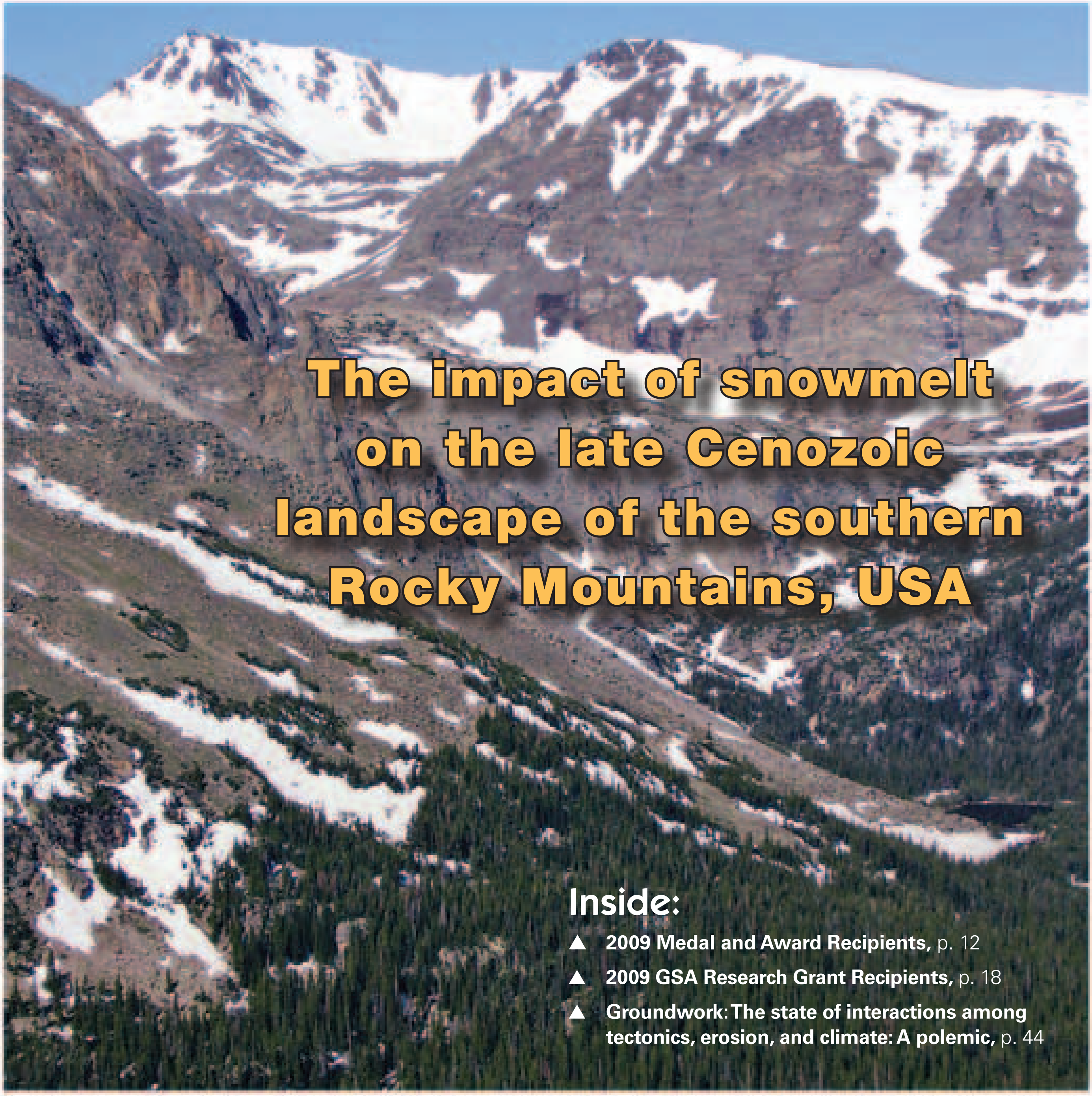
# GSA TODAY

VOL. 19, No. 7 A PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA JULY 2009



## The impact of snowmelt on the late Cenozoic landscape of the southern Rocky Mountains, USA

# GSA TODAY

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THE
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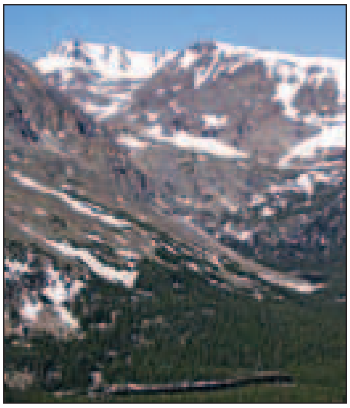
VOLUME 19, NUMBER 7 ▲ JULY 2009

## SCIENCE ARTICLE



**Cover:** View of snow-covered peaks and cirque lake in Rocky Mountain National Park, Colorado, USA. This issue's science article argues that snowmelt-induced flooding has played a major role in shaping the landscape of the southern Rocky Mountains in the late Cenozoic era. See "The impact of snowmelt on the late Cenozoic landscape of the southern Rocky Mountains, USA" by Jon D. Pelletier, p. 4–11.

**Erratum:** The 2009 Geologic Time Scale on p. 61 of the April-May *GSA Today* contained an error: Hirnantian was misspelled. A corrected time scale is posted at www.geosociety.org/science/timescale/.

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# The impact of snowmelt on the late Cenozoic landscape of the southern Rocky Mountains, USA

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## ABSTRACT

The intramontane basins of the southern Rocky Mountains, USA, have undergone up to 1.5 km of erosion from the middle Miocene to the present. Here I explore the hypothesis that this erosion could have been caused primarily by an increase in the intensity of snowmelt flooding. In the middle Miocene, snowmelt runoff was limited to the highest elevations (>3 km) and hence impacted only a small fraction of the regional landscape. As the global climate system cooled during the late Miocene and Plio-Quaternary periods, the fraction of total river discharge derived from snowmelt increased significantly in areas between 1.5 and 3 km elevation, thereby increasing the magnitude of flooding during periods of snowmelt and the resulting bedload sediment flux and erosion of rivers in that elevation range. In this paper, the fraction of modern discharge derived from snowmelt is used, together with an assumed lapse rate, to map the change in snowmelt discharge and sediment flux through time from the middle Miocene to the Quaternary in the southern Rocky Mountain region. These data are then used as input to a landscape evolution model that maps the spatial distribution of late Cenozoic snowmelt-driven erosion in the region. The model predicts a spatial distribution of erosion that broadly matches the actual distribution determined from geographic information system (GIS) analyses and dated basin-fill remnants. In the model, a factor-of-four increase in sediment flux within the 1.5–3 km elevation range, well within reasonable estimates, is capable of producing the observed magnitude of late Cenozoic erosion in the region. The longitudinal profiles of major rivers sourced from the southern Rocky Mountains are also modeled through time in order to better understand the downstream response to intramontane basin erosion. Model results indicate that erosion would have triggered widespread deposition downstream from those basins, which is broadly consistent with the magnitude, timing, and spatial distribution of the Ogallala Formation. The results of this study suggest that snowmelt-driven erosion may be an important component of late Cenozoic landscape evolution in mid- to high-elevation regions worldwide.

## INTRODUCTION

The intramontane basins of the southern Rocky Mountains have undergone up to 1.5 km of erosion in the late Cenozoic (McMillan et al., 2006). A particularly vivid illustration of this erosion is found in the Bighorn Basin. Figure 1 illustrates the view near Cody, Wyoming, USA, where the North Fork Shoshone River has incised at least 800 m into the Eocene Willwood Formation (near horizon) and lower units, exposing sediments as old as Triassic. Shale maturation data suggest that Cenozoic erosion in this area could have been as great as 1.5 km (Heasler and Kharitonona, 1996), indicating that the thickness of basin fill sediments could have been much greater than the 800 m exposed in Figure 1. Broad, low-relief Quaternary strath terraces illustrate that local downcutting took place episodically, followed by periods of lateral erosion (Mackin, 1937; Hancock and Anderson, 2002). Dated basalt flows within basin fill remnants indicate that most of this erosion took place from the late Miocene to the present (McMillan et al., 2006).

The Bighorn Basin is not unique—significant magnitudes of late Cenozoic erosion took place in all of the intramontane basins of the southern Rocky Mountains. McMillan et al. (2006) used GIS techniques and dated basin-fill remnants to map the spatial distribution of minimum erosion in the region and found that up to 1.5 km of late Cenozoic erosion occurred in the southern Rocky Mountain intramontane basins. McMillan et al.'s (2006) map provides only minimum estimates for erosion, however, due to incomplete preservation of basin-fill deposits. The greatest erosion took place in the central portion of the southern Rocky Mountains, with values decreasing toward the Great Plains to the east and the Colorado Plateau to the southwest. Working in the Colorado Plateau, Pederson et al. (2002) used similar techniques to map the magnitude and spatial distribution of erosion and obtained broadly similar estimates to those of McMillan et al. (2006).

One of the most remarkable aspects of the late Cenozoic erosion of the southern Rocky Mountain region is that so much of the erosion occurred in the broad, low-relief intramontane basins, challenging the prevailing notion that erosion rates are necessarily greater in areas of high-relief and/or high-elevation. Limited data exist on erosion rates in the high peaks of the southern Rockies and adjacent ranges, but available data suggest that the peaks have eroded much more slowly than the basins. In the Pleistocene, for example, the highest portions of the Wind River Range have eroded at rates of 0.005–0.015 m/ka (Small et al., 1997), while the adjacent basins have eroded at rates approximately ten times higher (i.e., up to 0.3 m/ka; Dethier, 2001; Heffern et al., 2007). Low-temperature thermochronologic data indicate that erosion of the high peaks has been similar to the rates measured by Small et al. (1997) throughout the Cenozoic (Crowley et al., 2002). Similarly, stable-isotope paleoaltimetry (Dettman and Lohmann, 2000; Mulch et al., 2004; Kent-Corson et al., 2006) and leaf margin analysis (Wolfe et al., 1998) suggest that peak elevations in the southern Rocky Mountains have undergone relatively little change in the Cenozoic. Alluvial rivers east of the Continental Divide have seen no significant change in base

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*GSA Today,* v. 19, no. 7, doi: 10.1130/GSATG44A.1

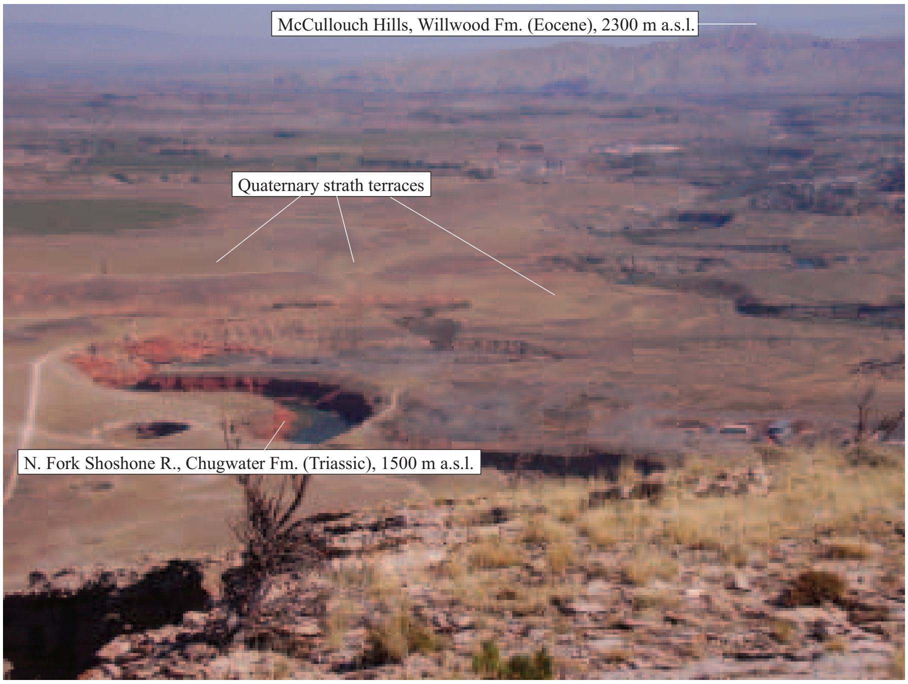

Figure 1. View of the Bighorn Basin near Cody, Wyoming, USA. The North Fork Shoshone River has incised a minimum of 800 m into the Eocene Willwood Formation (near horizon), down to the level of the modern river, exposing sediments as old as Triassic (m a.s.l.—meters above sea level).

level during the Cenozoic as the Mississippi River has drained into the Gulf of Mexico. Basins west of the Continental Divide became adjusted to a base level at or close to that of the Kaibab Limestone (i.e., the “rim surface” of Grand Canyon) by the middle Miocene (Young, 2008). Recent erosion of Grand Canyon has triggered upstream propagation of a knickpoint, but the intramontane basins of the Colorado Plateau have not yet been affected by this base-level change (Karlstrom et al., 2008). The emerging view, therefore, is one in which most of the high and low elevations of the region have eroded at relatively slow rates and have undergone little change in elevation, while the intermediate elevations (1.5–3 km) have undergone much higher rates of erosion despite the broad, gently sloping nature of the topography.

Epeirogenic uplift is one traditional explanation for the erosion of the southern Rocky Mountain intramontane basins and the deposition of the adjacent Ogallala Formation (Epis and Chapin, 1975; Trimble, 1980; Diffendal, 1982; Eaton, 1987, 2008; McMillan et al., 2006; Riihimaki et al., 2007). Epeirogenic uplift, however, is difficult to reconcile with paleoaltimetric data showing Cenozoic peak elevations as high or higher than today given the apparently slow rates of summit erosion. Climate change has been invoked as an alternative explanation for the late Cenozoic erosion of the southern Rocky Mountain region specifically (Gregory and Chase, 1994; Zaprowski et al., 2001, 2005) and for late Cenozoic river erosion worldwide (Molnar, 2001). The impact of climate change on rivers can take on a number of different scenarios, but these studies cite an increase in the frequency of intense rainfall during the late Cenozoic transition to a more arid climate as the primary mechanism. More arid climates put less total water on the landscape per unit time, but they do so in larger, more geomorphically effective floods. Larger floods transport disproportionately more sediment due to the nonlinear relationship between sediment flux and discharge in alluvial rivers (Wolman and Miller, 1960). The key question, then, is which of these two opposing effects (less water or more intense storms) dominates? Existing climatically driven models for late Cenozoic erosion have not fully answered this question. Gregory and Chase’s (1994) argument is based on a landscape evolution model in which discrete units of runoff occur in each cell and the erosion due to each unit of runoff is treated independently. Their model, therefore, includes only the effects of isolated thunderstorm-type events and does not adequately model the effects of large, spatially extensive flood events. Molnar (2001) used a power-law frequency-size distribution for discharge, together with a nonlinear sediment transport relationship, to illustrate the geomorphic effectiveness of extreme flood events. A later analysis by Molnar et al. (2006), however, concluded that greater aridity does not, in general, lead to higher sediment transport rates. Given these uncertainties, it is unclear how, or even whether, climate change is capable of causing large-magnitude erosion in the absence of active uplift.

