density, lead to multiple paths from source to receiver. Some of the rays go through the inner core, some go around it, and these will have different arrival times.

The key is in noting that the difference in arrival times between the through-the-core and avoid-the-core rays changes steadily over time. It increases, meaning that the through-the-core waves are being delayed more and more. This is measured by comparing data from two earthquakes that occur at the same place but at significantly different times. This is a *doublet*, identified as happening at the same place by the similarity of waveform. For earthquake doublets separated by decades or more, the arrival-time difference increases as the time between events increases. This suggests that something is steadily changing in the relative conditions between the inner core and the mantle.

The explanation, the account of what is changing and thereby causing the increase in arrival-time difference, starts with the idea that the inner core is grainy, like wood, with the grain running more or less parallel to the axis of Earth's rotation. The speed of seismic waves will depend on their orientation to the grain. If the inner core turns with respect to the mantle, the orientation of the grain will change and the speed of a wave will change. This explanation was suggested by Kenneth Creager even before the doublet data: "The most likely cause of time-varying changes in structure within the Earth is that the inner core is rotating with respect to the mantle and that the elastic structure of the inner core is not axi-symmetric" (Creager, 1997, p. 1285).

The logic of the confirmation is noteworthy. It starts with theoretical prediction of arrival times using a model with a rotating inner core. The measured arrival times then match those predicted. This is exactly the form of reasoning often called hypothetico-deductive confirmation, and it is the foundation of most descriptions of scientific method. Deduce a prediction from a hypothesis, then observe the prediction to be true.

From the original geodynamic conjecture to the more direct evidence in waveform doublets, the arguments have the same logic. They are versions of an inverse problem, inferring parameters of the core based on surface data. They pivot on a

*GSA Today*, v. 20, no. 7, doi: 10.1130/GSATG90GW.1

premise in which data are predicted from aspects of a model of the core. That pivotal premise is a conditional of the form: IF the core has this feature, then the data will be such and such. In other words, IF model, then data; it is not IF data, then model.

Insofar as an inverse problem is about cause and effect, the key step in solving the problem is predicting measurable consequences of the cause. If the inner core rotates with respect to the mantle, then the difference in arrival times will steadily increase. The cause (super-rotation) is the antecedent, and the effect (arrival-time details) is the consequent. The "inverse" in an inverse problem refers to the direction of the logic. The ultimate inference, about the cause, has to work back against the conditional relation between cause and effect—the one that says, IF cause, then effect. The logic has to work back along the causal chain.

The logical challenge of an inverse problem is characteristic of the challenge of most scientific reasoning. We observe effects and work to figure out the details of the cause. Our models of causes are typically in terms of sufficient conditions for the effect. Theories and theoretical calculations can say what would lead to and explain what is observed, but they can rarely say that it is the only thing that could. That is, models of causes are not necessary conditions for the observed effects. There are always other possible explanations for the data.

The fact that there are other theories, perhaps not proposed or even imagined at this time, that would explain the data shows that what passes the tests now is always vulnerable to future refutation. What we call confirmation is neither foolproof nor to be based on an individual test. The confirmation of super-rotation—the reason to believe it is real—is not in the latest evidence but in the overall corroboration from independent evidence and reasoning. The geodynamic modeling of Earth's magnetic field suggests the faster rotation. The waveform-doublet data corroborate this. And a third source of information, measurements of free oscillation of the whole Earth, how Earth rings after a large seismic event, is consistent with super-rotation as well. The logic in this last case follows the pattern in which observations are predicted by the model and then subjected to a "hypothesis test" (Laske and Masters, 2003, p. 11). We can label different results as "observations" or "evidence" or "inference" or "detection" of inner-core rotation (Song, 2003, p. 54), but there is no important difference in the logical structure or status. No particular case is the confirmation of the rotation by virtue of being more direct. The credibility of the hypothesis derives from the agreement among the different kinds of data.

## CONCLUSION

The super-rotation of the inner core explains the details in differential arrival times of seismic waves from very distant earthquakes. In this way, solving the inverse problem is explanatory. In general, the model of a cause explains the observed effects, and by doing so, the model gains credibility. The logic in this case is the same as the logic of confirmation; the cause implies (and thereby explains) the observed effect.

The logic of an inverse problem is essentially the logic of hypothetico-deductive confirmation; the hypothesis implies observable effects. In no case is the evidence conclusive proof of a hypothesis. The more realistic assessment of scientific reasoning acknowledges that the credibility of a hypothesis accumulates as it fits into broad agreement with a variety of sources, both empirical and theoretical. The hypothesis of super-rotation fits the theoretical models of Earth's magnetic dynamo. It fits the empirical data of global free-oscillations. And it fits the more particular empirical data of wave-form doublets. This exemplifies what the philosopher of science, Karl Popper, called corroboration, "the degree to which a hypothesis has stood up to severe tests, and thus 'proved its mettle'" (Popper, 1965, p. 251). A severe test requires the hypothesis to entail observable data, and the test is survived when the data are in fact observed. The logic of Popper's corroboration is precisely the logic in the case of the rotation of the inner core.

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*Manuscript received 5 Feb. 2010; accepted 26 April 2010.*

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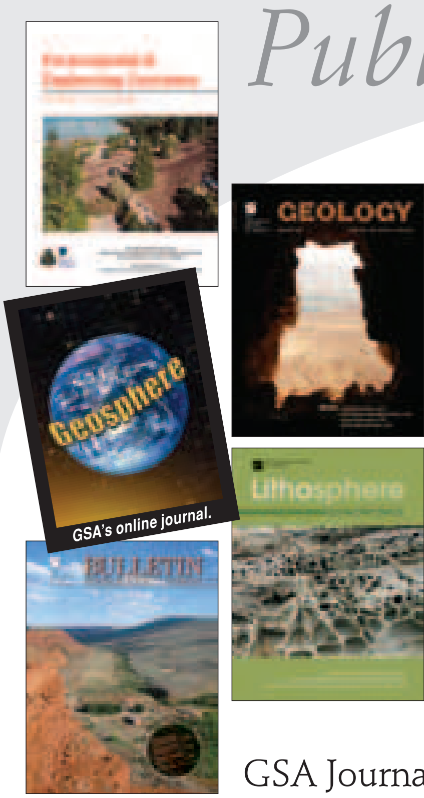


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