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Clinker geochronology, the first glacial maximum, and landscape evolution in the northern Rockies

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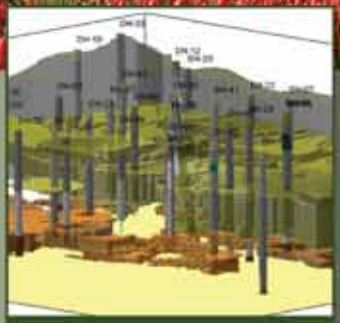

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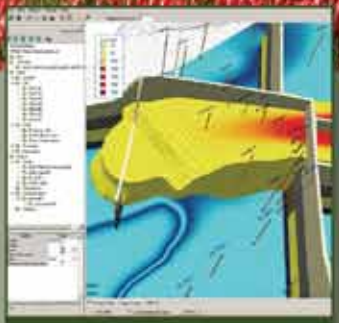

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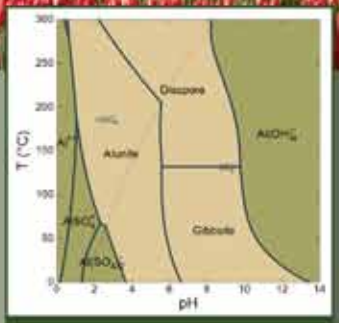

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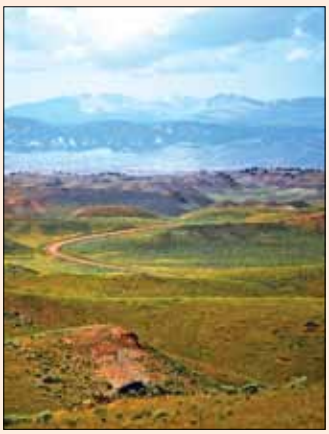

Cover: Clinker-capped terraces and buttes in the Eocene Wasatch Formation of the central Powder River Basin, with foothills and high peaks of the Bighorn Mountains in the western distance. Clinker in these exposures formed by shallow exhumation and natural coal burning between ~40 and 200 ka. Photo by Pete Reiners. See related article, p. 4–9.

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Clinker geochronology, the first glacial maximum, and landscape evolution in the northern Rockies

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ABSTRACT

Late Cenozoic erosion in the Powder River Basin of northern Wyoming and southern Montana has exhumed numerous coal beds to shallow depths where they burn naturally, forming erosion-resistant metamorphic rocks called clinker. Because most clinker forms tens of meters from the surface, its formation age records the timing and rate of exhumation through this depth, which can be used to constrain incision and lateral backwasting rates and the evolution of topographic relief. Zircon (U-Th)/He ages from ~100 distinct clinker units provide several insights into the geomorphic evolution of the region. Ages of in-situ clinker range from as old as 1.1 Ma to as young as 10 ka, but most formed in one of the last three interglacial periods, reflecting either changes in fluvial incision caused by glacial-interglacial cycles or other climatic effects on rates of natural coal burning. Most clinker older than ca. 200 ka is either detrital or >~200 m above local base level. Detrital clinker atop a broad strath terrace in the northern part of the basin provides a maximum age of 2.6 ± 0.2 Ma for terrace formation. This corresponds to the onset of major Northern Hemisphere glaciation interpreted from marine records, suggesting that the terrace formed by lateral erosion of the landscape as rivers were overwhelmed with sediment during the earliest Plio-Pleistocene glacial episode. The overall correlation of in-situ clinker ages with elevation above local base level can be interpreted with a simple model for shallow exhumation ages that requires increasing incision and topographic relief over at least the past ~1 Myr at rates of ~0.1–0.3 km/Myr, assuming typical clinker formation depths of 20–40 m.

INTRODUCTION

Landscapes lacking large spatial gradients in rock uplift rates are typically dominated by erosional landforms with relief of tens to hundreds of meters. The evolution of these features reflects changes in regional drainage patterns that in turn reflect climatic and tectonic forcing over large areas. Conventional low-temperature thermochronologic approaches are not well suited to understanding the evolution of erosional landforms at these scales because even low-temperature systems have closure depths much greater than the scales of the features themselves and therefore constrain denudation rates over much larger length scales and time scales. Conversely, cosmogenic nuclide approaches generally constrain denudation rates through depths at approximately meter-length scales, much smaller than those of the landforms. Quantitative understanding of how landscape features in the range of tens to hundreds of meters in scale evolve requires an approach that provides estimates of ages and rates of exhumation through commensurate depths.

In this paper, we summarize insights on landscape evolution of the Powder River Basin derived from formation ages of both in-situ and detrital clinker—metamorphic rock produced by the near-surface natural burning of coal. The approaches we use to interpret shallow exhumation ages provide several conclusions about the evolution of the region and highlight how similar types of constraints may be used to reveal patterns of relief change in erosional landscapes.

THE POWDER RIVER BASIN AND CLINKER

The Powder River Basin (Fig. 1) covers ~60,000 km^2 of northeastern Wyoming and southeastern Montana near the northeast margin of the Rocky Mountain plateau, a region characterized by alternating mountain ranges with elevations up to 4.2 km above sea level and sedimentary basins with up to 11 km of Cenozoic structural depth. The Powder River Basin is both a Laramide syncline filled by Cretaceous and Paleogene sedimentary rocks and a modern drainage basin occupied by the Powder and Tongue Rivers draining to the north and the Belle Fourche and Cheyenne Rivers to the east. Most exposed rocks are fluvial sandstones and shales of the Paleocene Fort Union and Eocene Wasatch Formations, with coal beds up to ~60 m thick (Flores and Bader, 1999). Some of the thickest and most laterally continuous coals are associated with the Wyodak-Anderson coal zone, which, together with a few other Fort Union beds, made up ~42% of the 1.2 billion tons of coal mined in the U.S. in 2008 (U.S. Dept. of Energy, 2009).

Powder River Basin coals are relatively low-grade and volatile-rich, causing them to burn naturally when ignited by spontaneous combustion or wildfires. Coal beds only burn when exhumed to depths less than a few tens of meters from the surface, where they are adequately ventilated and above the water table. Burning results in locally intense heating of adjacent rock units (primarily those overlying the coal, due to advection of heat by escaping gases), producing a variety of baked and melted rock types collectively called clinker (Rogers, 1918; Cosca et al., 1989; Heffern and Coates, 2004; Heffern et al., 2007), which covers ~3700 km^2 of the Powder River Basin.

Clinker tends to form erosion-resistant units that create escarpments and mesas, so its distribution dominates topography over much of the basin. Most of the southern Powder River Basin has broad rolling hills and flat-topped buttes capped by clinker, with relief typically <~200 m. However, large (~200 m) clinker-capped escarpments are present in some areas, such as the Rochelle Hills on the eastern side of the basin, formed by

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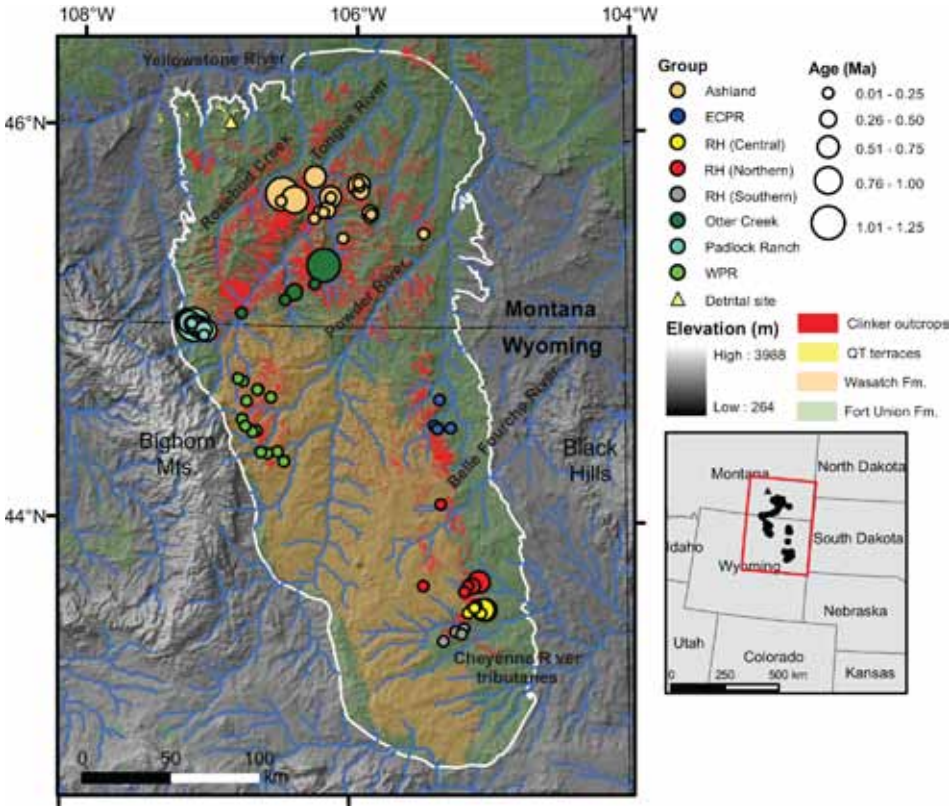