## HYDROCLIMATOLOGICAL ANALYSIS

Many subalpine rivers in the western United States experience their greatest flooding during spring and/or summer periods of snowmelt discharge (Troendle et al., 1996; Merz et al., 2006; Dyer, 2008). These warm-season floods are primarily a late Cenozoic phenomenon because warmer temperatures in the early to middle Miocene would have limited snowmelt runoff to only the highest elevations (i.e., >3 km). Figure 2A illustrates the relationship between the seasonality of precipitation (filled circles), discharge (open circles), and elevation in the southern Rocky Mountain region. The seasonality of precipitation, $S_p$, defined as the ratio of precipitation (including snow water equivalent) in the wettest three consecutive months to precipitation in the driest three consecutive months, was computed from parameter-elevation regressions on independent slopes model (PRISM) mean monthly 1 km/pixel grids (Daly et al., 1994) for the southern Rocky Mountain region. Seasonality values were then averaged in 10-m elevation bins from 1 to 3.5 km elevation to isolate the effects of elevation. These data illustrate that $S_P$ is between 2 and 7, with high-elevation regions experiencing, on average, lower seasonality values. Values for the seasonality of discharge, $S_Q$, computed using undammed U.S. Geological Survey gaging stations, are similar to $S_P$ values for elevations lower than ~1.5 km but increase significantly (to as high as 15) at high elevations (see supplementary data item 2009162[1]). The difference between the seasonality of precipitation and discharge is largely attributable to snowmelt runoff.

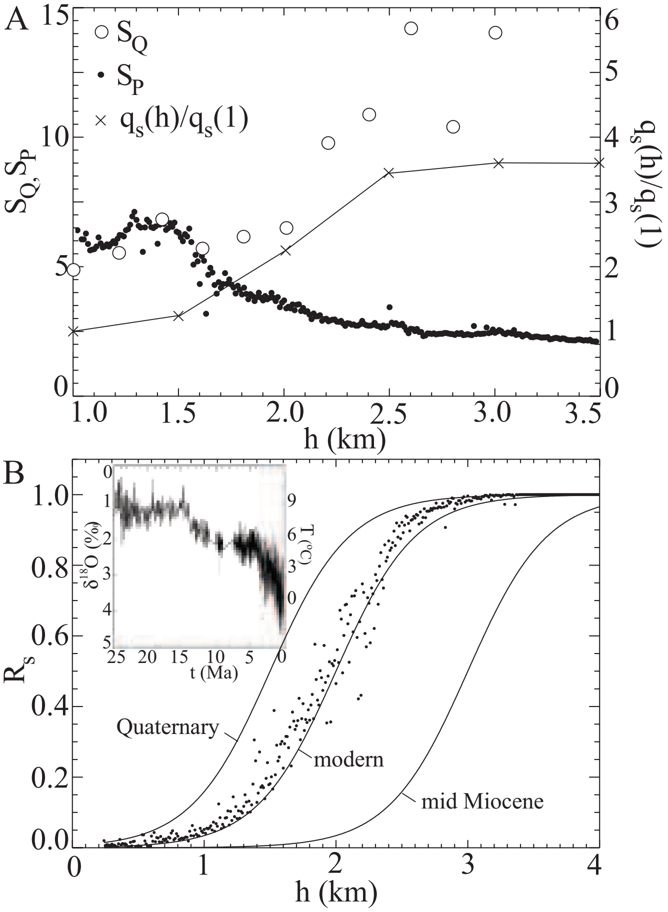

Figure 2. Measured and modeled relationships between hydroclimatology and elevation in the southern Rocky Mountain region. (A) Plots of seasonality of precipitation, $S_p$ (filled circles), seasonality of discharge, $S_Q$ (open circles), and the ratio of long-term bedload sediment flux for an elevated model basin to the same basin at 1 km elevation, $q_s(h)/q_s(1)$ (crosses), as a function of elevation, $h$. (B) Plot of the "snow ratio," $R_s$ (i.e., the fraction of discharge derived from snowmelt for modern climate conditions [dots] and estimated curves for mean Quaternary conditions and middle Miocene conditions, assuming the same empirical function [equation {1}]) as modern conditions and a lapse rate of 6 °C/km. Inset graph (after Zhang et al., 2001) plots $\delta^{18}O$ from deep-sea sediment cores, illustrating global cooling events at ca. 15 and 4 Ma.

The geomorphic impact of sequestering precipitation during cold-season months and releasing it during warm-season months can be illustrated with a simple hypothetical example. Consider a drainage basin that transports 1 kg/s of sediment as bedload, has no snowmelt runoff and, for simplicity, a constant discharge of 10 $m^3/s$ throughout the year. Now imagine the same drainage basin under a cold-climate scenario in which all of the precipitation that falls during the autumn, winter, and spring months is released as a constant discharge in the summer months as snowmelt runoff. Discharge during the summer would then be 40 $m^3/s$. Bedload sediment flux is a power-law function of discharge with exponent values (i.e., the "bedload rating exponent") ranging from 2 to 5 (Emmett and Wolman, 2001). Assuming a bedload rating exponent of 2, the sediment flux in our hypothetical cold-climate drainage basin would be 16 kg/s during the summer or 4 kg/s on a mean annual basis (i.e., four times greater than the same basin under a warm-climate scenario).

This hypothetical example greatly oversimplifies the complexity of the hydrological and geomorphic consequences of snowmelt runoff. However, a more sophisticated analysis that incorporates a realistic frequency-intensity distribution of rainfall and thaw-driven runoff yields broadly similar results. I used the HydroTrend model of Kettner and Syvitski (2008) to quantify the ratio of the long-term bedload sediment flux of a high-elevation model drainage basin to the same basin at low elevation, assuming a lapse rate (i.e., slope of the temperature versus elevation relationship) of 6 °C/km. In this analysis, the bedload sediment flux was first calculated for a hypothetical drainage basin with an area of 100 $km^2$, an outlet elevation of 1 km, a uniform elevation-area relationship, and a relief of 500 m subject to realistic stochastic models of temperature and precipitation. The model assigns daily precipitation to rain or snow depending on whether the temperature is above or below freezing, respectively. Warm-season snowpack thaw is modeled, producing snowmelt flooding. The elevation of this hypothetical basin was then increased in 500-m intervals up to an outlet elevation of 3.5 km, and the bedload sediment flux was recalculated in order to compute the ratio of long-term bedload sediment flux for the elevated basin to that of the original basin, $q_s(h)/q_s(1)$. The resulting data plotted in Figure 2A show that $q_s(h)/q_s(1)$ increases from a value of 1 at $h = 1$ km (by definition) to a value of 3.6 at $h = 3.5$ km, assuming a bedload rating exponent of 3. The value of 3.6 is not unique, however, and varies from 2 to 8 depending on the bedload rating exponent, the frequency-intensity distribution of precipitation, and the seasonalities of temperature and precipitation (see supplementary data [footnote 1]). The results of this analysis illustrate that snowmelt flooding can lead to a significant increase in long-term bedload sediment flux, and that snowmelt-driven transport increases with elevation (i.e., with the fraction of discharge derived from snowmelt).

The next step in modeling the spatially distributed geomorphic response to snowmelt flooding is to estimate the fraction of discharge derived from snowmelt as a function of elevation

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[1] GSA supplemental data item 2009162, further discussion and model results for snowmelt-driven erosion, is available at www.geosociety.org/pubs/ft2009.htm; copies may also be requested from GSAToday@geosociety.org.

through the late Cenozoic. The filled circles in Figure 2B illustrate the fraction of discharge derived from snowmelt, $R_s$, as a function of elevation calculated using PRISM gridded data sets (Daly et al., 1994). First, PRISM data sets for mean monthly temperature and precipitation were used to create daily time series data for precipitation and temperature analogous to those produced by HydroTrend. The difference in this step of the analysis is that time series data were produced explicitly for each 1 km$^2$ pixel in the Rocky Mountain region based on site-specific data for monthly mean values. The modeled volumes of snow (or, properly, snow-water equivalent) and rain were then routed downstream through a 1 km/pixel digital elevation model (DEM) of the region, and the ratio of the total volume of snow to the total volume of all precipitation draining through each pixel was calculated. Then, the ratios of discharge as snowmelt for all channels with a contributing area >1000 km$^2$ were averaged in 10-m elevation bins to obtain a relationship between river elevation and the fraction of discharge derived from snowmelt. I used only data from large (>1000 km$^2$) rivers in this analysis because, during periods of river incision, large rivers migrate laterally and hence can be expected to dominate the erosional behavior of the intramontane basins relative to small rivers. The resulting data (Fig. 2B) follow a sigmoidal or S-shaped curve as a function of elevation that is well represented by the empirical function

$$R_s = \left(1 + \exp\left(-\frac{h - h_{50}}{h_{range}}\right)\right)^{-1} \qquad (1)$$

with $h_{50}$ = 2 km and $h_{\mathrm{range}}$ = 300 m, where $h_{50}$ is the elevation at which $R_s$ = 0.5, and $h_{\mathrm{range}}$ is the elevation range above and below $h_{50}$ over which the ratio decreases or increases from 0.5 by a factor of *e*. Using this modern "snow-ratio" curve as a reference, past snow-ratio curves can be estimated assuming a lapse rate of 6 °C/km, shifting the value of $h_{50}$ up or down by an amount consistent with the observed temperature change. Climate reconstructions for the late Cenozoic (inset graph, Fig. 2B) indicate that global temperature cooled by ~3 °C from the late Miocene to the Pliocene and by another 6 °C from the Pliocene to Pleistocene full-glacial conditions (Fig. 2B). To estimate the snow-ratio curve for mean Quaternary conditions, I assumed that the average Quaternary temperature was 3 °C cooler than modern conditions (i.e., halfway between Holocene and latest Pleistocene temperatures), yielding $h_{50}$ = 1.5 km. The snow-ratio curve for the middle Miocene can be estimated by shifting $h_{50}$ up to 2.5 km because the middle Miocene global temperature was ~6 °C warmer than the mean Quaternary temperature. The difference between the middle Miocene and mean Quaternary snow ratio curves in Figure 2B identifies 1.5–3 km as the elevation range that experienced the most significant changes in late Cenozoic snow-ratio values (i.e., ≥0.5).

## GEOMORPHIC ANALYSIS

Models for the evolution of fluvial channels come in two basic types: transport-limited and detachment-limited. I assume that the channels incising into the early Cenozoic and Mesozoic sediments of the southern Rocky Mountain intramontane basins and points downstream are transport-limited channels. This assumption is consistent with the weakly consolidated nature of these sediments and with previous modeling studies (e.g., Hancock and Anderson, 2002). The long-term volumetric sediment flux per unit channel width, $q_s$, in transport-limited channels is proportional to the average unit stream power, i.e., the product of mean unit discharge and channel slope (e.g., Dade and Friend, 1998):

$$q_s = \kappa(x,y,t)\frac{Q}{w}S(x,y,t), \qquad (2)$$

where $Q$ is mean discharge, $w$ is channel width, $S$ is channel slope, and $\kappa$ is a transport coefficient that includes the effects of grain size and density, the frequency-size distribution of flooding, and snowmelt runoff. Both $\kappa$ and $S$ are written explicitly as functions of space and time to clarify steps in the analysis. Here I assume that $Q/w$ is a power-law function of $A$ with exponent $m$, so that (2) can be written as

$$q_s = \kappa(x,y,t)A^m S(x,y,t). \qquad (3)$$

The modeling strategy is to use the data in Figure 2 to quantify the relative change in transport coefficient $\kappa$ as a function of space and time in the southern Rocky Mountain region and then reconstruct the paleoslopes and paleotopography associated with those changes in $\kappa$. The form of (2) shows that, if $Q/w$ and $q_s$ remain constant, the relative changes in channel slope are inversely proportional to the relative changes in the transport coefficient $\kappa$. Expressed mathematically, this implies that, given modern channel slopes $S(x,y,t_0)$, paleoslopes at a previous time, $t_1$, can be calculated as

$$S(x,y,t_1) = S(x,y,t_0)\frac{\kappa(x,y,t_0)}{\kappa(x,y,t_1)}. \qquad (4)$$

It is unlikely that mean unit discharge and sediment flux are, in fact, constant over any length of geologic time, but by assuming they are constant, I can isolate the effects of snowmelt-driven changes in $\kappa$ separately from other possible mechanisms for erosion. The results of the hydroclimatological analyses above suggest that the transport coefficient $\kappa$ increases proportionately to the snow ratio $R_s$:

$$\frac{\kappa(x,y,t_1)}{\kappa(x,y,t_0)} = \frac{1 + cR_s(h,t_1)}{1 + cR_s(h,t_0)}, \qquad (5)$$

where $c$ is a coefficient of proportionality equal to the variation in sediment transport per unit change in snow ratio. The linear relationship between $\kappa$ and $R_s$ expressed in (5) follows from the fact that the transport efficiency $\kappa$ is equal to the ratio $q_s(h)/q_s(1)$, and the results in Figure 2 indicate that $q_s(h)/q_s(1)$ and $R_s$ have the same sigmoidal shape. The value of $c$ is a constant (independent of elevation) that represents the factor increase

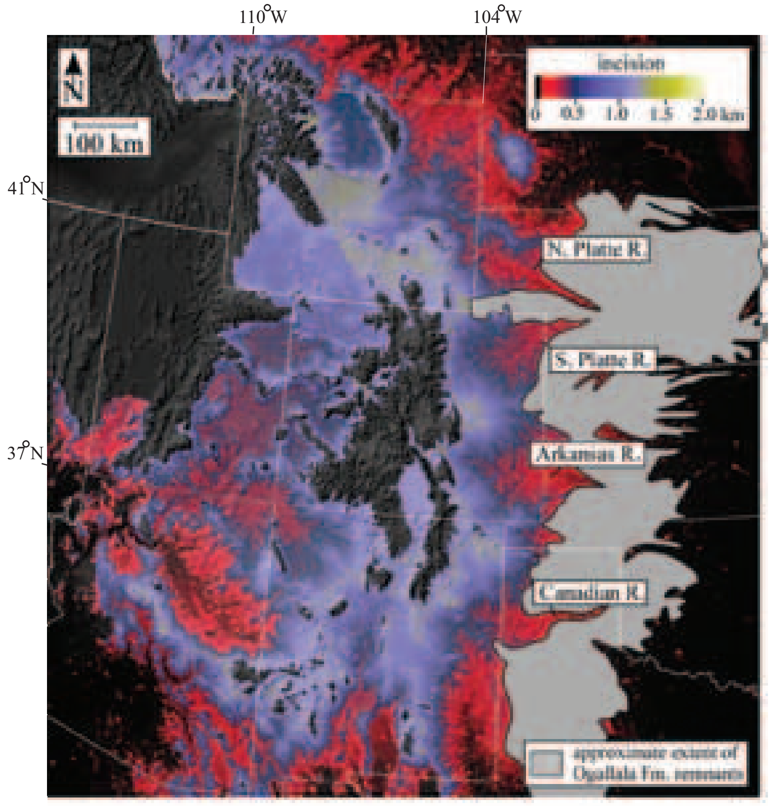

Figure 3. Color map of model-predicted late Cenozoic erosion in the southern Rocky Mountain region, obtained by integrating paleoslopes calculated using equation (6) with $c = 4$. Erosion in the model varies from ~0.5 km to 1.5 km, with generally lower values in low-elevation basins (Powder River, Bighorn, Uinta, San Juan, Paradox) and higher values in higher-elevation basins (Wind River, Green River, Piceance). This map is broadly similar to the geologically observed erosion map of McMillan et al. (2006) both in terms of magnitude and spatial distribution. Also shown, in gray, is the approximate extent of remnants of the Ogallala Formation.

in $q_s(h)/q_s(1)$ for a unit increase in $R_s$. The value of $c$ is not precisely constrained, but HydroTrend modeling suggests that $c = 4$ is a reasonable reference value assuming a bedload rating exponent of 3. Substituting (5) into (4) gives an equation for the paleoslopes at a previous time, $t_1$, as a function of the modern topography and the modern and past snow-ratio curves:

$$S(x,y,t_1) = S(x,y,t_0)\frac{1+cR_s(h,t_0)}{1+cR_s(h,t_1)}. \tag{6}$$

The model-predicted paleotopography can then be obtained by integrating the new slope values pixel-by-pixel upstream starting from the base-level boundary conditions (e.g., $h = 0$ at the Gulf of Mexico and $h = 1000$ m at the Kaibab rim surface of Grand Canyon). By calculating the difference between the paleotopography and the modern topography, an erosion map is predicted based on the difference between the channel profiles calculated for time $t_1$ based on the slopes at time $t_0$ (i.e., the modern topography). Areas with a modern elevation above 2700 m and those draining to the Great Basin or Pacific Northwest were not included in the analysis. Areas currently above 2700 m are predominantly resistant bedrock and hence the transport-limited model of this paper does not apply.

Predicted late Cenozoic erosion in the model (Fig. 3) varies from ~0.5 km to 1.5 km, with generally lower values in the low-elevation basins (Powder River, Bighorn, Uinta, San Juan, Paradox) and higher values in the high-elevation basins (Wind River, Green River, Piceance). This map is broadly similar to the geologically inferred erosion map of McMillan et al. (2006), both in terms of magnitude and spatial distribution (see supplemental data for further discussion of Fig. 3 [footnote 1]). Since (6) is a linear equation, the magnitude of erosion predicted by the model is proportional to the value of $c$. As a result, Figure 3 can also be interpreted as a map of relative erosion per unit $c$. For every unit increase in the value of $c$ above 1, ~500 m of peak erosion is predicted by the model.

Erosion of the Rocky Mountain intramontane basins would have delivered a pulse of sediment to downstream rivers beginning at 15 Ma. These downstream rivers, adjusted to smaller, middle-Miocene sediment loads, would have aggraded in response to the increase in sediment delivered from the intramontane basins. Here I model this dynamic downstream response to late Cenozoic incision upstream using a two-dimensional (2-D) model framework based on conservation of mass:

$$\frac{\partial h}{\partial t} = -\frac{\partial q_s}{\partial x} = \frac{\partial}{\partial x}\left(\kappa(h,t)A^m\frac{\partial h}{\partial x}\right). \tag{7}$$

Equation (7) can be solved for a specified model domain given an initial condition $h(x)$ and appropriate boundary conditions. My focus is on channels east of the Continental Divide, which drain from the southern Rocky Mountains to the Gulf of Mexico over distances ranging from ~2500–3500 km. The appropriate boundary conditions are constant base level at the downstream end of the system [i.e., $h(L) = 0$, where $L$ is taken to be 3000 km as a representative value, and a constant sediment supply from upstream hillslopes and bedrock channels]. As before, it is unlikely that $q_s$ is constant over geologic time scales, but by assuming a constant $q_s$, I can separate the effects of an increase in the value of $\kappa$ from other mechanisms for deposition. An appropriate initial condition for the model can be obtained by integrating (2) for constant $q_s$:

$$h(x) = \frac{q_s}{\kappa} \int_0^x \frac{dx'}{x'^{2m}}, \tag{8}$$

where $x'$ is a variable of integration, the basin area is assumed to be proportional to the square of the distance from the divide, and the constant of proportionality between $x^2$ and $A$ is incorporated into κ. Assuming $m = 1/2$, (8) can be integrated to yield

$$h(x) = -\frac{q_s}{\kappa} \ln\left(\frac{x}{L}\right) \tag{9}$$

(i.e., a logarithmic function of $x$). The middle Miocene sediment flux is unknown, but the maximum elevation of pre-erosion basin fill can be estimated to be ~1.5 km higher than modern basin elevations given the results in Figure 3, giving the initial condition

$$h(x) = \frac{h_0}{\ln\left(\frac{x_0}{L}\right)} \ln\left(\frac{x}{L}\right), \tag{10}$$

where $h_0 = 3.5$ km, and $x_0 = 10$ km is a representative distance downstream from the Continental Divide to where alluvial channels begin. Given (10), the incoming sediment flux at the upstream boundary can be computed from (2) to match the sediment flux within the river profile, thereby giving self-consistent initial and boundary conditions for a channel adjusted to carry the middle Miocene sediment flux delivered from upstream. The initial and upstream boundary conditions calculated in this way were input into the model with no change in κ to verify that no erosion or deposition took place. An appropriate value for the product of the middle-Miocene transport coefficient and distance downstream, $\kappa x$, can be determined from a relationship that depends on discharge and river type (Paola et al., 1992). Values for braided and meandering rivers range between $10^4$ and $10^5$ ($m^2/a$) for a catchment length of 100 km. Here I use $\kappa = 0.1$ m/a, which translates into a value of $10^5$ $m^2/a$ for the product $\kappa x$ at a distance of 100 km from the Continental Divide (i.e., within the range that Paola et al. [1992] proposed). In the model, the $\kappa(h)$ values are changed instantaneously at $t = 15$ Ma from middle Miocene values (i.e., $h_{50} = 2.5$ km; $h_{\text{range}} = 300$ m, with a reference value of 0.1 m/a) to mean Quaternary values ($h_{50} = 1.5$ km; $h_{\text{range}} = 300$ m) assuming $c = 4$.

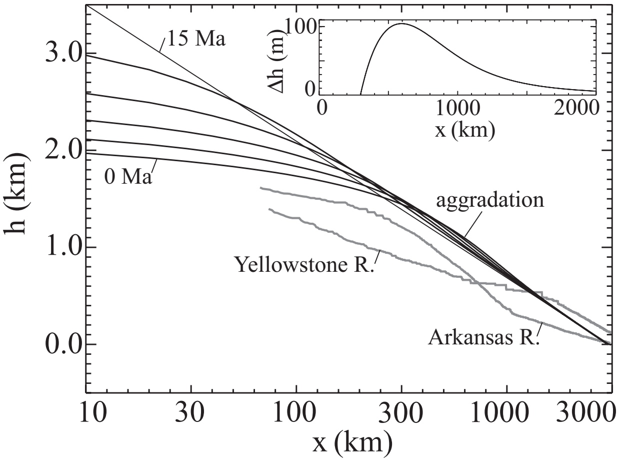

Figure 4. Model-predicted evolution of the longitudinal profiles of alluvial channels draining the southern Rocky Mountain intramontane basins to the Gulf of Mexico. Note logarithmic scale on *x* axis. The initial condition for the model (at 15 Ma) is a steady-state logarithmic profile (equation [10]). Snowmelt-driven erosion into the headwaters of the model domain (i.e., the elevation range from 1.5 to 3.5 km) delivers a pulse of sediment that triggers aggradation in downstream channels, which were adjusted to pre–late-Miocene conditions of lower sediment supply. The profiles of the Yellowstone and Arkansas rivers, plotted as a function of distance *x* downstream from the Continental Divide, are shown for comparison. Inset plot illustrates the cross section of the model-predicted deposit at 0 Ma, shown with linear scales. The portion of the deposit greater than 30 m in thickness is located 300–1200 km downstream from the Continental Divide, is lenticular in shape, and has a maximum thickness of just over 100 m.

Figure 4 illustrates the longitudinal-profile evolution predicted by the model plotted in 3-million-year increments from 15 Ma to the present. Note the logarithmic scale on the $x$ axis: The river profile is actually concave even though on these scales it appears linear. Erosion in the 1.5–3.5 km range triggers deposition downstream in the model. As time progresses, the depositional wedge thickens to a maximum value of 100 m (inset plot, Fig. 4) and progrades downstream while, simultaneously, erosion is initiated at the upstream end of the deposit. The final model profile is similar to, but slightly steeper than, modern river profiles in the region, as illustrated by comparison with the Yellowstone and Arkansas rivers (and the rivers into which they drain, up to distances of 3000 km from the Continental Divide) in Figure 4. The results of the model are relatively insensitive to the specific values of $h_0$ and $x_0$; changes in these values within reasonable limits yield only slight differences in the predicted depositional thicknesses.

The timing, spatial distribution, and magnitude of deposition predicted by the model are all broadly similar to the fluvial sediments of the Ogallala Formation. Deposition of the Ogallala Formation (extent of remnants shown in Fig. 3) began ca. 17 Ma (Izett, 1975; Naeser et al., 1980) on an eroded surface of Triassic and Permian age rocks and Cretaceous and Jurassic age sediments (Diffendal, 1982) and continued into the Pliocene. The late-stage deposition of the Ogallala was characterized by widespread fan deposition to an average thickness of 70 m and a maximum thickness of >200 m (Ryder, 1996). Significant deposition in the model (i.e., >30 m) occurs at distances of 300 km to 1200 km downstream from the Continental Divide and at elevations up to 1500 m, both similar to the actual Ogallala Formation. The model predicts a somewhat thinner deposit than observed, a difference that is likely due to the 2-D geometry of the model and to uncertainty in the value of $m$. A time-dependent three-dimensional depositional model is needed to refine the model predictions (see supplemental data for a discussion of the 2-D model results [footnote 1]). Sedimentation occurred throughout the southwestern U.S. and offshore from the late Miocene to the Pliocene (McMillan et al., 2006; Chapin, 2008; Galloway et al., 2000). The widespread nature of this sedimentation strongly suggests climate as the key driver (Chapin, 2008).

## DISCUSSION AND CONCLUSIONS

Late Cenozoic river erosion triggered isostatic rock uplift throughout the region at distances of up to 300 km (i.e., a flexural wavelength) away from where significant erosion occurred. Leonard (2002) and McMillan et al. (2004) both used flexural-isostatic modeling to determine the causes of post-depositional tilting of the Ogallala Formation and concluded that isostasy could produce at most half of the estimated rock uplift. However, both studies neglect the unloading of the Colorado Front Range immediately to the west of the Great Plains. Given the sensitivity of flexural-isostatic calculations to the spatial distribution of unloading regionally (e.g., Pelletier, 2004), neglecting the unloading west of the Great Plains is unlikely to be valid to the extent required to distinguish between active and passive uplift scenarios.

The hypothesis of snowmelt-driven erosion is consistent with recent evidence that the seasonality of temperature influences erosion rates in the Bighorn and Powder River Basins. While the size of the snowpack exerts the principal control on the magnitude of snowmelt-driven erosion, warm-season temperatures also play a role because warmer temperatures lead to faster melting and hence more intense snowmelt-driven flooding. Heffern et al. (2007) and Riihimaki et al. (2008) documented higher rates of erosion and/or more frequent coal fires during periods of greater orbital eccentricity using the distribution of cooling ages in coal fires in these basins. While these data cannot be uniquely attributed to pulses of erosion, they are consistent with the snowmelt-driven erosion hypothesis.

Molnar and his colleagues documented an abrupt increase in sedimentation rates in many, though not all, depositional basins worldwide from 4 to 2 Ma (Zhang et al., 2001), including many low-latitude regions where late Cenozoic glaciation has not occurred. Sparser evidence also suggests a pulse beginning at 15 Ma (Molnar, 2004). Molnar and colleagues attributed these pulses primarily to an increase in the variability of global climate beginning at 15 and 4–2 Ma. The snowmelt-driven erosion hypothesis, however, provides a possible alternative explanation for the widespread increase in erosion rates.

## ACKNOWLEDGMENTS

The idea for this project developed during an ExxonMobil field trip in the Bighorn Basin. I thank Lori Summa and Steve May for organizing the trip and for helpful conversations on the regional geology. In particular, the view illustrated in Figure 1 was a stop on that field trip. I also thank Pete Reiners and Pete Decelles for helpful conversations and Joel Johnson and an anonymous reviewer for their thoughtful comments that improved this paper.

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*Manuscript received 19 January 2009; accepted 10 April 2009.* ❄

## *GSA Names*

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**Bruce F. Molnia**
U.S. Geological Survey–Reston

* * *

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* * *

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YOUNG SCIENTIST AWARD (DONATH MEDAL)
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Rice University

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**Judge John E. Jones III**
Federal Judge, U.S. District Court for the
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**John T. Leftwich**
Shell Onshore

* * *

AGI MEDAL IN MEMORY OF IAN CAMPBELL
To be announced

* * *

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD
**Jonathan L. White**
and **Celia Greenman,**
for Colorado Geological Survey, 2008, Engineering Geology 14, "Collapsible Soils in Colorado."

* * *

These medals and awards will be presented during the 2009 GSA Annual Meeting Presidential Address & Awards Ceremony on Saturday, 17 October, 7–9 p.m., at the Oregon Convention Center in Portland. Also, please join us on Sunday, 18 October, 5–7 p.m., for the inaugural GSA Gold Medal Lectures, brief talks by this year's Penrose, Day, and Donath medalists.