Figure 1. Physiography of the Powder River Basin and surroundings showing primary drainage patterns (blue), distribution of the Paleocene Fort Union and Eocene Wasatch Formations (green and brown, respectively), clinker outcrops (red), and approximate limit of the Powder River Basin as defined by the Cretaceous-Paleogene boundary. Filled circles are clinker sample locations with colors denoting groups listed to right. ECPR—East-central Powder River; RH—Rochelle Hills; WPR—Western Powder River.

burning of the Wyodak-Anderson coal east of the major active mines (Fig. 1). In the central and northern parts of the basin, the Powder River, Tongue River, and Rosebud Creek and their tributaries have carved drainages containing subhorizontal flights of clinker-capped terraces and plateaus with relief in the hundreds of meters.

Like other Laramide basins, the Powder River Basin shows geomorphic and stratigraphic evidence for late Cenozoic incision and regional exhumation up to ~1 km (McMillan et al., 2006, and references therein), though the timing and cause of exhumation are debated (e.g., Riihimaki et al., 2007; Pelletier, 2009). Isolated erosional remnants of Oligocene units of the White River Formation are present near the center of the Powder River Basin, suggesting that much of the erosion was post-Oligocene, and other stratigraphic correlations and regional considerations suggest it was after 12–8 Ma (McMillan et al., 2006).

DATING CLINKER AND SHALLOW EXHUMATION

Quantitative interpretations of landscape evolution from clinker ages rely on an assumption of the depth of clinker formation, which is closely related to burn depth, or the depth at which coal burns to form clinker. Burning is primarily limited to depths where there is adequate air ventilation from the surface, although in some cases it may also be controlled by the water table. These factors may produce variation in local burn depths, but in general, observations of modern and historical burning and coal-clinker contacts suggest that burn depth is usually ~20–40 m (Shellenberger and Donner, 1979; Woessner et al., 1980; Coates and Naeser, 1984), which serves as a useful approximation for the typical maximum depth at which clinker is formed (see GSA Supplemental Data Repository[1] for further discussion).

Our approach to dating clinker relies on resetting of thermochronologic ages of detrital zircon grains caused by the heat from burning coal. Zircon is abundant in many Powder River Basin sedimentary units and has relatively high U and Th concentrations that produce measureable quantities of fission tracks (FT) and radiogenic ^{4}He over 10^4–10^6 yr timescales. Zircon FT ages in several places in the Powder River Basin show systematic age-distance trends in the Rochelle Hills, and relatively old clinker ages (2.2 ± 0.8 and 2.9 ± 0.9 Ma) were found at high elevations in the Little Wolf Mountains and in detrital clinker (3.8 ± 1.2 Ma) (Coates and Naeser, 1984; Heffern et al., 2007). However, zircon FT dating of clinker is limited by high uncertainty for samples with ages younger than ca. 1 Ma (typically 30%–60% [2σ]). Our work uses zircon (U-Th)/He (zircon He) dating of clinker, which has the main advantage of higher precision (reproducibility of single-grain analyses is generally <10% [2σ]). The vast majority of our single-grain ages display young ages (<1–3 Ma) and reproducibility consistent with full resetting during clinker formation. Cases of incomplete

[1]GSA supplemental data item 2011193, data tables and discussion of clinker formation depths, groundwater effects, alternative landscape models, detrital double dates, and basin-wide age patterns, is available online at www.geosociety.org/pubs/ft2011.htm. You can also request a copy from *GSA Today* P.O. Box 9140, Boulder, CO 80301-9140, USA; gsatoday@geosociety.org.

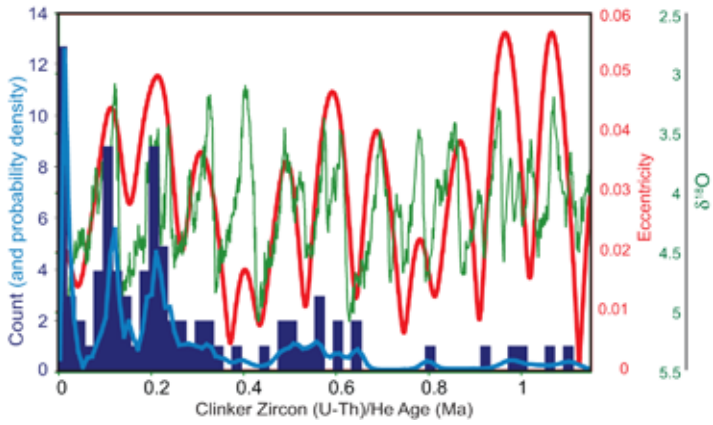

Figure 2. Histogram and probability density (blue bars and trend) of zircon He ages from 86 in-situ clinker in the Powder River Basin. Also shown are $\delta^{18}O$ of benthic foraminifera (Lisiecki and Raymo, 2005) and orbital eccentricity (Berger and Loutre, 1991) from 1.2 Ma to present. Clinker ages are clustered in peaks corresponding to the last three interglacials, two of which correspond to periods of high eccentricity (and maximum precessional variation in solar insolation).

resetting, which are sometimes observed in thin clinker units, are easily distinguished by much older and irreproducible single-grain ages. Here we present 187 zircon (U-Th)/He dates from 92 distinct clinker units throughout the Powder River Basin (Tables S1 and S2 [see footnote 1]; ages from 55 of these units were previously reported in Riihimaki et al., 2009). Other new data reported here include 106 detrital zircon U/Pb ages and 15 double-dated He-Pb ages of detrital zircons (Tables S3 and S4 [see footnote 1]), as described in the following section.

IMPLICATIONS OF CLINKER AGE DISTRIBUTIONS

Dates from 86 in-situ clinker units range from <10 ka to 1.1 Ma (Fig. 2) and show a strongly clustered distribution, similar to that observed on a smaller dataset (n = 55) by Riihimaki et al. (2009). Most ages are clustered in three distinct peaks at ca. 10, 100, and 200 ka, with subsidiary peaks ca. 300 ka and between 450–550 ka. The exact significance of the apparently strong clustering in the last three interglacial periods and the hint of 100-k.y. periodicity is not known. It may reflect a basin fluvial response to regional glacial cycles (e.g., Hancock and Anderson, 2002). But, as noted by Riihimaki et al. (2009), the age distribution is better correlated with orbital eccentricity than with $\delta^{18}O$ of benthic foraminifera or Pacific sea-surface temperatures. This is partly due to slight offsets in clinker age peaks and $\delta^{18}O$/SST maxima, but it also reflects a clear paucity of clinker ages ca. 400 ka (MIS 11), one of the largest and longest positive $\delta^{18}O$ anomalies in the past 1 Myr (Fig. 2). The ~400 k.y. gap in clinker dates may reflect exceptional climatic or glacial conditions in this region at that time or possibly a different climatic influence more directly related to eccentricity.

DETRITAL CLINKER AND PLIOCENE-PLEISTOCENE GLACIATION

In the northwestern Powder River Basin, a strath terrace forms a broad mesa ~300 m above surrounding fluvial channels and ~360 m above the nearby Yellowstone River (Fig. 1). This terrace and similar ones to the west were carved into Paleocene sandstone of the Fort Union Formation and are capped by ~2- to 20-m-thick alluvium containing detrital clinker clasts, as well as diverse lithologies, including volcanics likely derived from ranges hundreds of kilometers to the west (Colton et al., 1996). Detrital zircons in the alluvium matrix and underlying Paleocene sandstone show distinct U/Pb age spectra. Both contain 75–80 Ma zircons probably from the Idaho batholith and related rocks to the northwest. However, whereas the Paleocene sandstone shows a dominant 1.8 Ga peak, the young alluvium is distinguished by a very large Archean peak, likely from nearby Laramide ranges, as well as a significant 40–50 Ma peak, likely derived from Absarokan volcanics to the west (Table S3; Fig. S1 [see footnote 1]). Zircon Pb-He double-dating of zircons from the younger alluvium also shows that grains younger than ca. 85 Ma have indistinguishable crystallization and cooling ages, likely from volcanics or hypabyssal intrusions to the west (Fig. S1; Table S4 [see footnote 1]).