# *GSA Divisions Announce*
# 2009 NAMED AWARDS

### RIP RAPP ARCHAEOLOGICAL GEOLOGY AWARD
*Archaeological Geology Division*
**Richard I. MacPhail**
University College of London

* * *

### GILBERT H. CADY AWARD
*Coal Geology Division*
**R.M. (Marc) Bustin**
University of British Columbia

* * *

### E.B. BURWELL, JR., AWARD
*Engineering Geology Division*
**Matthias Jakob**
EBA Engineering Consultants Ltd., Vancouver, Canada

**Oldrich Hungr**
University of British Columbia
*Debris-flow hazards and related phenomena,*
2005: Springer-Verlag, 739 p.

* * *

### GEORGE P. WOOLLARD AWARD
*Geophysics Division*
**Seth A. Stein**
Northwestern University

* * *

### BIGGS AWARD FOR EXCELLENCE IN EARTH SCIENCE TEACHING
*Geoscience Education Division*
**Laura A. Guertin**
Penn State–Brandywine

* * *

### MARY C. RABBITT HISTORY OF GEOLOGY AWARD
*History of Geology Division*
**Davis A. Young**
Calvin College (emeritus)

### O.E. MEINZER AWARD
*Hydrogeology Division*
**W. Michael Edmunds**
Oxford Centre for Water Research

* * *

### DISTINGUISHED CAREER AWARD
*International Division*
**Yildirim Dilek**
The Miami University

* * *

### G.K. GILBERT AWARD
*Planetary Geology Division*
**Robert G. Strom**
Lunar and Planetary Laboratory, Arizona (emeritus)

* * *

### KIRK BRYAN AWARD
*Quaternary Geology and Geomorphology Division*
**Ellen Wohl**
Colorado State University
"Limits of downstream hydraulic geometry,"
2004: *Geology*, v. 32, p. 897–900.

* * *

### LAURENCE L. SLOSS AWARD
*Sedimentary Geology Division*
**Raymond V. Ingersoll**
University of California at Los Angeles

* * *

### CAREER CONTRIBUTION AWARD
*Structural Geology and Tectonics Division*
**Paul F. Hoffman**
Harvard University

# 2009 GSA FELLOWS

## Elected by Council 3 May 2009

GSA's newly elected Fellows will be recognized at the 2009 GSA Annual Meeting Presidential Address & Awards Ceremony on Saturday, 17 Oct., at the Oregon Convention Center in Portland. Brief citations for each Fellow are posted at www.geosociety.org/members/fellow.htm.

**Richelle M. Allen-King,** University at Buffalo
*GSA Affiliations:* Northeastern Section and Hydrogeology Division
*Nominator:* Robert W. Ritzi

**Richard B. Alley,** Pennsylvania State University
*GSA Affiliations:* Northeastern Section and Quaternary Geology & Geomorphology Division
Elected to Fellowship as the 2008 GSA Public Service Award recipient

**William M. Alley,** U.S. Geological Survey–San Diego
*GSA Affiliations:* Cordilleran Section and Hydrogeology Division
*Nominator:* Carol M. Wicks

**J. Ramón Arrowsmith,** Arizona State University
*GSA Affiliations:* Cordilleran Section and Geoinformatics, Quaternary Geology and Geomorphology, and Structural Geology and Tectonics Divisions
*Nominator:* Paul J. Umhoefer

**Robert L. Badger,** State University of New York College at Potsdam
*GSA Affiliations:* Northeastern Section and Structural Geology and Tectonics Division
*Nominator:* Jeffrey R. Chiarenzelli

**David A. Benson,** Colorado School of Mines
*GSA Affiliations:* Rocky Mountain Section and Hydrogeology Division
*Nominator:* Hongbin Zhan

**Robert J. Bodnar,** Virginia Polytechnic Institute and State University
*GSA Affiliation:* Southeastern Section
*Nominator:* Michael F. Hochella Jr.

**Raymond M. Burke,** Humboldt State University
*GSA Affiliations:* Cordilleran Section and Quaternary Geology and Geomorphology Division
*Nominator:* Alan R. Gillespie

**William F. Cannon,** U.S. Geological Survey–Reston
*GSA Affiliation:* Northeastern Section
*Nominator:* Klaus J. Schulz

**Philip R. Christensen,** Arizona State University
*GSA Affiliations:* Cordilleran Section and Planetary Geology Division
Elected to Fellowship as the 2008 G.K. Gilbert Award recipient

**Andrew Cooper,** University of Ulster
GSA Affiliation: Southeastern Section
*Nominator:* Orrin H. Pilkey

**Derek H. Cornforth,** Cornforth Consultants Inc. (retired)
*GSA Affiliations:* Cordilleran Section and Engineering Geology Division
Elected to Fellowship as the 2008 E.B. Burwell, Jr., Award recipient

**Salvatore Critelli,** Università della Calabria, Italy
*Nominator:* William Cavazza

**William M. Dunne,** University of Tennessee–Knoxville
*GSA Affiliations:* Southeastern Section and Structural Geology and Tectonics Division
*Nominator:* Charles M. Onasch

**Todd A. Ehlers,** University of Michigan
GSA Affiliation: North-Central Section
*Nominator:* Stephen E. Kesler

**W. Crawford Elliott,** Georgia State University
GSA Affiliation: Southeastern Section
*Nominator:* Samuel M. Savin

**Lisa Ely,** Central Washington University
*GSA Affiliations:* Cordilleran Section and Quaternary Geology and Geomorphology and International Divisions
*Nominator:* Ellen E. Wohl

**Rolf Emermann,** GeoForschungs Zentrum, Germany
Elected to Fellowship as the 2008 Distinguished Career Award recipient.

**Kenneth A. Farley,** California Institute of Technology
*GSA Affiliation:* Cordilleran Section
Elected to Fellowship as the 2008 Arthur L. Day Medalist

**Alan J. Gallegos,** U.S. Department of Agriculture–Forest Service
*GSA Affiliations:* Cordilleran Section and Engineering Geology, Limnogeology, and Quaternary Geology and Geomorphology Divisions
*Nominator:* Jerome V. DeGraff

**Cynthia A. Gardner,** U.S. Geological Survey–Vancouver
*GSA Affiliation:* Cordilleran Section
*Nominator:* Richard M. Iverson

**Ervan G. Garrison,** University of Georgia
*GSA Affiliations:* Southeastern Section and Archaeological Geology and Quaternary Geology and Geomorphology Divisions
*Nominator:* Norman Herz

**Gregory A. Good,** American Institute of Physics
*GSA Affiliations:* Southeastern Section and History of Geology Division
Elected to Fellowship as the 2008 Mary C. Rabbitt History of Geology Award recipient

**Laurel B. Goodwin,** University of Wisconsin–Madison
*GSA Affiliations:* North-Central Section and Hydrogeology and Structural Geology and Tectonics Divisions
*Nominator:* Steve F. Wotjal

**Deborah Reid Harden,** San José State University (retired)
*GSA Affiliations:* Cordilleran Section and Quaternary Geology and Geomorphology Division
*Nominator:* Marith C. Reheis

**Robert N. Harris,** Oregon State University
*GSA Affiliations:* Cordilleran Section and Geophysics Division
*Nominator:* Andrew T. Fisher

**Stephen T. Hasiotis,** University of Kansas
GSA Affiliation: North-Central Section
*Nominator:* William C. Johnson

**M. James Hendry,** University of Kansas
GSA Affiliation: North-Central Section
*Nominator:* Alan E. Fryar

**John L. Isbell,** University of Wisconsin–Milwaukee
*GSA Affiliations:* North-Central Section and Coal Geology, Geoscience Education, Planetary Geology, Quaternary Geology and Geomorphology, and Sedimentary Geology Divisions
*Nominator:* James W. Collinson

**Scott E. Johnson,** University of Maine–Orono
*GSA Affiliations:* Northeastern Section and Structural Geology and Tectonics Division
*Nominator:* Daniel R. Lux

**Paul A. Kapp,** University of Arizona
*GSA Affiliations:* Cordilleran Section and Structural Geology and Tectonics Division
Elected to Fellowship as the 2008 Young Scientist Award (Donath Medal) recipient

**David A. Kring,** Universities Space Research Association, Lunar & Planetary Institute
*GSA Affiliations:* South-Central Section and Planetary Geology Division
*Nominator:* James Wright Horton

**Victoria E. Langenheim,** U.S. Geological Survey–Menlo Park
*GSA Affiliations:* Cordilleran Section and Geophysics and Structural Geology and Tectonics Divisions
*Nominator:* Douglas M. Morton

**R. Mark Leckie,** University of Massachusetts–Amherst
*GSA Affiliations:* Northeastern Section and Geobiology & Geomicrobiology and Geoscience Education Divisions
*Nominator:* Michael L. Williams

**Chusi Li,** Indiana University
*GSA Affiliation:* North-Central Section
*Nominator:* Anthony J. Naldrett

**Jacob B. Lowenstern,** U.S. Geological Survey–Menlo Park
*GSA Affiliation:* Cordilleran Section
*Nominator:* Charles R. Bacon

**Maria Mastalerz,** Indiana Geological Survey
*GSA Affiliations:* North-Central Section and Coal Geology Division
Elected to Fellowship as the 2008 Gilbert H. Cady Award recipient

**Larry D. McKay,** University of Tennessee–Knoxville
*GSA Affiliations:* Southeastern Section and Hydrogeology Division
Elected to Fellowship as the 2008 Birdsall-Dreiss Distinguished Lecturer

**Donald F. McNeill,** University of Miami
*GSA Affiliations:* Southeastern Section and Sedimentary Geology Division
*Nominator:* Robert N. Ginsburg

**Roberto S. Molina-Garza,** Universidad Nacional Autónoma de México–Juriquilla
*GSA Affiliations:* Cordilleran Section and Structural Geology and Tectonics Division
*Nominator:* Timothy Lawton

**Randall R. Parrish,** University of Leicester
*GSA Affiliation:* Cordilleran Section
*Nominator:* P. Jonathan Patchett

**Brian R. Pratt,** University of Saskatchewan
*GSA Affiliations:* Rocky Mountain Section and Sedimentary Geology Division
*Nominator:* Nora K. Noffke

**Lisa M. Pratt,** Indiana University
*GSA Affiliations:* North-Central Section and Geobiology & Geomicrobiology, Limnogeology, Planetary Geology, and Sedimentary Geology Divisions
*Nominator:* Chen Zhu

**Gary D. Rosenberg,** Indiana University–Purdue University
*GSA Affiliations:* North-Central Section and Geobiology & Geomicrobiology, Geoscience Education, and History of Geology Divisions
*Nominator:* Stephen M. Rowland

**Darrel W. Schmitz,** Mississippi State University
*GSA Affiliations:* Southeastern Section and Engineering Geology and Hydrogeology Divisions
*Nominator:* John W. Williams

**Madeline E. Schreiber,** Virginia Polytechnic Institute and State University
*GSA Affiliations:* Southeastern Section and Hydrogeology Division
*Nominator:* F. Edwin Harvey

**Sheila J. Seaman,** University of Massachusetts–Amherst
*GSA Affiliation:* Northeastern Section
*Nominator:* Laurie L. Brown

**James W. Sears,** University of Montana–Missoula
*GSA Affiliations:* Rocky Mountain Section and Structural Geology and Tectonics Division
*Nominator:* Raymond A. Price

**Bruce W. Selleck,** Colgate University
GSA Affiliation: Northeastern Section
*Nominator:* James M. McLelland

**Allen M. Shapiro,** U.S. Geological Survey–Reston
*GSA Affiliations:* Northeastern Section and Hydrogeology Division
*Nominator:* Leonard F. Konikow

**Joann M. Stock,** California Institute of Technology
*GSA Affiliations:* Cordilleran Section and Geophysics, International, and Structural Geology and Tectonics Divisions
*Nominator:* Peter H. Molnar

**Chi-Yeung John Suen,** California State University–Fresno
*GSA Affiliations:* Cordilleran Section and Hydrogeology Division
*Nominator:* Seymour Mack

**Mohamed I. Sultan,** Western Michigan University
*GSA Affiliation:* North-Central Section
*Nominator:* Robert J. Stern

**Donald C. Thorstenson,** U.S. Geological Survey–Denver (retired)
*GSA Affiliations:* Rocky Mountain Section and Hydrogeology Division
Elected to Fellowship as the 2008 O.E. Meinzer Award recipient

**Alison B. Till,** U.S. Geological Survey–Anchorage
*GSA Affiliations:* Cordilleran Section and Structural Geology and Tectonics Division
*Nominator:* Cynthia Dusel-Bacon

**Wendy Van Norden,** Harvard–Westlake School
*GSA Affiliations:* Cordilleran Section and Geoscience Education Division
*Nominator:* Raymond V. Ingersoll

**C. Geoff Wheat,** University of Alaska–Fairbanks
*GSA Affiliation:* Cordilleran Section
*Nominator:* Michael B. Underwood

**Lisa D. White,** San Francisco State University
*GSA Affiliation:* Cordilleran Section
Elected to Fellowship as the 2008 Randolph W. “Bill” and Cecile T. Bromery Award for the Minorities recipient

**Nicholas B. Woodward,** U.S. Department of Energy
*GSA Affiliations:* Rocky Mountain Section and Structural Geology and Tectonics Division
*Nominator:* Donald J. DePaolo

**Dongxiao Zhang,** University of Southern California
*GSA Affiliations:* Cordilleran Section and Hydrogeology Division
*Nominator:* Chunmiao Zheng

**Society Fellowship** is an honor bestowed on the best of our profession by election at the spring GSA Council meeting. GSA members are nominated and elected to Fellowship in recognition of their distinguished contributions to the geosciences through such avenues as publications, applied research, teaching, administration of geological programs, contributing to the public awareness of geology, leadership of professional organizations, and taking on editorial, bibliographic, and library responsibilities. Learn more at **www.geosociety.org/members/fellow.htm.**

# GSA Celebrates New 50-Year Members for 2009

***Thanks for your continued membership!***

GSA salutes the following members and Fellows who are celebrating their 50-year membership anniversary this year. We appreciate their dedication and loyalty to GSA. To see a complete list of GSA members who have surpassed the 50-year mark, please go to **http://rock.geosociety.org/membership/50YearMembers.asp.** Asterisks indicate GSA Fellows.

Theodore Arnow*
Daniel S. Barker*
Sidney J. Barker
Hubert L. Barnes*
James O. Berkland*
Stanley S. Beus*
Sabihuddin Ahmed Bilgrami*
John M. Bird*
Peter W. Birkeland*
Robert G. Blair*
Carl J. Bowser*
Elwood R. Brooks*
Richmond Flint Brown*
Peter R. Buseck*
John Arthur Campbell*
Neil P. Carroll
Richard Chase*
William A. Clemens*
Nicholas K. Coch*
Charles E. Corbato*
Richard H. De Voto*
Joseph S. Gates*
Richard J. Gentile*
John C. Green*
M. Grant Gross*
Gerald H. Haddock
Spenst M. Hansen*
Stanley R. Hart*
Mark Lawrence Holmes
Richard H. Johnston*
Richard D. Jones
W. Barclay Kamb*
Walter P. Kessinger
Keith B. Ketner*
Marvin A. Lanphere*
Leo F. Laporte*
Byron Larsen
Donald H. Lindsley*
Robert A. Loney*
Ernest L. Lundelius*
Jerome F. Machamer*
Alexander R. McBirney*
Malcolm Ernest McCallum*
James R. McNitt*
John Ezra Moore*
Eldridge M. Moores*
L.J. Patrick Muffler*
James W. Mytton*
Ronald E. Notkin
James F. O'Connell
Lawrence Ogden
Richard K. Olsson*
Neil D. Opdyke*
E. Ron Oxburgh*
H.C. Palmer*
E.C. Pirkle*
Stephen Cummings Porter*
Douglas W. Rankin*
John F.V. Riva*
Peter Robinson*
Joseph S. Rosenshein*
Fred G. Rueter
Robert M. Sanford
Frederick A. Schilling
Lloyd John Schmaltz*
Robert Lee Schuster*
Phyllis Scudder Snow
Robert J. Stanton*
David P. Stewart*
Desiree E. Stuart-Alexander*
Maurice J. Terman*
J. Cotter Tharin
Robert Ingersoll Tilling*
Don M. Triplehorn*
John Vecchioli*
Jerry D. Vineyard*
Nels B. Vollo
Don E. Wilhelms*
Robert J. Willard*
Michael O. Woodburne*
Donald L. Woodrow*
Edward J. Young*
E-an Zen*

## GSA Fellows:

## Nominate Your Colleagues

If you see colleagues on the list above who you think should be GSA Fellows, please follow up on your duty to nominate these deserving geoscientists. Keep GSA Fellowship strong and vibrant by sending in your nominations today! Guidelines and nomination forms are at www.geosociety.org/members/fellow.htm. **Questions?** Please e-mail awards@geosociety.org or call +1-800-472-1988, ext. 1028, or +1-303-357-1028.

THE GEOLOGICAL SOCIETY
OF AMERICA®

## Join GSA's PolicyComNet

The Geological Society of America (GSA), established in 1888, is a global professional society with a growing membership of more than 22,000 individuals in 97 countries. As such, GSA is a trusted source of information for promoting the geosciences in service to society and for wise Earth stewardship.

GSA has created an online geoscience-based networking tool, **PolicyComNet,** to assist GSA members in planning communications with public policy officials on pending regional, state, and local decisions.

Learn more and get involved at
**http://policycomnet.wikidot.com/.**

The Geological Society of America

# 2009 RESEARCH GRANT RECIPIENTS

The GSA Committee on Research Grants met at GSA Headquarters on 21 March 2009 and awarded US$520,425 to 194 graduate students (30% of the applicants). The average grant was US$2,683. The committee also selected eleven 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.

Special thanks to the 2009 committee members: Lisa Stillings (chair), Nan Crystal Arens, Elizabeth Jones Crafford, Rupali Datta, Robert V. Demicco, Missy Eppes, James E. Evans, Darren Grocke, Anita Grunder, Patricia Holroyd, Jeffrey Lee, Tim Lowenstein, Michelle Markley, Joseph Meert, Susannah M. Porter, Michael F. Roden, Dibyendu Sarkar, Kaye Shedlock, Paul Tomascak, Timothy White, Peter D. Wilf, and Kevin M. Yeager. The GSA Graduate Student Research Grant Program is funded by GSA, the GSA Foundation, GSA Divisions, and the National Science Foundation.

Certificates and ribbons will be presented to the Outstanding Mention, Specialized Award, and Farouk El-Baz Grant recipients in a formal recognition ceremony at the 2009 GSA Annual Meeting in Portland, Oregon, USA.

## 2009 Outstanding Mentions

The committee recognized the following grant proposals to be of exceptionally high merit in conception and presentation:

**Evan Bargnesi,** University of Kansas, “Thermochronometric constraints on detrital provenance and source thermal evolution from a supradetachment basin in Paros, Greece.”

**Kelsey Bitting,** Rutgers University, “Optically-stimulated luminescence dating of a widespread Holocene unconformity within Delaware River Valley alluvial deposits.”

**Erin Eastwood,** The University of Texas at Austin, “Paleoclimate reconstructions using aeolian cross-strata.”

**Sarah Evans,** University of Kansas, “Tectonic evolution of a Tethyan rift margin and ocean-continent transition in the Eastern Alps—An integrated magnetite and zircon (U-Th)/He approach.”

**Emily Gercke,** Indiana University, “Sedimentary analysis of prehistoric hurricanes on Catalina Island, Dominican Republic.”

**Eric Hogan,** University of Tennessee, “Detailed sequence stratigraphic analysis of the basal Sauk Supersequence across a craton hinge zone, eastern California.”

**Elisha Hughes,** The University of Texas at Arlington, “Chemostratigraphy and thin section petrography of the Smithwick Formation, Fort Worth Basin, San Saba County, TX.”

**Angela Hull,** Kent State University, “Testing models of Paleoproterozoic crust formation in central North America.”

**Elliot Jagniecki,** Binghamton University, “Temperature and $CO_2$ phase equilibria of the Green River Formation Na-carbonates.”

**Bronwen Konecky,** Brown University, “Abrupt climate changes in southern east Africa during marine isotope Stage 3: A new precipitation record from Lake Malawi.”

**Isaac Larsen,** University of Washington, “Quantifying spatial patterns in landslide frequency to assess coupling among erosion, tectonics, and climate.”

**Adam Lee,** Texas A&M University, “Characterization of channel stability and evaluation of restoration efforts on the Uncompahgre River between Ouray and Ridgeway, Colorado.”

**Ryan McKeon,** Lehigh University, “Demystifying Appalachian topography through new ideas in apatite (U-Th)/He thermochronology.”

**Amy Mueller,** Massachusetts Institute of Technology, “A multiple-sensor/multivariate signal processing architecture for in-situ water chemical analysis.”

**Dolores Neshyba-Bird,** Emporia State University, “Using direct push electrical conductivity and geochemical profiling to map chloride migration in the Equus Beds aquifer.”

**Paul Probasco,** University of Virginia, “Effects of riparian zone landscape on denitrification in groundwater near streams of the Eastern Shore of Virginia.”

**Adam Springer,** University of South Florida, “Constraining basin geometry and fault kinematics on the Santo Tomas Segment of the Agua Blanca Fault.”

**Jessica Tierney,** Brown University, “Reconstructing Holocene hydrology in central Indonesia via a molecular approach.”

**Amelinda Webb,** Yale University, “Repair scars and vital effects: Brachiopod shell chemistry.”

# 2009 Specialized Awards

## *Sponsored by the GSA Foundation*

The committee also selected recipients of the following specialized awards, which are named in honor of the donors or as memorials to former Society members.

### Gretchen L. Blechschmidt Award

**Amelinda Webb,** Yale University

The Gretchen Louise Blechschmidt Award funds women in the geosciences who have an interest in achieving a Ph.D. in the fields of biostratigraphy and/or paleoceanography, sequence stratigraphy analysis, particularly in conjunction with research in deep-sea sedimentology, and a career in academic research.

### John T. Dillon Alaska Research Award

**Matthew Malkowski,** Michigan State University

The John T. Dillon Alaska Research Award honors the memory of this geoscientist. Dillon was particularly noted for his radiometric age-dating work in the Brooks Range, Alaska. The award supports field-based studies dealing with the structural and tectonic development of Alaska and studies 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

**Adam Lee,** Texas A&M University

The Robert K. Fahnestock Award honors the memory of this former member of the Research Grants Committee, who died indirectly as a result of service on the committee. The grant is awarded for the best proposal in sediment transport or related aspects of fluvial geomorphology, Fahnestock's field.

### Lipman Research Award

**Duane Smythe,** University of Toronto

The Lipman Research Fund was established in 1993 and is supported by gifts from the Howard and Jean Lipman Foundation. The purpose of the fund is to promote and support student research in volcanology and petrology. The president of the Lipman Foundation, Peter W. Lipman, was the recipient of a GSA research grant in 1965.

### Bruce L. "Biff" Reed Scholarship Award

**Corrine Griffing,** University of Nevada–Las Vegas

The Bruce L. "Biff" Reed Scholarship Fund provides research grants to graduate students pursuing studies primarily on the tectonic and magmatic evolution of Alaska and also can fund other geologic research.

### Alexander Sisson Research Award

**Emily Gercke,** Indiana 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.

### Harold T. Stearns Fellowship Award

**Sean Bryan,** University of Colorado–Boulder

**Adam Springer,** University of South Florida

The Harold T. Stearns Fellowship Award, established by Stearns in 1973, funds student research on the geology of the Pacific Islands and the circum-Pacific region.

### John Montagne Fund

**Isaac Larsen,** University of Washington

The John Montagne Fund was established in 2000 to support one recipient's research in the field of Quaternary geology/geomorphology.

### Alexander & Geraldine Wanek Fund

**Elisha Hughes,** The University of Texas at Arlington

The Wanek Fund, established in 2002, 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.

### Charles A. & June R.P. Ross Research Fund

**Bronwen Konecky,** Brown University

The Ross Research Fund was established in 2002 to support research in the fields of biostratigraphy, including, but not limited to, fossil age dating and the study of evolutionary faunal successions; stratigraphy and stratigraphic correlation; paleogeography and paleobiogeography; interpreting past environments of deposition and their biological significance; and the integration of these research areas into a better global understanding of (1) past plate motions (plate tectonics and sea-floor spreading); (2) past sea-level events, including their identification and ages; and/or (3) climate changes and the effects of those changes on Earth's inhabitants over geologic time.

### Parke D. Snavely, Jr., Cascadia Research Award Fund

**Walter Frueh,** Oregon State University

The Parke D. Snavely, Jr., Cascadia Research Award Fund provides US$1500 to support field-oriented graduate student research that contributes to the understanding of the geologic processes and history of the Pacific Northwest convergent margin or to the evaluation of its hazard or resource potential.

## INTERNATIONAL STUDENT RESEARCH GRANTS

### Farouk El-Baz Student Research Grant

**Christopher Hein,** Boston University, "Sea-level changes and the regressive Wadi infilling of a Pharaonic harbor."

**Sarah Kennan,** University of Bristol, "Rare earth elements and rates of fossilization in dinosaur bones from various depositional environments of the Late Cretaceous, Montana."

This Farouk El-Baz grant encourages and supports desert studies by students worldwide who are either in the senior year of their undergraduate studies or at the masters or Ph.D. level.

### The Maurice "Ric" Terman Fund

The recipient will be named in autumn 2009.

The Maurice "Ric" Terman Fund provides one-year grants to fund the Ph.D. theses and post-doctoral research of East Asian scientists. Countries currently include Cambodia, China, Indonesia, Japan, Korea, Malaysia, Papua New Guinea, Thailand, and Vietnam.

# OTHER 2009 GSA RESEARCH GRANT RECIPIENTS

The following are the remaining GSA research grant recipients not listed under the outstanding mention or specialized award categories.

Ramil Ahmadov
Mishal Al-Johar
Erika Amir
Brian Anderson
Jennifer Arbuszewski
Jessica Ball
Brent Barker
Katherine Barnhart
Isolde Belien
Matthew Bennett
Jayne Bormann
Janice Brahney
Courtenay Brown
Ian Browne
Alena Buhler
Daniel Bulger
Bernadette Cap
Tamara Carley
Mark Carlson
Humberto Carvajal-Ortiz
William Cassata
Mary Cauthen
Nolwenn Coint
Jennifer Coor
Leah Courtland
Joel Cubley
Howard Cyr
Robyn Dahl
Daniel Danehy
Padmini Das
Prabhu Das
Michael DeAngelis
Erin DiMaggio
Colleen Donegan
Steve Doo
Miao Du
Rachel Dunham
Gregory Dyer
Ashley Edelman
Nathan Eichelberger
Carla Eichler
Gary Eppich
John Ezell
Xuan Feng
Benjamin Ferreira
Timothy Fischer
G. Burch Fisher
Melissa Foster
T.J. Fudge
JoAnn Gage
Erika Gallo
Ian Gapp
Patrick Getty
James Girardi
Nicholas Godinez
Peter Gold
Kyle Gorynski
Joseph Goshorn-Maroney
Jennifer Goyette
Kellen Gunderson
Emily Guthrie
Herve Guyard
Benjamin Hallett
Laura Hamlin
William Hassett
Anne Hayden
Katherine Heckman
Anna Henderson
Fabiany Herrera
Andrew Herrs
Amanda Hintz
Jeffrey Hoeft
Erik Hoffmann
Denise Honn
Adam Ianno
Mauricio Ibanez-Mejia
Brady Johnson
Joseph (Beau) Johnson
Aaron Jones
Holly Kagy
Alan Kasprak
Sarah Keenan
Brian Kelley
Daniel King
Sarah Kolbe
Michele Koons
Mary Ruth Kotelnicki
Andrew Kowler
Stephanie Kyriazis
Anne Lagomarcino
Andrew Lamb
Karl Lang
Peter Lanzarone
Richard Lease
Erin Leckey
Jamie Levine
Rebekah Levine
Hosanna Lillydahl-Schroeder
Katherine Lindeburg
Yanan Liu
Sean Long
Richard MacKenzie
Katharine Magary
Neil McKenzie
Julie McKnight
Paula Mejia-Velasquez
Sachidananda Mishra
Bryan Moravec
Jennifer Murphy
Natalie Nahill
Michael Nakagaki
Andrew Neal
David Nicklaus
Simone Normand
Mike Novick
John Nowinski
Jill Onken
Lara Owens
Melissa Park
Elias Parker Jr.
Andrew Parsekian
Mariela Perignon
Noah Planavsky
Nancy Price
Pravin Punamiya
Amanda Reynolds
Tonya Richardson
Jessica Rodysill
Warren Roe
Holly Rotman
Nira Salant
Morgan Schaller
Peter Schillig
Samuel Schon
Joseph Sheffield
Deborah Shulman
Matthew Sisk
Toni Smith
Elizabeth St. Clair
Mark Stelten
Michelle Stropky
Daniel Sturmer
Jenny Suckale
Travis Swanson
Nicholas Swanson-Hysell
Lidya Tarhan
Anita Thapalia
Svetoslava Todorova
Nathan Toke
Christopher Tressler
Amanda Turner
Carrie Tyler
David Ullman
Alexander Ullrich
Peter van Hengstum
Jessica Vaughan
Dustin Ward
Laura Webb
Nicholas Welsh
Benjamin Weston
Joshua Wilkins
Amanda Williams
Carol Wilson
Kelsey Winsor
Yaicha Winters
Jeannette Wolak
Catherine Wolner
Nicolas Young
Andrew Zaffos
Fangfu Zhang

**Selected Alternates**

Brittney Bates
Sarah Beth Cadieux
Jennifer Cash
Michael Hardy
Ghanashyam Neupane
Emily Pope
Joanna Redwine
Katherine Skalak
Ciprian Stremtan
Annette Trierweiler
Jie Xu

# 2009 GSA Division and Section Student Research Awards

## DIVISION AWARDS

Five GSA Divisions have recognized the following research grant recipients for submitting grant proposals of exceptionally high merit in conception and presentation.