Detrital clinker in the strath-terrace alluvium yields zircon He dates ranging from 2.6 to 5.5 Ma (Table S2 [see footnote 1]). The oldest dates come from two clasts with a large date range (2.9–4.8 Ma and 4.7–5.5 Ma), consistent with partial resetting during clinker formation. The largest peak in this distribution, however, is 2.6–2.8 Ma, and two grains from one clast have indistinguishable ages of 2.65 ± 0.27 and 2.63 ± 0.19 Ma. Given that most in-place clinker in the Powder River Basin today is younger than ca. 200 ka, and assuming a similar source-to-alluvium lag time for the clinker in this deposit, we suggest that 2.6 ± 0.2 Ma is a reasonable estimate for the alluvium and strath terrace.

A variety of marine climate and ice-rafted debris records have been used to establish 2.7 Ma as the onset of major Northern Hemisphere glaciation (e.g., Prueher and Rea, 1998; Haug et al., 2005). Complementary records of continental chronologies have been hard to establish, however, partly because they have been obscured by multiple advance-retreat cycles. Thus far, the oldest recognized age for the first glacial maximum in North America is a cosmogenic burial age of 2.41 ± 0.14 Ma for a paleosol beneath a glacial till in Missouri (Balco et al., 2005). We suggest that this terrace and its capping alluvium represent outwash from one of the earliest phases of major Plio-Pleistocene alpine glaciation in the northern Rockies. The broad strath terrace and overlying thick alluvium containing far-travelled clasts are consistent with widespread lateral erosion and subsequent deposition by fluvial systems containing large quantities of sediment (as envisioned by Hancock and Anderson [2002] for younger terraces in Wyoming) derived from Absarokan glaciers, as well as nearby basinal clinker. This terrace is one of the most prominent erosional and Quaternary depositional surfaces in the region, and it appears to be correlated with others ~100 km to the west. We speculate that the earliest widespread glacial episode in a region that has not experienced prior glaciation might mobilize an extraordinarily large sediment load, producing strong lateral erosion and subsequent deposition. Downstream, the first major ice sheets may also produce the most significant changes in drainage configurations and transport capacity. Our interpretation of this terrace as the first major glaciation in the northern Rockies could be tested with further detrital geochronology, as well as cosmogenic burial dating, in this region.

IN-SITU CLINKER AND INCISION OF THE POWDER RIVER BASIN

If the detrital-clinker–bearing terrace was formed by the Yellowstone River that is now ~360 m below it, this implies a local average fluvial incision rate of 0.14 km/Myr since 2.6 Ma. This is similar to rates of 0.10–0.15 km/Myr calculated by Dethier (2001) for several Wyoming basins using the 0.64-Ma Lava Creek B ash bed. Spatial patterns of in-situ clinker dates have the potential to provide local estimates of erosion rates and relief changes over a longer time interval and over a much broader region, and are typically not minimum rates associated with deposition of dateable markers on preexisting surfaces.

Following conventional thermochronologic and cosmogenic approaches, to first order the ratio of depth and age of clinker formation is a local time-averaged erosion rate. Assuming a typical burn depth of 20–40 m provides an estimate of clinker formation depth. For formation depth of 30 m, the range of ages from 10 ka to 1.1 Ma implies time-averaged local erosion rates of 0.03–3 km/Myr. Long-term rates in any given location must be more uniform than this suggests, because maintaining these rate differences over million-year time scales would produce several kilometers of relief, much greater than the 10^2-m scale relief in the Powder River Basin. Because clinker formation itself produces relatively erosion-resistant lithologies, both erosion rates and topographic relief are likely to vary through time as clinker is produced, exhumed, and eroded away. This spatial and temporal variability in erosion should be evident in relationships between clinker age and topographic metrics.

At the broadest scale, most of the oldest in-situ clinker ages are near the periphery of the Powder River Basin (Fig. 1; Fig. S3 [see footnote 1]), reflecting the broad basinward dip of major coal beds, which are exhumed at progressively lower elevations toward the center of the basin. Young ages are common throughout the basin, however. Clinker ages do not show any discernable or statistically significant relationships with simple geomorphic indices such as local slope, elevation above sea level, or upstream drainage area. We have also examined correlations between clinker age and characteristics of each sample's nearest stream, as defined by a channel with a drainage area >100 km^2. Neither trunk-stream drainage area nor slope show significant correlations with age. In contrast, clinker ages show the best correlation with elevation above local base level (EABL), as defined by the elevation above the nearest stream segment with a >100 km^2 drainage area.

The age of clinker (τ) now at the surface is the ratio of its formation depth (Z_c) to the average rate at which it approached the surface after formation. In a landscape with changing relief, this rate depends on EABL (e.g., if relief is increasing, samples at low EABL approach the surface fastest). Here we model the relationship between τ and EABL by assuming separate rates of vertical incision (I) and lateral backwasting (L) (Fig. 3). Another rate for regionally uniform (vertical) erosion, e_b, can also be included to simulate broad erosion causing exhumation but no change in relief. A similar model, which produces similar results, involves two different rates of purely vertical erosion at channel bottom and valley rim (see discussion in GSA Supplemental Data Repository [footnote 1]). Provided that rates are constant through time, both models lead to a simple relationship between clinker age τ and its vertical position normalized to valley depth Z/Z_b, or the normalized EABL, that does not depend on either the initial morphology or absolute dimensions of the valley (Fig. 3). In all cases, τ is Z_c/I at the valley bottom and Z_c/L at the valley rim.

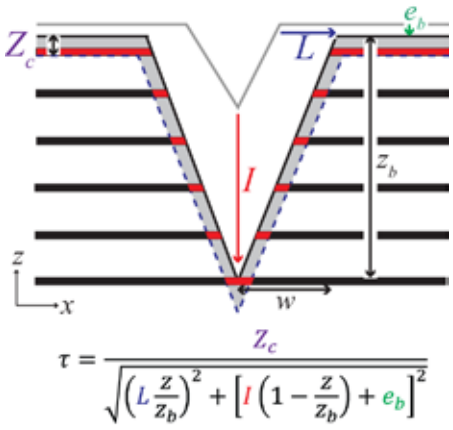

Figure 3. Model cartoon for evolution of a cross-valley profile used for predicting clinker ages, τ, as a function of elevation above local base level (Z/Z_b). L and I are rates of lateral backwasting at the valley rim, and incision at its base; e_b is the spatially uniform vertical erosion rate; Z_c is the formation depth of clinker. Black bands are unburned coal beds; red is clinker.

There are three general classes of age-EABL relationships. The first is one in which valley topography is either steady-state ($I = L = 0 \neq e_b$) or approaches a self-similar form ($I = L \neq 0$) (Fig. 4, top). If erosion rates are spatially uniform, topography is unchanged and τ is independent of EABL. Similarly, if $I = L \neq 0$, the valley grows larger and approaches a constant depth-to-width ratio. Here τ is slightly higher at intermediate elevations, because of the quadratic partitioning of erosion rates (this does not occur in the purely vertical erosion model). The second case is when $L > I$, resulting in valley widening, decreasing relief, and an inverse correlation between τ and EABL over most of the valley profile (Fig. 4, middle). The third case is when $I > L$, resulting in incision, increasing relief, and a positive correlation between τ and EABL (Fig. 4, bottom). This all assumes constant Z_c. If Z_c varies with EABL, as might be expected if groundwater exerts a stronger control than air ventilation on Z_c, low-elevation ages will be younger (see GSA Supplemental Data Repository [footnote 1]).