### GEOPHYSICS DIVISION

*Allan V. Cox Student Research Grant*

**Brent Barker,** Colorado State University

*Geophysics Student Research Grant Award*

**Leah M. Courtland,** University of South Florida

### HYDROGEOLOGY DIVISION

*Hydrogeology Division Student Research Grant Awards*

**Dolores Neshyba-Bird,** Emporia State University

**Paul Probasco,** University of Virginia

### QUATERNARY GEOLOGY AND GEOMORPHOLOGY DIVISION

*Arthur D. Howard Student Research Award*

**Scott Reynhout,** University of Cincinnati

*Arthur D. Howard Student Research Award Honorable Mention*

**Benjamin Ferreira,** Western Washington University

*J. Hoover Mackin Student Research Award*

**Isaac Larsen,** University of Washington

*J. Hoover Mackin Student Research Award Honorable Mention*

**Esteban Sagredo,** University of Cincinnati

*Marie Morisawa Student Research Award*

**Jill Onken,** University of Arizona

*Marie Morisawa Student Research Award Honorable Mention*

**Britta Jensen,** University of Alberta

### SEDIMENTARY GEOLOGY DIVISION

*Sedimentary Geology Division Student Research Grant Award*

**Eric Hogan,** University of Tennessee

### STRUCTURAL GEOLOGY AND TECTONICS DIVISION

*Structural Geology and Tectonics Division Student Research Grant Awards*

**Sarah Evans,** University of Kansas

**Angela Hull,** Kent State University

**Ryan McKeon,** Lehigh University

## SECTION AWARDS

Two GSA Sections have recognized the following research grant recipients for submitting grant proposals of exceptionally high merit in conception and presentation.

### GSA Southeastern Section Research Grants

**Deniz Z. Altin,** University of Georgia

**Sarah Beth Cadieux,** University of Tennessee

**Miles Henderson,** University of Tennessee

**Patricia Lee,** University of Tennessee

**James Thomka,** Auburn University

**Devi Udgata,** University of Kentucky

**Christy Visaggi,** University of North Carolina–Wilmington

**John Warden,** University of Kentucky

**David Weinstein,** University of Miami

### GSA Northeastern Section Student Research Grant Awards

**Ryan Dockstader,** SUNY-Potsdam

**Paul Durkin,** McMaster University

**Cullen Kortyna,** Bucknell University

**Erik Leithauser,** Slippery Rock University

**Eric Lynch,** Bucknell University

**Thomas McCarthy,** University of Connecticut

**Hilary Morgan,** University of Pittsburgh

**Alejandra Ortiz,** Wellesley College

**Shirley Pulawski,** SUNY-Fredonia

**Timothy Sime,** University of Massachusetts

**Daniel Slane,** SUNY-Potsdam

**Allyson Tessin,** University of Pittsburgh

**Petr Yakovlev,** Boston College

### 2009 Northeastern Section Meeting Poster Award Competition

*Graduate Students*

1st Place: **James Pyburn,** Boston College

2nd Place: **Jennifer C. Meyers,** University of Maine–Orono

3rd Place: **Edwin A. Escarraga,** Acadia University–Nova Scotia

Honorable Mention: **Benjamin P. Hooks,** University of Maine–Orono

*Undergraduate Students*

1st Place: **Maya Li Wei-Haas,** Smith College

2nd Place: **Amanda Bucci,** Union College

3rd Place: **Richard W. Munschauer,** Hamilton College

Honorable Mention: **Kyle D. Trostle,** Franklin and Marshall College

# POST-DOCTORAL RESEARCH GRANTS

## 2009 Gladys W. Cole and W. Storrs Cole Memorial Research Awards

*These awards are funded by the GSA Foundation.*

**Mark R. Sweeney** of the University of South Dakota has been granted US$9,900 from the **Gladys W. Cole Memorial Research Award** fund for research on the geomorphology of semiarid and arid terrains for his research project "Late Holocene geomorphic response to Kelso Wash, eastern Mojave Desert: Climatic versus base level control of desert dust source." The award will be presented at the October 2009 GSA Annual Meeting QG&G Awards Ceremony.

**Michael A. Kaminski** of University College London has been granted US$9,100 from the **W. Storrs Cole Memorial Research Award** fund for research on invertebrate micropaleontology for his research project "Late Cretaceous biostratigraphy, paleobiogeography and paleoceanography of the western Barents Sea—an integrated micropaleontological and palynological study." The award will be presented at the October 2009 GSA Annual Meeting Cushman Foundation for Foraminiferal Research Awards Ceremony.

# Call for GSA Committee Service

THE GEOLOGICAL SOCIETY OF AMERICA®

### 2010–2011 COMMITTEE VACANCIES

**Deadline to apply or submit nominations:** 15 July 2009

GSA invites you to volunteer or nominate one of your fellow GSA members to serve on a Society committee or as a GSA representative to other organizations.

Go to **www.geosociety.org/aboutus/committees** and click on "View Committee Vacancies" to access the application form and to learn more.

Terms begin **1 July 2010** unless otherwise indicated. If you have questions or cannot find the information you need on the GSA Web site, please contact Pamela Fistell, +1-303-357-1044, +1-800-472-1988, ext. 1044, pfistell@geosociety.org.

*Impact the Future of Geoscience by Serving on a GSA Committee!*

# The Kerry Kelts Research Awards of the Limnogeology Division

**Application Deadline:** 3 August 2009

The GSA Limnogeology Division's Kerry Kelts Research Awards for undergraduate or graduate student research offers up to three awards of US$400 each for use in research related to limnogeology, limnology, and paleolimnology.

**To apply:** Send a summary of the proposed research, its significance, and how the award will be used (in PDF format; five-page max.) along with your name and a short CV (two-page max.) to Michael Rosen, chair of the Limnogeology Division, mrosen@usgs.gov. Awards will be announced at the Limnogeology Division Business Meeting and Reception at the October 2009 GSA Annual Meeting in Portland, Oregon, USA.

If you are interested in supporting this awards program, 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

## *News about GSA's Members*

In June 2009, GSA Fellow **Paul F. Hoffman** of Harvard University received the Wollaston Medal, the highest award of the Geological Society, London. The Wollaston Medal is given annually to geologists who have had a significant influence by means of a substantial body of research. A field geologist, Hoffman is an outspoken advocate for Precambrian plate tectonics and the "Snowball Earth" hypothesis.

In April 2009, GSA Fellow **Frank Spear** of Rensselaer Polytechnic Institute was named the Edward P. Hamilton Distinguished Professor of Science Education for excellence as both a researcher and an educator.

Also in April, GSA Fellow **Robert Bodnar** of Virginia Tech received a USGS mineral research grant to study the Coles Hill uranium deposit in south-central Virginia, and GSA member **Craig Hart** of the University of British Columbia received a USGS mineral research grant to fund investigation of the regional geology and age of igneous rocks of the Pebble copper deposit in southwest Alaska.

In March 2009, The Society for Science & The Public (SSP) announced its first class of SSP Fellows. Two GSA K–12 Teacher Members were among this first class of Fellows, selected for their unique plan to reach students in underserved communities and to inspire excellence in independent scientific research: **Raymond Nance,** from Carlsbad High School in Carlsbad, New Mexico, USA, and **Susan Vincent,** from the Young Women's Leadership School of East Harlem, New York City, New York, USA.

GSA Fellow **H. Jay Melosh** is the recipient of the 2009 Shoemaker Memorial Award. This award, presented by the BEYOND Center for Fundamental Concepts in Science at Arizona State University, recognizes his life work as a planetary scientist and impact specialist.

GSA Fellow **Richard B. Alley** of Penn State has received the 2009 Tyler Prize for Environmental Achievement, which he will share with Veerabhadran (Ram) Ramanathan of the Scripps Institute of Oceanography (UC–San Diego). Both scientists are credited with demonstrating the global reach and severity of human impacts on climate. Alley is also the recipient of GSA's 2008 Public Service Award.

View the member news archive at **www.geosociety.org/news/memberNews.htm.**

# In Memoriam

Between 20 Jan. and 26 Apr. 2009, GSA was notified of the deaths of the members respectfully listed below. To honor one of these colleagues with a GSA Memorial, please go to **www.geosociety.org/pubs/memorials/index.asp.** This page also lists the GSA member memorials already completed and available as downloadable PDFs. If you would like to contribute to the member Memorial Fund, please contact the GSA Foundation at +1-303-357-1054, drussell@geosociety.org, www.gsafweb.org.

**Richard C. Anderson**
Rock Island, Ill., USA
8 Jan. 2009

**Rachel M. Barker**
Arlington, Vt., USA
25 Feb. 2009

**Richmond Bennett**
Jefferson, Ohio, USA
16 Jan. 2009

**Lui-Heung Chan**
Baton Rouge, La., USA
notified 13 Apr. 2009

**George M. Clark**
Canoga Park, Calif., USA
notified 13 Apr. 2009

**Thomas A. Cullinan**
Metairie, La., USA
15 Dec. 2008

**Jules R. DuBar**
Charlottesville, Va., USA
17 Mar. 2009

**Giovanni Flores**
Firenze, Italy
notified 29 Jan. 2009

**Ralph J. Gray**
Monroeville, Pa., USA
notified 24 Mar. 2009

**David K. Johnston**
Oakdale, La., USA
notified 13 Apr. 2009

**Edmond F. Lawrence**
Spanish Fort, Ala., USA
4 Jan. 2009

**Steven A. Moskowitz**
La Palma, Calif., USA
notified 6 Apr. 2009

**Brian J. O'Neill**
New Orleans, La., USA
26 June 2008

**Rick H. Russell**
Sandy, Utah, USA
6 Apr. 2009

**Joseph Avery Sharps**
Coarsegold, Calif., USA
notified 12 Feb. 2009

**Thompson M. Stout**
Lincoln, Neb., USA
notified 21 Apr. 2009

**Jorg Trappe**
Bonn, Germany
notified 5 Mar. 2009

**Rudolf Trumpy**
Kusnacht, Switzerland
1 Jan. 2009

**Leonard Alton Wood**
Oakton, Va., USA
10 Nov. 2008

**J. Lamar Worzel**
Wilmington, N.C., USA
26 Dec. 2008

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The following individuals joined the Society between September 2008 and March 2009 and were elected into membership by GSA Council at its May 2009 meeting.

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# *GSA Foundation Update*

**Donna L. Russell,** *Director of Operations*

## Government Affairs & Public Policy: Fostering Active Dialogue with Decision Makers

Created as part of GSA's National Leadership Initiative, GSA's geoscience policy office in Washington, D.C., opened in September 2007 in the American Association for the Advancement of Sciences headquarters building. GSA established this office to further the Society's core mission to be a leader in advancing the geosciences while enhancing the professional growth of its members and promoting the geosciences in the service of humankind. The director of GSA's Government Affairs & Public Policy Office is Craig Schiffries, cschiffries@geosociety.org.

The overarching goal of the Washington office is to provide GSA and its members with leadership in public policy through active involvement in decision making and implementation processes. The office fulfills this goal through four major areas of activity:

1. Monitoring public policy issues and participating in information-sharing and educational efforts directed toward the legislative and executive branches of government;
2. Working with the GSA community to increase member involvement in public policy–related activities;
3. Supporting adequate funding for science at the federal level; and
4. Encouraging and improving the use of scientific information in public policy decision making.

**This office also takes part in the following activities:**

- Congressional briefings on geoscience topics of special interest to Congress. Recent briefings include "Climate Change: Intersections of Science and Policy," "Grand Challenges for Disaster Reduction," and "Improving Tsunami Warnings Nationwide."
- Congressional Visits Days, encouraging GSA members to engage in informal meetings with Senators, Representatives, and congressional staff, and providing training sessions and congressional receptions.
- GSA is a founding member of the first Geosciences Congressional Visits Day, which engaged more than 60 geoscientists from 26 states in meetings with more than 100 congressional offices in a single day.
- GSA serves on the organizing committee of the Science-Engineering-Technology Congressional Visits Day and participates in similar events.
- Congressional testimony and correspondence—GSA was the lead author of congressional testimony submitted on behalf of the USGS Coalition in 2008 and plans a growing portfolio of congressional testimony in the future.
- Capitol Hill events—GSA helps organize a wide range of events on Capitol Hill, including press conferences in the U.S. Capitol building; awards to congressional leaders; and the Coalition for National Science Funding Exhibition.
- Strengthening relationships with Congress and federal agencies—GSA's Washington office builds and maintains strong relationships with leaders of federal geoscience programs and key congressional staff.

To make a contribution in support of GSA's Government Affairs & Public Policy Office in Washington, D.C., you may use the coupon below and send your check directly to the GSA Foundation, or go to the Foundation's Web site, www.gsafweb.org, for more options.

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## 2008–2009 Congressional Science Fellow Report

David Szymanski

# Congressional Connections and Earth Science Literacy

When Congress is in session, a big part of my day is consumed by meetings. Like other aspects of life in Washington, D.C., meetings on the Hill have a faster pace compared to meetings on the "outside." Seasoned congressional staffers seem to thrive on the often frenetic pace, and understanding how the process works helps keep many a lobbyist employed. In addition to other responsibilities, it is not unusual for legislative staffers to have six or eight 15- to 30-minute constituent meetings in a day, often back-to-back and sometimes overlapping.

By Friday night, the week can seem to have been just a flurry of handshakes and customary business card swaps, but, ultimately, the purpose of every meeting is the same: to identify connections. The connections that members of Congress seek are pieces of information that link stakeholder concerns to specific legislation (or sometimes to congressional oversight). The stakeholders may be constituents from the Congress member's district or state, professional or trade organizations, businesses or entire industries, or the general public. The specific legislation may take the form of a new (or amended) law or simply an appropriation to fund an existing program.