Figure 5 shows the actual Powder River Basin clinker ages as a function of normalized EABL. The overall distribution is most similar to model predictions for a valley profile in which incision is faster than lateral backwasting and relief is increasing (Fig. 4). The colored fields show predicted age-EABL correlations assuming clinker formation depths ranging from 20–40 m, incision rates of 0.1, 0.3, and 2 km/Myr, and a low lateral backwasting or broad-scale erosion rate (or combination of the two) of 0.025 km/Myr. Low lateral backwasting is required to explain the lack of in-situ clinker ages older than ca. 1.1 Ma. Assuming that all of the samples can be treated with a single set of regional erosion rates, the overall age distribution is similar to model predictions for a drainage network incising between 0.1 and 2 km/Myr. For clinker formation depths of 20–40 m, a model trend with I = 0.3 km/Myr provides a

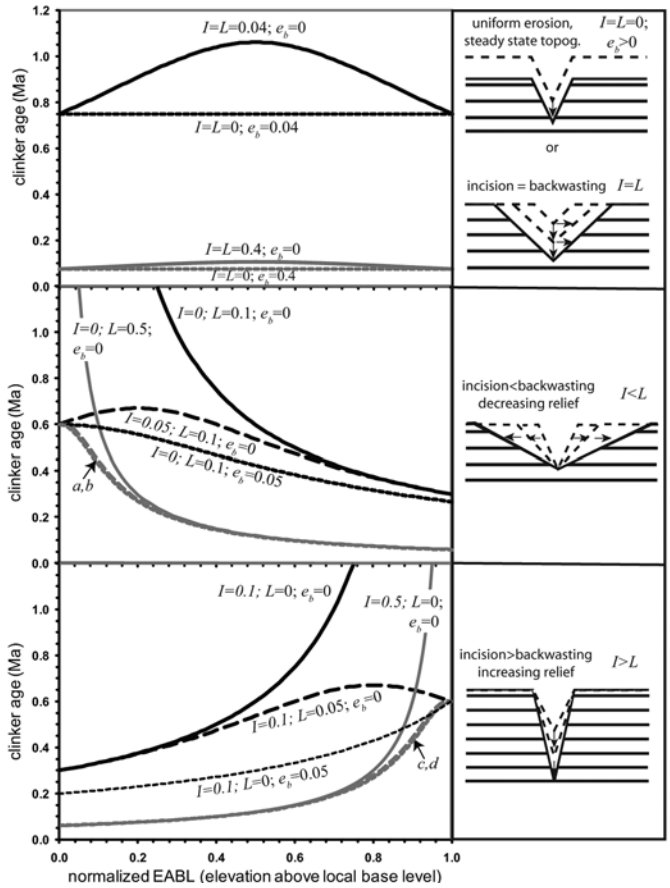

Figure 4. Relationships between clinker age τ and normalized elevation above local base level (EABL) resulting from different combinations of rates of incision, *I*, lateral backwasting, *L*, and background erosion, e_b, in the model valley profile shown in Fig. 3 and shown schematically as evolving profiles to right (horizontal black lines denote coal/clinker). All rates shown in left panel are in km/Myr; examples shown here assume clinker formation depth, Z_c, of 30 m. In all left-hand panels, zero-elevation intercept is ratio of formation depth to erosion rate at valley bottom, and unity-elevation intercept is this ratio at valley rim. Upper panels: Cases of spatially uniform vertical erosion, e_b, with zero incision, *I*, and lateral backwasting, *L* (steady-state topography), produce horizontal trends, with τ inversely proportional to e_b, whereas cases in which $I = L$ produce humped trends. Middle panels: Cases in which $I < L$, producing valley widening (decreasing topographic relief). Curve a: $I = 0.05$; $L = 0.5$; $e_b = 0$ km/Myr. Curve b (just below curve a at low EABL): $I = 0$; $L = 0.5$; $e_b = 0.05$ km/Myr. Lower panels: Cases in which $I > L$, producing valley deepening/incision (increasing topographic relief). Curve c: $I = 0.5$; $L = 0.05$; $e_b = 0$ km/Myr. Curve d (just below curve c at high EABL): $I = 0.5$; $L = 0.0$; $e_b = 0.05$ km/Myr.

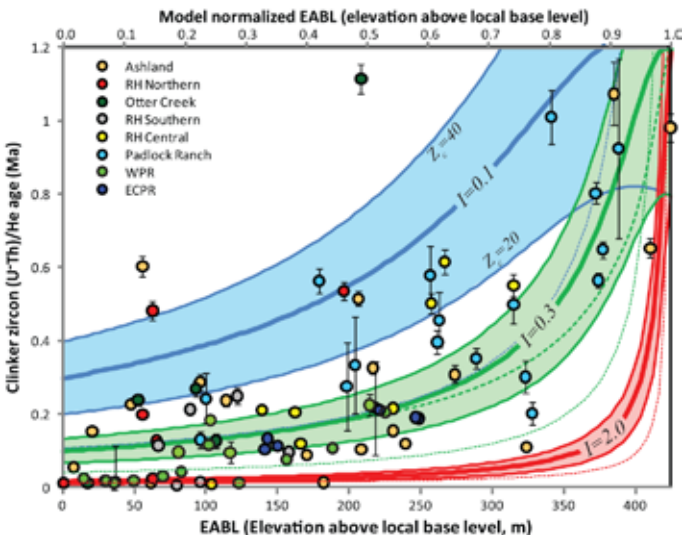

Figure 5. Zircon He ages of in-situ clinker (colored circles) as a function of elevation above local base level (EABL). Blue, green, and red fields represent incision rates of 0.1, 0.3, and 2 km/Myr, with clinker formation depths, Z_c, between 20 m (upper bounds) and 40 m (lower bounds). Bold colored lines are for clinker Z_c of 30 m. These trends assume $L = 0.025$ km/Myr and $e_b = 0$; swapping *L* and e_b rates produces insignificant changes, showing that while it is possible to constrain the rate of the dominant erosive process (incision), it is not possible to say whether the relatively small contribution to erosion that makes most clinker ages at high elevation younger than 1.1 Ma is due to lateral backwasting or more uniform broad-scale erosion. Blue, green, and red thin dashed lines represent incision rates of 0.1, 0.3, and 2.0 km/Myr, and $L = e_b = 0$ for low Z_c of 10 m. Thicker green dashed line represents predictions of alternative simpler model described in the GSA Supplemental Data Repository (see text footnote 1), with $I = 0.3$ and $R = 0.025$ km/Myr. Although no single trend reproduces all the observations, there is an overall positive correlation between age and EABL that is consistent with incision rates of ~0.1–1 km/Myr, lateral backwasting or broad-scale erosion rates <~0.025 km/Myr, and increasing topographic relief since ca. 1.1 Ma.

reasonable fit to the largest number of data. As shown by the fine dotted trends in Figure 5, if the clinker closure depth is more typically 10 m, incision rates as low as ~0.1 km/Myr may explain many of the data, as long as lateral backwasting and/or background erosion rates are nearly zero. In any case, whatever value is used for valley incision rate must be much greater than those for both lateral backwasting and background erosion. This requires increasing topographic relief.

Several points at low EABL have ~10–20 ka ages that fall below the 0.1–0.3 km/Myr model trends that explain most of the data. This may reflect more rapid incision (at rates approaching ~1–2 km/Myr) of streams relatively recently (e.g., during the current interglacial). Similarly, abundant ca. 100-ka ages between ~60 and 240 m EABL may represent rapid incision during the last interglacial. The few points with ca. 500–600-ka ages at relatively low elevations above base level, as well as the age of 1.1 Ma in the Otter Creek group, may represent locations where lateral backwasting approaches vertical incision rates.

The fact that no single set of regional erosion rates can fit all the data from the Powder River Basin likely reflects variations in local clinker formation depths, differences in local erosion rates, and the limitations of using a simplified 2-D valley-profile model with distinct and constant erosion rates to model complex and evolving 3-D topography. Nonetheless, it is clear that at the scale of large drainage basins and the Powder River Basin as a whole, topographic relief must have increased over the past ~1 Myr at rates of ~0.1–0.3 km/Myr, though this may be episodic. We also note that the basic approach taken here for interpreting changes in relief may also be appropriate for other methods of dating shallow exhumation, including cosmogenic and pedogenic dating.

Based on the difference between reconstructed basin fill and modern topography, McMillan et al. (2006) calculated as much as ~1 km of Neogene incision in the Powder River Basin,

though a more representative value over a larger area would appear to be ~0.8 km or less. At rates of ~0.3 km/Myr, 0.8 km of incision would require ~2.7 Myr, which is intriguingly similar to the 2.6 Ma age of the strath terrace that we interpret to be a result of the first major glaciation in the region, as well as the oldest in-situ clinker (2.2–2.9 Ma) found so far in the Powder River Basin (Heffern et al., 2007). Alternatively, using incision rates of ~0.1 km/Myr, consistent with a shallower estimate of clinker formation depth (Fig. 5), the longer-term average suggested by the 2.6 Ma strath terrace, and the highest regional incision rate of Dethier (2001), 0.8 km of incision would require ~8 Myr, similar to McMillan et al.'s (2006) estimate for the initiation of regional incision.

CONCLUSIONS

Most clinker in the Powder River Basin formed during one of the last three interglacial periods, which may reflect more efficient incision of low-sediment rivers during interglacials or a more direct climatic control on clinker formation, possibly associated with eccentricity. However, much older clinker is found throughout the Powder River Basin, including as detrital clasts in alluvium atop a strath terrace ~360 m above the Yellowstone River, and as in-situ units typically >~200 m above local channels. Ages of detrital clinker suggest that the strath terrace and its capping alluvium are products of one of the, if not *the*, earliest major Plio-Pleistocene alpine glaciations in the region at 2.6 ± 0.2 Ma, which overwhelmed fluvial systems with sediment from distant mountain ranges, producing widespread lateral erosion of the landscape. The overall positive correlation between ages of in-situ clinker units and their elevation above local base level (which could be extended to other types of shallow exhumation ages) can be interpreted in the context of a simple model that constrains rates of incision, lateral backwasting, and evolution of topographic relief. Assuming typical clinker formation depths of 20–40 m, our data are most consistent with average incision and relief generation rates of ~0.1–0.3 km/Myr over the past ~1 Myr.

ACKNOWLEDGMENTS

We appreciate analytical assistance from Stefan Nicolescu, Victor Valencia, and George Gehrels, and field assistance from Zoe Ruge, Camille Jones, Jessica Scheick, Kaia Davis, and Jason Whiteman. Thanks to Don Luse and staff at the Padlock Ranch for access. This work was supported by NSF grants EAR-0518818 to Reiners and EAR-0518754 to Riihimaki.

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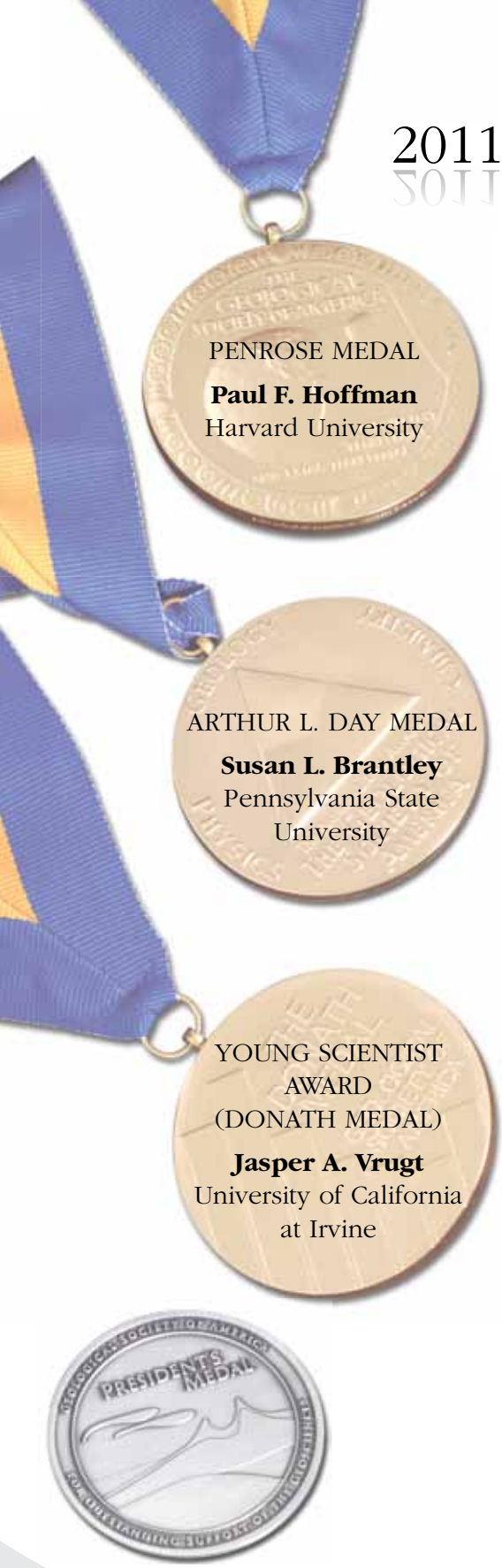
2011 MEDAL & AWARD RECIPIENTS

GSA's 2011 medals and awards will be presented at the Presidential Address & Awards Ceremony at the 2011 GSA Annual Meeting on **Sunday, 9 October,** from 6:30–8:30 p.m. at the Minneapolis Convention Center. Also, please join us for the GSA Gold Medal Lectures—the 2011 Penrose, Day, and Donath medalists are scheduled to give half hour lectures that reflect on their scientific careers. GSA's awardees will also be highlighted in the Hall of Fame in the Minneapolis Convention Center.



PENROSE MEDAL

Paul F. Hoffman
Harvard University

ARTHUR L. DAY MEDAL

Susan L. Brantley
Pennsylvania State University

YOUNG SCIENTIST AWARD (DONATH MEDAL)

Jasper A. Vrugt
University of California at Irvine

PRESIDENT'S MEDAL OF THE GEOLOGICAL SOCIETY OF AMERICA

Name to be announced

GSA PUBLIC SERVICE AWARD

Scott F. Burns
Portland State University

GSA DISTINGUISHED SERVICE AWARD

Richard C. Berg
Illinois State Geological Survey

Brendan Murphy
Saint Francis Xavier University

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

A. Wesley Ward
Western Regional Geologist, U.S. Geological Survey (retired)

AGI MEDAL IN MEMORY OF IAN CAMPBELL

Harrison Schmitt
Consultant

SUBARU OUTSTANDING WOMAN IN SCIENCE AWARD
Sponsored by Subaru of America Inc.

Naomi E. Levin
Johns Hopkins University

JOHN C. FRYE ENVIRONMENTAL GEOLOGY AWARD

Joseph P. Cook,
Ann Youberg,
Philip A. Pearthree,
Jill A. Onken,
Bryan J. MacFarlane,
David E. Haddad,
Erica R. Bigio,
and
Andrew L. Kowler

for

Mapping of Holocene River Alluvium along the San Pedro River, Aravaipa Creek, and Babocomari River, Southeastern Arizona: DM-RM-1, 6 sheets, scale: 1:24,000, 77 p. (2009).

2011 GSA DIVISION NAMED AWARDS

RIP RAPP ARCHAEOLOGICAL GEOLOGY AWARD
Archaeological Geology Division

Don G. Wyckoff
Oklahoma Museum Natural History

GILBERT H. CADY AWARD
Coal Geology Division

William A. DiMichele
Smithsonian Institution

E.B. BURWELL, JR., AWARD
Environmental and Engineering Geology Division

Lynn Highland and **Peter Bobrowsky**
for *The Landslide Handbook: A Guide to Understanding Landslides*: USGS Circular 1325 (2008).

GEORGE P. WOOLLARD AWARD
Geophysics Division

Leigh H. Royden
Massachusetts Institute of Technology

BIGGS AWARD FOR EXCELLENCE IN EARTH SCIENCE TEACHING
Geoscience Education Division

Natalie Bursztyn
Bakersfield College

MARY C. RABBITT HISTORY OF GEOLOGY AWARD
History and Philosophy of Geology Division

Sally Newcomb
Silver Springs, Maryland, USA

O.E. MEINZER AWARD
Hydrogeology Division

Graham E. Fogg
University of California at Davis

DISTINGUISHED GEOLOGIC CAREER AWARD
Mineralogy, Geochemistry, Petrology, and Volcanology Division

John M. Ferry
Johns Hopkins University

ISRAEL C. RUSSELL AWARD
Limnogeology Division

W. Berry Lyons
Ohio State University–Columbus

G.K. GILBERT AWARD
Planetary Geology Division

Steven W. Squyres
Cornell University

KIRK BRYAN AWARD
Quaternary Geology and Geomorphology Division

Robert C. Walter and **Dorothy J. Merritts**
(Franklin and Marshall University) for "Natural streams and the legacy of water-powered mills": *Science*, v. 319, p. 299–304 (2008).

LAURENCE L. SLOSS AWARD
Sedimentary Geology Division

John P. Grotzinger
California Institute of Technology

CAREER CONTRIBUTION AWARD
Structural Geology and Tectonics Division

Richard H. Sibson
University of Otago

2011 GSA FELLOWS

Society Fellowship is an honor bestowed on the best of our profession by election at the spring GSA Council meeting. GSA members are nominated by existing GSA Fellows 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's newly elected Fellows will be recognized at the 2011 GSA Annual Meeting Presidential Address & Awards Ceremony on Sunday, 9 October, at the Minneapolis Convention Center. We invite you to read some of what their nominators had to say:

Jayne C. Aubele, New Mexico Museum of Natural History and Science, "has been involved in a spectrum of research and geological education for 35 years, from early field studies of hydromagmatic vents and volcanic processes, pioneering planetary geologic research from *Viking* Mars missions to radar mapping missions to Venus, and public education about the local geology of central New Mexico." —Eric B. Grosfils

Sally Bilodeau, AECOM Technology Corporation; elected to Fellowship as the 2010 E.B. Burwell, Jr., Award recipient.