In this respect, all meetings on the Hill are at least partly informational, but a successful meeting also involves an "ask"—a highly specific request that addresses the concern. The ask is the legislative equivalent of "what's the relevance of what you are telling me?" that faculty members use to bedevil graduate students after research presentations. Without an "ask," meetings tend to get lost among countless other distractions competing for members' and staffers' time. Asks may not always be politically palatable or even realistic, but at least they identify connections.

Geoscientists are stakeholders in this process—often as recipients of federal funding, but also as drivers of national policy on energy, water, natural resources, and climate change. Meeting with members of Congress and their staff is unquestionably an important activity for earth scientists. In fact, professional societies like GSA and the American Geological Institute (AGI) organize congressional visits for their members to help maximize their impact and visibility on the Hill. My predecessors and I have given detailed advice in these pages on how to communicate with Congress. In fact, the purpose of this fellowship is in part to provide a resource for colleagues across academia, industry, and government.

But congressional visits are not the only way to advance science policy. In terms of a lasting effect, collectively, scientists have a much greater impact on policy through other kinds of outreach. In a recent editorial in *Science* (13 March 2009), Christopher Reddy, Director of the Coastal Ocean Institute of Woods Hole Oceanographic Institution, argued that universities should provide more incentives for their scientists to communicate with policymakers, the public, and—*gasp*—the media. As accessibility to information and disinformation expands exponentially via the Internet, the responsibility of scientists to explain what they do becomes even more important. Reddy writes, "That doesn't mean scientists need to be celebrities, politicians or lobbyists—just citizens."

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Geoscientists can impact science policy by helping the public identify important, but often less apparent, connections between society and the earth systems we study. By explaining the relevance of their scientific research, geoscientists help improve earth-science literacy, which would ostensibly make it easier to craft and pass legislation that directly or indirectly involves earth systems. This type of outreach can be done in a number of ways, in addition to directly lobbying Congress or giving interviews.

For example, the Earth Science Literacy Initiative (ESLI), a project funded by the National Science Foundation (NSF), recently released a community-based document that outlines the "big ideas" in earth science—the things every American should know. The document was developed, written, and revised by earth scientists with the goal of not only guiding educational standards but legislation as well by calling attention to the myriad connections among earth materials, earth processes, and society. The resulting framework parallels similar documents produced by the ocean, atmosphere, and climate science communities. The result: geoscientists can use these "big ideas" to both frame and explain the relevance of what they do to the public.

Despite the cumulatively slow pace of enacting legislation, it is clear that these kinds of connections are being made in Washington, D.C. The Obama Administration and majority leadership in both the Senate and House of Representatives have signaled that climate-change legislation must be directly and intimately linked to national energy policy. It remains to be seen whether combining every aspect of the two in a sweeping energy bill is politically prudent. At the time of this writing (April 2009), discussion has just begun on draft climate-change legislation authored by Representatives Henry Waxman (D-Calif.) and Edward Markey (D-Mass.).

Scientific connections are being made on a smaller scale in Congress, too. Senate Energy and Natural Resources Committee Chair Jeff Bingaman (D-N.Mex.) and ranking member Lisa Murkowski (R-Alaska) recently introduced S.531, The Energy and Water Integration Act of 2009. The bill represents unprecedented federal recognition of the nexus between energy production and water use/consumption in the United States. Among the provisions of S.531 are a congressionally mandated study by the National Academy of Sciences on the impact of energy development on water resources and a directive to the Department of Interior to set research priorities for the Brackish Groundwater National Desalination Facility in Alamogordo, New Mexico, including the integration of renewable energy with desalination technologies.

Whether we choose to recognize it or not, scientific research drives national policy. Regardless of how removed your research may seem from the halls of Congress, the cumulative results of scientific progress are the basis for many policy decisions. Geoscientists can influence the direction of those decisions from the inside as advocates and from the outside as grassroots educators. Perhaps helping the public and policymakers make these kinds of connections can demonstrate the value of programs like volcano monitoring—and maybe even without a karmic case-in-point eruption.

This manuscript is submitted for publication by David Szymanski, 2008–2009 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. 08HQGR0141. 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. Szymanski can be reached at David_Szymanski@tester.senate.gov.

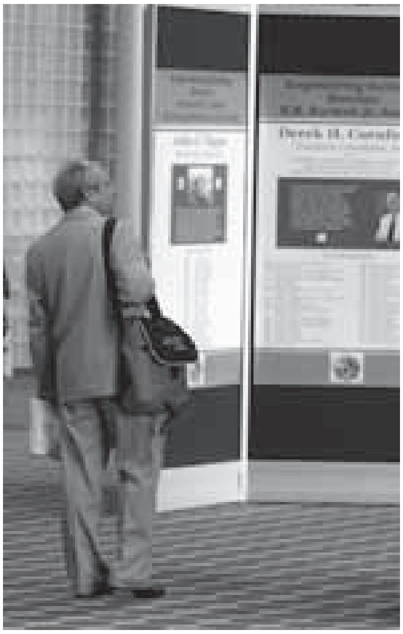
## Thanks
## to GSA's Campus Reps!

**GSA has a network of nearly 600 volunteer campus representatives**—members on two- and four-year college and university campuses around the world who advocate for the Society and its mission. GSA Campus Reps distribute information to students and colleagues, answer questions about the Society and its programs, and act as ambassadors for GSA. We appreciate their efforts and their vital role in furthering GSA's outreach.

**To learn more** and to see a list of current GSA Campus Reps, go to **www.geosociety.org/members/campus.htm.** If there is no GSA Campus Rep at your college or university and you would like to volunteer, please contact us at campusreps@geosociety.org.

## GSA's 2009 Hall of Fame: Living with Dynamic Leaders

*Pause in the bustle of the 2009 GSA Annual Meeting to visit the Hall of Fame and acknowledge your well-deserving and hard-working colleagues, mentors, and students—and maybe even see a banner honoring you!*



**This year, the Hall of Fame honors:**

- Current and past GSA geoscience award winners;
- Current and past recipients of the AGI Medal in Memory of Ian Campbell;
- Current and past GSA Division awardees;
- All GSA Fellows and Honorary Fellows;
- GSA's 25- and 50-year members for 2009;
- Associated Society award recipients; and
- Top-ranked graduate student research grant recipients.

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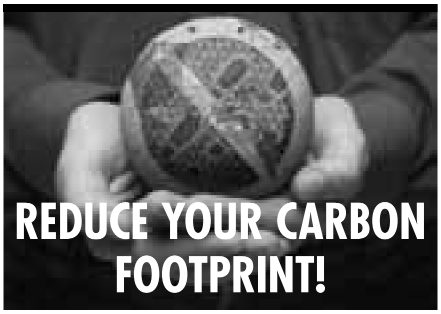

## REDUCE YOUR CARBON FOOTPRINT!

GSA has teamed with Sustainable Travel International, www.sustainabletravel.com, to help you offset your carbon footprint.

- Go to **https://sustainabletravelinternational.org/documents/op_carboncalcs.html;**
- Use the site's calculator to determine your travel footprint; and
- Donate to a number of high-quality, verified carbon-offset projects around the world, including a project based in Portland, Oregon, USA.

## International Division Travel Grants

**Application deadline:**
1 August 2009

GSA's International Division is offering travel grants to assist the participation of international scientists and students in the annual meeting. Funds are limited; these grants will never cover the full cost of attending the meeting but are intended to help defray the combined cost of registration, housing, and travel. To apply, go to the GSA International Division's Web page, **www.geosociety.org/sectdiv/idiv/travelGrants.htm.**

### Questions?

Contact John Wakabayashi at jwakabayashi@csufresno.edu.

To make a donation in support of these travel grants, please go to the GSA Foundation Web site, **www.gsafweb.org/makeadonation.html,** select "International Division Fund" and type "Portland travel grant" in the comment field.

### 2009 GSA Annual Meeting
### Portland, Oregon, USA

# Lunchtime Keynote Lectures

Oregon Convention Center 12:15–1:15 p.m.

Bring your lunch, relax, and be informed by GSA's new Lunchtime Keynote Lectures.

Patricia Woertz

## Lunchtime Keynote Lecture 1: Toward a Shared Energy Future: Carbon Sequestration and the Global Corporation

**Patricia A. Woertz,** GSA Geology and Society Division Distinguished Lecturer

Sunday, 18 Oct. 2009

Patricia Woertz is chair, CEO, and president of Archer Daniels Midland Company (ADM), a leading agricultural processor working to improve its environmental performance, particularly through carbon sequestration research and its BioEnergy program.

In 2007, ADM teamed with the Midwest Geological Sequestration Consortium, the Illinois State Geological Survey, and Schlumberger Carbon Services to advance one of the nation's first large-scale geologic carbon sequestration research studies. The demonstration project will inject carbon dioxide from the company's Decatur, Illinois, ethanol plant 8,000 feet underground into the Mount Simon Sandstone, a large, saline-bearing rock formation. ADM is partnering in the project to help determine whether this technology can improve the environmental footprint of alternative fuels by capturing and storing carbon emissions associated with their production.

Woertz will discuss how partnerships among corporations, government agencies, academic institutions, and nongovernmental organizations are essential to effecting environmental improvement while ensuring that the food and energy needs of a growing global population are met. She will outline the challenges and opportunities inherent in these complex collaborations and provide perspective on how shared scientific and environmental goals are serving as rallying points for organizations in various sectors.

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***Check future issues of* GSA Today *as we unveil subsequent lectures.***
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**Submit abstracts at http://gsa.confex.com/gsa/2009AM/cfp.epl**
*Still have field work to do?* You now have until **11 August** to prepare and submit abstracts.

**Register at www.geosociety.org/meetings/2009/reg.htm**
**Early registration deadline:** 14 September
*Receive a coupon for US$10 off at the onsite GSA Bookstore if you register before 31 July!*

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**Photo:** Portland, Oregon, USA. Photo courtesy Travel Portland/Steve Terrill and the Portland Oregon Visitors Association.

# 2009 GSA Gold Medal Lectures

Oregon Convention Center ✷ Sunday, 18 Oct., 5–7 p.m.

Please join us for the inaugural **GSA Gold Medal Lectures,** a special event hosted by GSA to honor its awardees. Penrose Medalist B. Clark Burchfiel of MIT, a specialist in continental tectonics; Day Medalist T. Mark Harrison of UCLA, a specialist in dynamic thermochronology; and Donath Medalist Cin-Ty A. Lee of Rice University, a multidisciplinary geologist studying the formation and stability of continents, are scheduled to speak and reflect on their scientific careers. Questions from the audience are encouraged. GSA President Jean Bahr will chair the program. *No reservations, tickets, or invitations required.*

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# EarthTrek™

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....the community being part of the solution

GSA is leading a new international effort to increase the number of people exposed to science through ***EarthTrek,*** a worldwide citizen science program that connects people in the community with scientific projects lead by scientists from a wide range of institutions. Following protocols set by these scientists, individuals, families, clubs, or school groups are encouraged to trek out into their environment and collect data, log that data online, and thus add to the pool of knowledge collected by other "EarthTrekkers" around the world.

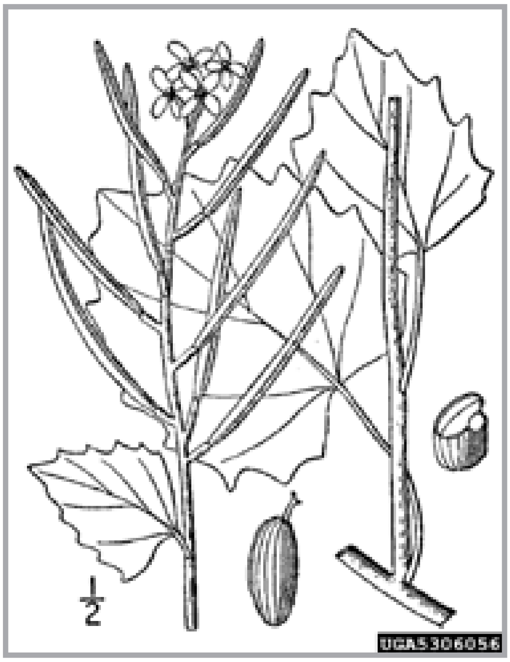
Scientists maintain contact with project participants so that each participant knows how his or her work aids in the understanding of a problem or issue and how the data will be used in future decision making. Participants also receive online incentives for their contributions by means of statistics records, certificates, and other rewards.

EarthTrek projects will focus on environmental issues in which community involvement is the key to understanding the real nature of the issue at a local, regional, and/or global scale. Projects can come from any field of science: earth science, biological sciences, atmospheric sciences, and more. The important thing is that the science is *real research* led by scientists who need the community's help to collect *real data*.

EarthTrek gravestone project location, Oslo, Norway.

### EarthTrek Gravestone Project

This EarthTrek project involves data collection from graveyards around the globe. Participants measure the thickness of marble gravestones, or, if lead lettering was used, how far the marble has receded from the lettering, so that project scientists can create a worldwide map of how gravestones weather over time. This information can provide insights into shifts in world pollution levels and climate change over time.



Invasive species *Alliaria petiolata* or garlic mustard plant; image courtesy USDA-NRCS Plants Database, *from* Britton, N.L., and Brown, A., 1913, *An illustrated flora of the northern United States, Canada and the British Possessions*: v. 2, p. 170.

### EarthTrek Garlic Mustard Field Survey

This project has participants identifying and measuring the location of garlic mustard plants in the northern hemisphere and comparing its invasive spread across the planet with growth in its native Europe.