William L. Bilodeau, California Lutheran University; elected to Fellowship as the 2010 E.B. Burwel, Jr., Award recipient.

Paul Bishop, University of Glasgow, "is a recognized authority in his field; he is the authority when one asks the question, 'How and at what rate does Earth evolve in the near-surface realm?' His published work is varied, innovative, and of the highest caliber; it is original and most certainly commands international recognition." —Ellen Wohl

John R. Bowman, University of Utah, "is one of the leading researchers in applying cutting edge methods in isotope geology, petrology, and geochemistry to problems in tectonics, mineral deposits, and geothermal systems, and interactions of crustal fluids with rocks in plutonic environments. He also has a distinguished career as an educator, training graduate students who go on to work in academia, industry, and government agencies." —Ronald L. Bruhn

Gary R. Byerly, Louisiana State University, "has made significant contributions in research on the Galápagos, Barberton Greenstone Belt, meteorite impacts, and komatiites. He is widely recognized for increasing minority participation in the earth sciences and increasing science abilities of secondary school teachers. He has been a success as department chair, associate dean, and residential college rector." —Thomas A. Vogel

Xunhong Chen, University of Nebraska–Lincoln, is nominated "based on his exceptional contribution in hydrogeology of High Plains Aquifer and his outstanding scientific leadership of both field-based and theoretical research on stream-aquifer interaction." —Hongbin Zhan

Timothy H. Dixon, University of Miami; elected to Fellowship as the 2010 George P. Woollard Award recipient.

R. Laurence Davis, College of Mt. St. Joseph, is recognized for his "distinguished contributions in building the public's awareness of geology and its impacts on environmental problems; his extensive service to GSA's Geology and Public Policy Committee, Northeastern Section, and the Geology and Society Division, and his assistance to local government agencies in solving environmental problems." —Jonathan H. Goodwin

Richard J. Diecchio, George Mason University, is nominated for Fellowship in recognition of his "outstanding 30-year career of teaching and scholarship, demonstrating a commitment to geology education while engaged in program development and administration. He has provided exemplary service to GSA and SEPM as a section officer and meeting organizer." —Donald W. Neal

Margaret R. Eggers, Eggers Environmental Inc., "owns a geotechnical company specializing in third-party review, expert testimony, and litigation support. She is an editor of the *Environmental Forensics Journal* and a subject matter expert for the CA Board for Geologists and Geophysicists. She chairs the Board of Trustees of the GSA Foundation." —P. Geoffrey Feiss

Dean B. Eppler, NASA–Johnson Space Center: "For many astronauts, engineers, and NASA managers, Dean Eppler is their main contact with the geosciences and how our profession is important to manned space flight. This is a geologic education at a very senior level and qualifies Eppler to be a GSA Fellow." —Grant H. Heiken

Christopher R. Fielding, University of Nebraska–Lincoln, "has done extensive field work in Europe, Australia, North America, and Antarctica. The current president of SEPM, Fielding has authored or co-authored 130 refereed research papers, primarily on clastic sedimentology and sequence stratigraphy. Thirteen students (including 8 Ph.D.s) have completed graduate degrees under his direction." —David B. Loope

Stanley C. Finney, California State University–Long Beach: "A renowned graptolite paleontologist, Stan Finney served for many years on the Ordovician Subcommission, and recently took over as chair of its parent International Commission on Stratigraphy to which is entrusted the geological time scale. Stan is a dedicated teacher and was head of department for almost 20 years." —Brian Pratt

Raymond C. Fletcher, Pennsylvania State University, "has dedicated his professional career as a structural geologist to understanding the formation of geologic structures, including folds, gneiss domes, pressure solution seams, faults, salt sheets, and veins. In 34 peer-reviewed publications, he successfully integrated detailed field observations with rigorous theoretical analyses based on mechanics and thermodynamics." —David D. Pollard

Haakon Fossen, University of Bergen, "has contributed nearly 100 original research articles and a textbook in structural geology and tectonics. He has published fundamental work on three-dimensional strain analysis (transpression/transtension), extensional collapse, and continental rifting, and developed stress and strain theories to interpret geological structures in the brittle and ductile crust." —Christian Teyssier

Gary S. Fuis, U.S. Geological Survey: "A geologist in geophysicist's clothing, Gary Fuis has been at the forefront in the use of seismic refraction methods to study continental evolution and tectonic deformation. He has led consortia projects such as TACT, PACE, and LARSE that examined the formation of the North America Cordillera and its western margins." —David A. Okaya

Eldon Gath, Earth Consultants International; elected to Fellowship as the 2010 E.B. Burwell, Jr., Award recipient.

Monica E. Gowan, University of Canterbury, is nominated for GSA Fellow in recognition of "her long and varied record of contributions in the geosciences, including most recently her efforts to bridge the geosciences and the behavioral and health sciences, in order to improve emergency management, disaster risk reduction, and preventive health care efforts." —John W. Geissman

Darryl E. Granger, Purdue University, "is an excellent research scientist with numerous refereed publications. Promoted to full professor based on teaching and research. Specialty is geomorphology and age dating; affiliated with Purdue PRIME facility. Major professor for M.S. and Ph.D. students who completed degrees. Applied research on age dating of sediments in caves." —Terry R. West

John M. Hanchar, Memorial University, "has contributed to many facets of Earth science as a versatile geochemist-mineralogist-petrologist. He is most renowned as a world expert on accessory minerals whose pioneering work has provided a foundation for the explosion of zircon as a powerful tool in geosciences in the last 15 years." —Calvin F. Miller

Stephen S. Harlan, National Science Foundation, "is a highly productive scientist whose work in paleomagnetism and geochronology has forged new directions for tectonic studies in the InterMountain West. Steve is nominated for his broad contributions ranging from being an inspirational teacher and researcher to influencing the direction of future science at the National Science Foundation." —Lisa A. Morgan

Susan S. Hubbard, Lawrence Berkeley National Laboratory; elected to Fellowship as the 2010 Birdsall-Dreiss Distinguished Lecturer.

Neal R. Iverson, Iowa State University, "has made significant contributions to our understanding of till deformation beneath glaciers. In laboratory experiments, he and his students have shown that till behaves plastically, not viscously. He has also described the coupling of ice to a soft bed, and has carried out ground-breaking experiments in a subglacial environment." —Roger L. Hooke

Karen H. Johannesson, Tulane University, "has made numerous and important contributions in chemical hydrology. She is one the world's experts on the speciation and geochemical behavior of rare earth elements in aquatic systems. Her recent work on the groundwater geochemistry of oxyanions forming elements is of the highest quality." —William Berry Lyons

Paul Karabinos, Williams College, "has been a long-standing GSA member, an active, productive scientist and educator and has assumed leadership roles at Williams College and GSA. He is a full professor and department chair. Paul has published 38 peer-reviewed papers including those in *GSA Bulletin*, *Geology*, GSA Special Papers and GSA Memoirs." —Arthur Goldstein

Keith A. Klepeis, University of Vermont, "has undertaken significant research on the evolution of orogenic belts along convergent and transform plate boundaries at all crustal levels. He has received numerous grants and has strong support from coworkers. His service includes serving as an NSF panelist and serving as an associate editor of *Tectonics*." —Maria Luisa Crawford

Richard P. Langford, University of Texas at El Paso, "has made major contributions to sedimentary geology through studies of both modern and ancient eolian systems; a distinguished service record with GSA as an officer in the Sedimentary Geology Division; and has been faculty mentor to more than 20 graduate students in the last decade." —Terry L. Pavlis

Chongxuan Liu, Pacific Northwest National Laboratory, is nominated for Fellowship "for his outstanding contributions to understanding of the kinetics of geochemical and biogeochemical reactions, diffusive mass transfer processes, and coupled reactions and mass transfer in porous media." —Chunmiao Zheng

Christopher G. Maples, Oregon Institute of Technology: "Maples' accomplishments include extensive publication in paleontology; stints at the Kansas Geological Survey, Indiana University, the Desert Research Institute, and program director at the National Science Foundation; contributions to professional organizations (including editorship of *Palaios*), and his current position as president of the Oregon Institute of Technology." —Rex C. Buchanan

William C. McClelland, University of Iowa, is recognized as a GSA Fellow "on the basis of his outstanding contributions to understanding the origin of the Cordilleran, Franklinian, and Caledonian orogenic systems of North America and his creative integration of information from geochronology, petrology, and structural geology." —George E. Gehrels