**www.goearthtrek.org**

For more information, contact Gary Lewis,
GSA Director of Education & Outreach
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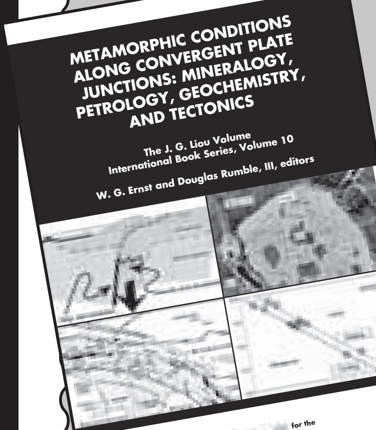
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The J. G. Liou Volume
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W. G. Ernst and Douglas Rumble, III, editors

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International Book Series, Volume 10

**Metamorphic Conditions along Convergent Plate Junctions: Mineralogy, Petrology, Geochemistry, and Tectonics—The J.G. Liou Volume**

*edited by W.G. Ernst and Douglas Rumble III*

This book assembles diverse papers on mineralogy, petrology, geochemistry, and tectonics produced for a symposium held at Stanford University on metamorphic conditions along convergent plate junctions. The scientific contributions, honoring Professor Juhn G. Liou on the occasion of his retirement from the regular Stanford faculty, mirror some of "Louie's" seminal scientific contributions in experimental mineralogy, low-grade and high- to ultrahigh-pressure (HP-UHP) metamorphic petrology-geochemistry, and plate tectonics of subducted Circumpacific and collisional terranes. The book, which emphasizes HP-UHP recrystallization, is divided into a lead section concerned with overarching principles, followed by topical studies of important high- and ultrahigh-pressure terranes around the world, including (1) east-central China, (2) western China–western Himalayas, (3) the southwestern Pacific, (4) northern Kazakhstan and the southern Ural Mountains, (5) the western Alps and central European massifs, (6) western Norway–east Greenland, (7) southwestern North American terranes, and (8) central Korea–southwestern Japan.

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Since this series' inception in late 2005, *GSA Today* has published the following 12 articles:

- **Advocates for cold-blooded dinosaurs: The new generation of heretics** (T.L. Clarey, v. 17, no. 1, p. 45–46)
- **Scientific uncertainty and public policy: Moving on without all the answers** (H.N. Pollack, v.17, no. 3, p. 28–29)
- **The future of hydrocarbons: Hubbert's peak or plateau?** (E.S. Cheney and M.W. Hawkes, v. 17, no. 6, p. 69–70)
- **The coupling between devaluation of writing in scientific authorship and inflation of citation indices** (T. Engelder, v. 17, no. 7, p. 44–45)
- **Celebrity meets science: Hollywood's environmentalism and its effect** (A. Gajda and S.W. Kieffer, v. 17, no. 10, p. 44–45)
- **Coal fires burning around the world: Opportunity for innovative and interdisciplinary research** (G.B. Stracher, v. 17, no. 11, p. 36–37)
- **Impacts, mega-tsunami, and other extraordinary claims** (N. Pinter and S.E. Ishman, v. 18, no. 1, p. 37–38; see an associated Comment by T.P. Bunch, J. Kennett, and D.K. Kennett, v. 18, no. 6, p. 11)
- **Accreditation: Wrong path for the geosciences** (T. Bralower et al., v. 18, no. 10, p. 52–53)
- **Generational and cyclical demographic change in the Geological Society of America** (D.D. Rhodes, v. 18, no. 11, p. 35–37)
- **Recruiting students to undergraduate geoscience programs through dual-credit and dual-enrollment classes** (A.A. Awad and S.R. Mattox, v. 19, no. 4/5, p. 58–59)
- **Painting the past: From scientific research to art** (P. Vickers-Rich, v. 19, no. 6, p. 50–51)
- **The state of interactions among tectonics, erosion, and climate: A polemic** (P. Molnar, this volume, p. 44–45)

*GSA Today* is interested in your contributions! Learn more and link to the submission page at **www.geosociety.org/pubs/gsatguid.htm.**

# CALENDAR OF UPCOMING GSA DEADLINES & EVENTS*

## August

1 **International Division Travel Grant** application deadline. See p. 36 of this issue or go to www.geosociety.org/sectdiv/idiv/travelGrants.htm for more information.

3 Last day to apply for the **Kerry Kelts Research Awards** of the Limnogeology Division. See p. 22 of this issue for more information.

11 **Last day to submit abstracts** for the 2009 GSA Annual Meeting in Portland, Oregon, USA. Go to **www.geosociety.org/meetings/2009** for a link and instructions.

29 **GSA GeoVentures** trip for everyone, "Geology of the Middle Fork of the Salmon River, Idaho," meets in Stanley, Idaho, USA, and runs through 4 Sept.

## September

9 **GSA Penrose Conference,** "Low $\delta^{18}$O rhyolites and crustal melting: Growth and redistribution of the continental crust," convenes in Twin Falls, Idaho, USA, and runs through 13 Sept.

13 **GSA Field Forum,** "Structure and neotectonic evolution of the northern Owens Valley and the Volcanic Tableland, California," convenes in Bishop, California, USA, and runs through 19 Sept.

14 **2009 GSA Annual Meeting** early registration and housing deadline. Student travel grant deadline.

21 **2009 GSA Annual Meeting** registration cancellation deadline.

## October

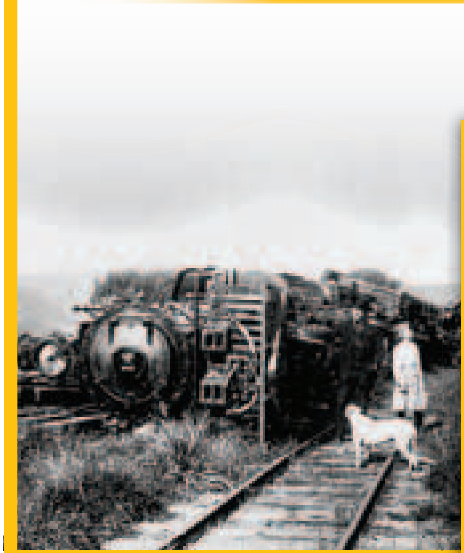
4 **GSA Penrose Conference,** "Tectonic development of the Amerasia Basin," convenes at the Banff Centre, Alberta, Canada, and runs through 9 Oct.

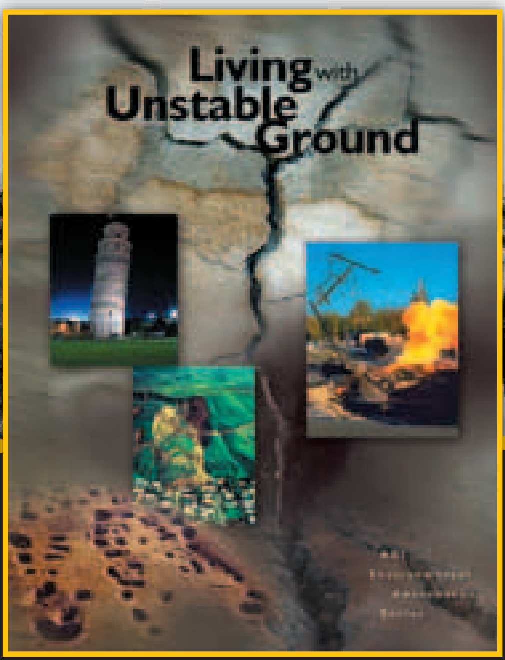
17 **2009 GSA Annual Meeting** Presidential Address & Awards Ceremony.

18 **2009 GSA Annual Meeting** Gold Medal Lectures and Welcoming Party & Exhibits Opening.

*See the June 2009 *GSA Today* or **www.geosociety.org/meetings/2009** for a detailed listing of events for the 2009 GSA Annual Meeting.

# Living with Unstable Ground





Thomas Holzer
ISBN 0-922152-82-9

*Living with Unstable Ground*, the 11th publication in AGI's Environmental Awareness Series, is a practical guide and will increase your awareness and understanding of how you can build safely in areas with unstable ground and what society can do to reduce the impact of unstable ground. Whether ground displacements are large and catastrophic or small and slow, their cumulative impact during the lifetimes of humans or civilizations may be large and destructive.

Produced by the American Geological Institute in cooperation with Association of Environmental & Engineering Geologists, Applied Technology Council with support from the ATC Endowment Fund, and the United States Geological Survey.

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12th Annual AAPG/SEG

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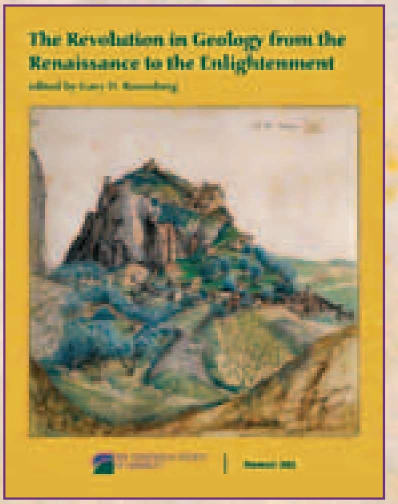

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GROUNDWORK
Furthering the Influence of Earth Science

# The state of interactions among tectonics, erosion, and climate: A polemic

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Since Dahlen and Suppe (1988) showed that erosion can affect the tectonics of the region undergoing that erosion, geodynamicists, tectonic geologists, and geomorphologists have joined in an effort to unravel the interrelationships among not only erosion and tectonics but also climate, which affects erosion and is affected by tectonics. The fruits of this effort grow continually, as shown in part by the attraction that this subject has for students and young scientists. Yet, it seems to me that progress has been limited by a misconception that has stimulated this polemic. Much effort seems to be expended in trying to understand what "controls" erosion, tectonics, or climate, or what "drives" erosion, "rock uplift," climate, and so forth. Although these questions are not meaningless in all cases, enough are.

My thesis is that erosion, climate, and tectonics interact with one another in a state that is usually and in most regions approximated as quasi-equilibrium. "Usually," because even if we ignore major storms, which are short-lived on any geologic time scale, climate changes continually with orbital pacing, and tectonic processes also change, though more slowly. "Most regions," because there always is a place where the unexpected occurs. "Quasi-equilibrium," because in a system as nonlinear as either climate or erosion, if not tectonics too, equilibrium cannot be sustained for long, and geologic time is long on the time scales of changing climate and erosion, if not tectonics.

An equation of state describes equilibrium. A good example is the perfect gas law:

$$PV = nRT. \qquad (1)$$

$P$ is pressure, $V$ is volume, $n$ is the number of moles of a gas, $R$ is the gas constant, and $T$ is absolute temperature. An equation of state, and likewise an equation of equilibrium, does not assign cause or effect, and hence does not attribute a controlling factor or driver to any of its elements, but simply expresses a balance. Of course, if one changes the pressure, then at least one of volume, temperature, and conceivably the number of moles of gas must change. Here it might make sense to ask what "controlled" the change in those quantities, or what "drove" them. The occurrence of change, external to "equation (1)," transforms questions that concern drivers or controls from being ill posed to well posed.

In the earth sciences, perhaps no concept illustrates better a state of quasi-equilibrium than isostasy. Isostasy is not a process; it exists. On short time scales (thousands of years), viscous deformation can retard the inexorable trend toward isostatic equilibrium, as is illustrated well by the rebound following the melting of Pleistocene ice sheets. Thus, on such time scales, one might understand pressure differences in the asthenosphere as "driving" the overlying lithosphere and surfaces of Canada or Fennoscandia upward. On longer geologic time scales, however, isostasy is maintained as a state of equilibrium; like the perfect gas law, "isostasy," therefore, does not drive anything, much as traffic laws do not "drive" cars.

Dahlen and Suppe (1988) considered the state of stress within a wedge of sediment obeying Coulomb friction and the equilibrium cross sectional shape of that wedge. It seems unlikely that erosion would suddenly excavate a divot from a fold and thrust belt, but it is easy to imagine that erosion rates could change relatively quickly on geologic time scales, for instance because of some change in climate (e.g., more typhoons). Dahlen and Suppe's work predicts that the deformation field would respond comparably rapidly to maintain the cross sectional shape of the wedge, so as to maintain a state of quasi-equilibrium.

Suppose we recognize that steep terrain offers its erosive agents more energy to do their job than gentle terrain, that more precipitation will remove more material (erode faster) than less precipitation, but that the stormier the climate the faster the erosion, and that tectonics can elevate terrain, which then is subject to erosion. I offer the following mnemonic:

*__P__recipitation rate* × *__V__ertical component of velocity* = *__n__umber of floods per annual precipitation* × *__R__ock removal rate* × *__T__ectonic movement.* (2)

Here, the ***Precipitation rate*** is some average, such as mean annual precipitation, a measure that can distinguish wet from arid environments. The ***Vertical component of velocity*** refers to movement of rock relative to base level, and might be called "rock uplift rate" except that that term is usually used without a clearly defined reference frame. The ***number of floods per***

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*GSA Today*, v. 19, no. 7, doi: 10.1130/GSATG00GW.1

*annual precipitation* would characterize the recurrence interval of some kind of typical flood, such that a small number means that most of the precipitation comes during a few floods, and a large number would imply little variability in precipitation. The ***R**ock removal rate* is the erosion rate or, perhaps mnemonically better, the *e**R**osion rate*. To be consistent with how it is commonly used in geomorphology, ***T**ectonic movement* is intentionally vague, but refers to processes that elevate the earth's surface, either by crustal thickening or by the alteration of mantle structure. Note that (2) is a mnemonic, not an equation to be solved.

Nevertheless, (2) captures much of the common sense statements that began the previous paragraph. With no changes to climate (***P*** or ***n***) and to erosion (***R***), tectonic movements (***T***) scale with the rate that rock goes up (***V***). In the absence of tectonics (***T***) or climate change (***P*** or ***n***), because of isostasy, the erosion rate (***R***) will scale with the rate that rock goes up (***V***). All else being equal, increased precipitation (***P***) will be proportional to the erosion rate (***R***). Moreover, if that precipitation (same ***P*** in each case) occurs in rare storms (small ***n***), erosion will be faster (big ***R***) than if precipitation is steady (large ***n*** and small ***R***). Of course, the mnemonic is imperfect, not just because it ignores glaciers. For instance, according to (2), in the absence of erosion (***R***) and tectonics (***T***), precipitation (***P***) would scale inversely with the rate of vertical movement of rock (***V***), which is nonsense (if, however, increasing ***V*** might, via orographic precipitation, call for an increase in ***P***). Anyhow, if (2) were perfect, wouldn't that be a gas?

Most of the preceding words are meant to urge geodynamicists, tectonic geologists, and geomorphologists to be more careful in how they view the interactions among tectonics, climate, and erosion. Yet, an exciting part of these subjects lies where equilibrium does not apply. For instance, to what extent does the relief that prevented elephants from reaching Rome or that challenges mountaineers reflect a transient state, and perhaps one that is decidedly not in equilibrium, because changes in erosion rates induced by climate change occur faster than the landscape can evolve? Moreover, there is a difference between (1) and (2) that should not be overlooked. The beauty of (1) lies in the state that it describes, and in that context, each of ***P***, ***V***, ***n***, ***R*** (especially), and ***T*** need not, individually, make for interesting study. In (2), beauty is in the mind of the beholder, and real progress may come more from understanding each of ***P***, ***V***, ***n***, ***R*** (again, especially), and ***T*** independently of the others, than from studying the interactions among them.

*Manuscript received 29 January 2009; accepted 2 February 2009.*

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