Vicki S. McConnell, Oregon Geological Survey, "serves as the governor's advisor on geological and natural hazards. She created a tsunami hazard mitigation program, seismic evaluation of public schools and emergency facilities, and a nationally recognized LiDAR consortium. She is truly an exemplary member of our profession in the realm of geology and public policy." —James C. Cobb

Charles Gil Mull, Alaska Division of Oil and Gas (retired): "For 50 years with state and federal agencies and oil companies Charles (Gil) Mull has contributed significantly to the geology, principally tectonics, structure, stratigraphy, and hydrocarbon potential, of the Brooks Range and Arctic slope of northern Alaska as recorded in more than 100 combined publications, talks, and quadrangles mapped." —James D. Lowell

Kathleen Nicoll, University of Utah, "has a unique blend of enthusiasm, scholarship, and communication skills that is of the highest quality. Her ability to clearly communicate complex geological explanations of Quaternary geology to students and the public and her publication of cutting edge science is the reason for her nomination for GSA Fellowship." —Michael R. Rosen

Jeffrey W. Niemitz, Dickinson College, "has made distinguished contributions to geological education, both within Dickinson College's Dept. of Earth Sciences and nationally for his service as an officer and leader in the National Association of Geoscience Teachers." —Noel Potter Jr.

Francisca E. Oboh-Ikuenobe, Missouri University of Science and Technology, is elected to Fellowship "for her significant contribution in advancing research and education in paleontology, palynology, and climate change as well as her outstanding role in mentoring and supporting women geoscientists." —Mohamed G. Abdelsalam

Lewis A. Owen, University of Cincinnati, "has distinguished himself through his publications on Quaternary glacial history and landscape development in high mountains, specifically the Himalaya and Tibet, and the application of innovative techniques such as optically stimulated luminescence and cosmogenic surface exposure dating." —William C. Haneberg

Ronald Lee Parsley, Tulane University, "is a widely published and cited author of studies of fossil echinoderms. He has read conference invited papers from 1974–2008, and he has published 87 manuscripts including coauthored studies with Americans, Czechs, and Chinese. In addition, he has trained 1000 undergraduates in geology." —John Projeta Jr.

Jack C. Pashin, Alabama Geological Survey, "has made many significant contributions to the geosciences in diverse fields of coal geology, energy resources, paleontology, sedimentology, stratigraphy, structural geology, and most recently carbon sequestration. As a researcher and administrator at the Alabama Geological Survey, he has served the professional geosciences community for 29 years." —Stephen F. Greb

Carle M. Pieters, Brown University; elected to Fellowship as the 2010 G.K. Gilbert Award recipient.

Louise M. Prockter, Johns Hopkins University, "is deserving of this recognition because of her high standing in the scientific community, contributions to major spacecraft missions, the significance of her planetary geology research, her leadership of scientific teams, and her service through editorships, peer review panels, and as a GSA officer in the Planetary Geology Division." —Herbert V. Fry

Robin W. Renaut, University of Saskatchewan, "is a world-renowned researcher of saline/alkaline lakes in Africa and elsewhere as well as a key expert on the geochemistry and sedimentology of hot springs worldwide. He also is a respected educator of undergraduates and graduate students. Robin has contributed his time and energy to the publication of many books and journals in an editorial role and has worked tirelessly administrating grant programs." —Elizabeth H. Gierlowski-Kordesch

Paul T. Robinson, Dalhousie University, is recognized as a GSA Fellow "because of his impressive publication record on the petrology and geochemistry of oceanic lithosphere, his significant contributions to the DSDP/ODP for over 40 years, and his service to the Chinese scientific community and to the GSA International Division as its Chair." —Yildirim Dilek

Dana Royer, Wesleyan University; elected to Fellowship as the 2010 Young Scientist Award (Donath Medal) recipient.

Dibyendu Sarkar, Montclair State University, "has dedicated his career to the development and administration of transdisciplinary geological science educational and research programs. He is deeply committed to excellence in student mentorship, to diversifying the geosciences, and to leveraging exceptional research into meaningful training of new geoscientists." —Robyn E. Hannigan

Craig M. Schiffries, The Geological Society of America, "has been involved with increasing the public awareness of geology since 1991 when he was a GSA Congressional Fellow. He has held policy positions with AGI, National Council for Science and the Environment, and GSA. Craig has served GSA on many different committees and as a staff member." —John W. Hess

C. Scott Southworth, U.S. Geological Survey, is nominated "for major advances in unraveling the complex geology of the Blue Ridge province in the Central and Southern Appalachians

and the western Piedmont of the Central Appalachians through geologic mapping and the initiation and follow-through of collaborative studies with geochemists and geochronologists." —Douglas W. Rankin

John C. Steinmetz, Indiana Geological Survey, "has served the geologic profession for over 30 years in academia (University of South Florida), the private sector (Marathon Oil Company), and state government (Montana and Indiana Geological Surveys). He was president of the Association of American State Geologists. Nationally, he has championed geoscience data preservation." —James M. Robertson

Barton G. Stone, Pincock, Allen & Holt, "is a distinguished minerals geologist who has made significant contributions in applying geology to ore deposits. Currently the Chief Geologist of Pincock Allen & Holt, Bart draws upon vast experience in exploration and open-pit and underground mining to specialize in the evaluation of mining properties." —Jonathan G. Price

Peter J. Sugarman, New Jersey Geological Survey, "has been a leader in deciphering the Late Cretaceous to Holocene record of the New Jersey coastal plain. He developed a sequence and chronostratigraphic framework for these deposits and interpreted their hydrostratigraphic significance, showing that aquifer-confining unit relations can be predicted using sequence stratigraphy." —Kenneth G. Miller

Frederick J. Swanson, USDA Forest Service, is nominated for his "significant contributions to understanding fundamental interactions among geomorphic and ecologic processes in disturbed landscapes and for developing improved strategies for managing public lands." —Jon J. Major

Peter N. Swift, Sandia National Labs, is elected to GSA Fellowship "for his distinguished contributions to the science and program management in the area of geological repository of nuclear wastes." —Hui-Hai Liu

Roger D.K. Thomas, Franklin & Marshall College: "In addition to being a superb paleontologist and scholar, Roger Thomas has been a workhorse for professional organizations. Among many other duties he has cheerfully embraced, Roger served as Secretary of the Paleontological Society from 2003 to 2009, and he is now Secretary-General of the International Palaeontological Association." —Stephen M. Rowland

Harvey Thorleifson, Minnesota Geological Survey, "has distinguished himself as a researcher in glacial geology and mineral resources, professor of geology and geophysics, state geologist of Minnesota, officer in several professional societies in the U.S. and Canada, 2011 GSA Annual Meeting general chair, Trustee of GSA Foundation, and member of the One Geology Management Committee." —Vincent Matthews

Jeffrey D. Vervoort, Washington State University, "is nominated for his original research in geochemical evolution of the crust and mantle." —Jonathan Patchett

Colin R. Ward, University of New South Wales; elected to Fellowship as the 2010 Gilbert H. Cady Award recipient.

Philip E. Wannamaker, University of Utah and Energy & Geoscience Institute, "is a pioneer in using electromagnetic geophysical methods to understand the geochemistry, petrology, and structure of the lithosphere. In particular, his work has provided fundamental insights into the role of fluids in both active tectonic margins and extensional terranes." —V.J.S. (Tien) Grauch

Christopher F. Waythomas, U.S. Geological Survey, is elected Fellow "for his publications on debris flows, floods, debris avalanches, tsunamis, and hazards at Alaskan volcanoes, administration of the Alaska Volcano Observatory, and leadership in the IAVCEI Commission on Volcano-Ice Interactions." —Charles R. Bacon

David R. Wunsch, National Ground Water Association, "has distinguished himself by advancing the visibility of the New Hampshire Geological Survey and expanding its mission to include many geological disciplines relevant to societal issues. He has effectively advocated for the geological sciences through his leadership posts at AGI and the Association of American State Geologists." —Robert G. Marvinney

Jingsui Yang, Chinese Academy of Geological Sciences, is elected "for his seamless integration of careful fieldwork with quantitative geochemical-geochronologic analysis to solve problems of the tectonics and continental crustal evolution of central Asia." —W.G. Ernst

Robert S. Young, Western Carolina University, "has followed a distinguished career in coastal geology. His impact is especially strong in societal debate about shoreline stabilization and the societal response to sea level rise. In addition, he has interacted widely with media outlets and is involved with many panels on shoreline management." —Orrin Pilkey

Lifei Zhang, Peking University, is elected for "his finding of coesite inclusions in garnet, establishment of a new Ultrahigh-*P* Metamorphic Terrane in Western China and significant contributions in petro-tectonic evolution of both oceanic and continental subduction in northern Tibet. He is one of the young geoscience leaders in China." —Juhn G. Liou

Haibo Zou, Auburn University, "has excelled in theoretical-geochemical research, in addition to having considerable laboratory analytical skills in mass spectrometry. He has published papers on trace element modeling, significantly contributing to chemical geodynamics with mantle melting models, and has also authored an important textbook on geochemical modeling, widely used by researchers worldwide." —Asish R. Basu

2011 COLE AWARDS

The 2011 Gladys W. Cole and W. Storrs Cole Memorial Research Awards for postdoctoral research are funded by the GSA Foundation.

GLADYS W. COLE MEMORIAL RESEARCH AWARD

David W. Marchetti of Western State College has been awarded US$6,500 from the *Gladys W. Cole Fund for research in geomorphology of semiarid and arid terrains* for his project, "Reconciling cosmogenic exposure ages and U-series soil carbonate ages of gravel deposits in the Fremont River drainage basin, Utah." The award will be presented at the QG&G Awards Ceremony at the 2011 GSA Annual Meeting in Minneapolis, Minnesota, USA, in October.

W. STORRS COLE MEMORIAL RESEARCH AWARD

Atsushi Ando of the Smithsonian Institution was awarded US$6,000 from the *W. Storrs Cole Fund for research in invertebrate micropaleontology* for his project, "Revised depth-ecology model of planktonic foraminifera and new insights into mid-Cretaceous global paleoceanography." The award will be presented at the Cushman Foundation for Foraminiferal Research Awards Ceremony at the 2011 GSA Annual Meeting in Minneapolis, Minnesota, USA, in October.

KERRY KELTS Student Research Award

Application deadline: 2 August

The 2011 Kerry Kelts Student Research Award of the Limnogeology Division of GSA offers US$1,000 for undergraduate or graduate student research related to limnogeology, limnology, or paleolimnology. To apply, send a summary (**PDF**) of the proposed research, its significance, and how the award will be used (five-page max.) along with a short CV (two-page max.) to the chair of the Limnogeology Division, Daniel M. Deocampo, **deocampo@gsu.edu.** Please include your name as part of each PDF file name.

The recipient will be announced at the Limnogeology Division Business Meeting and Reception at the 2011 GSA Annual Meeting in Minneapolis, Minnesota, USA, this October.

GSA's Limnogeology Division hopes to increase the number of these awards. Your membership dues help with this and other important Division activities. If you are interested in supporting this awards program more substantially, 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.

Thanks for Your Membership!

GSA CELEBRATES NEW 50-YEAR MEMBERS FOR 2011

GSA salutes the following members and Fellows on their 50-year membership anniversaries. We appreciate their dedication and loyalty to GSA for all these years.

For a list of members who have surpassed the 50-year mark, please visit **http://rock.geosociety.org/membership/50YearMembers.asp;** the list of Fellows is at **http://rock.geosociety.org/membership/50Yearfellows.asp.**

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

Donald H. Adair*
Clarence R. Allen
Richard P. Alvord*
Patrick J. Barosh
Richard T. Bell
Milton C. Blake
John P. Bluemle
Otto H. Bohnenberger
Douglas C. Brew*
Charles Richard Burnette
Roger L. Burtner
Marvin P. Carlson
Paul R. Carlson
H. Edward Clifton
Robert G. Coleman
James W. Collinson
Robert W. Deininger
Bruce R. Doe
Robert G. Douglas
H. Stewart Edgell
Philip A. Emery
Ernest H. Ern Jr.
George M. Farlekas*
Laing Ferguson
Edward D. Fields*
John E. Frost
Robert J. Fulton Sr.
Jay O. Gallagher*
Lee C. Gerhard
Ernest H. Gilmour
David P. Gold
Richard E. Gray
David W. Greenlee*
John R. Griffin*
Lewis B. Gustafson
Donald F. Hammer*
Harry J. Hansen*
Kay C. Havenor
John W. Hawley
Edward A. Hay
B. Carter Hearn Jr.
Richard C. Hepworth*
Charles E. Herdendorf
Willis A. Holland Jr.*
David M. Hutchison*
William M. Jordan
George H. Keller
Rodney V. Kirkham
James E. Kline*
Bernard E. Leake*
John P. Lockwood
William E. Long*
D. Bradford Macurda
Louis J. Maher Jr.
John W. Mason
William G. Melson
Fred K. Miller
Michael W. Morgans
Clifford M. Nelson
James E. Noble*
Robert Q. Oaks Jr.
Donald E. Owen*
Gary L. Peterson
Thomas E. Pickett
Orrin H. Pilkey
Karl F. Pohlmann*
Peter Popenoe*
Noel Potter Jr.
George W. Putman
Mitchell W. Reynolds
Charles L. Rice*
William D. Rose Jr.
David A. Ross
Malcolm J. Rutherford*
Robert O. Rye
Anne Coates Sangree*
William D. Sevon
Charles E. Shaw
Nolan G. Shaw
Alan G. Smith
Nancy S. Stehle*
Richard C. Stenstrom
David A. Stephenson
Gordon R. Stephenson
Harold W. Sundelius
Harmon R. Taber*
John Thrailkill
Stanley M. Totten
John G. Vedder
Robert J. Weimer
Pat Wilde
Edward W. Wolfe
Lee A. Woodward
Thomas Lawton Wright*
Donald H. Zenger

2011 GSA RESEARCH GRANT RECIPIENTS

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

The 2011 GSA Committee on Research Grants awarded US$530,445 to 220 graduate students (35% of the 633 who applied), with an average grant of $2,411. The committee also selected 12 alternate candidates in the event that any grantees return all or part of their funds due to a change in their research project or receipt of funds from another source.

Committee members: Kevin M. Yeager (Chair), Diana Elder Anderson, Nan Crystal Arens, Julia A. Baldwin, David Borrok, Elizabeth Jones Crafford, Rupali Datta, Shanaka L. de Silva, Robert V. Demicco, James E. Evans, David P. Gillikin, Allen M. Gontz, V.J.S. (Tien) Grauch, Stephen S. Harlan, Antun Husinec, Oliver Korup, Jeffrey Lee, Francisca E. Oboh-Ikuenobe, Frederick K. Partey, Susannah M. Porter, Michael F. Roden, Dawn Y. Sumner, Julia Smith Wellner, and Peter D. Wilf.

Specialized awards will be presented at the 2011 GSA Annual Meeting in Minneapolis, Minnesota, USA, in October.

Outstanding Mentions

James Berglund, Missouri State University

Lauren Colwell, University of Wyoming

Angela Cota, Western Washington University

Justin Davis, University of South Carolina

Matthew Dettinger, University of Arizona

Jeff La Frenierre, Ohio State University

Anna Lindquist, University of Minnesota–Twin Cities

Daniel McInnis, University of Notre Dame

Benjamin Melosh, University of California at Santa Barbara

Theo Mlynowski, University of Northern British Columbia

John Moore, University of California at Santa Barbara

Jesse Morris, University of Utah

Jonathan Pratt, University of South Carolina

Glenn Sharman, Stanford University

Aaron Shultis, University of Nebraska–Lincoln

Alison Sloat, University of Nevada–Las Vegas

Drew Thomas, University of Missouri–Columbia

Sheldon Turner, Michigan State University

Fan Wang, Purdue University

Andrea Wolfowicz, Boise State University

The primary role of the GSA Research Grants Program is to provide partial support for master's and doctoral thesis research in the geological sciences for graduate students enrolled in universities in the United States, Canada, Mexico, and Central America. Starting in 2012, the maximum available grant will be US$2,000. The 2012 application for will be available in early December at **www.geosociety.org/grants/gradgrants.htm** and grant applications are due 1 Feb. 2012.

Specialized Awards

Sponsored by the GSA Foundation

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

Gretchen L. Blechschmidt Award

Olivia Turner, *Colorado School of Mines*

The Gretchen Louise Blechschmidt Award Fund was established for women in the geological sciences 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

Michael Badding, *University at Buffalo*

This award honors Dillon's work on radiometric age-dating in the Brooks Range, Alaska, USA. Selection of the awardee is guided by method of study, including field-based studies dealing with the structural and tectonic development of Alaska and/or studies which include some aspect of geochronology (either paleontologic or radiometric) to provide new age control for significant rock units in Alaska.

Robert K. Fahnestock Award

Jennifer Schmitz, *University of Wisconsin*

This award honors the memory of Robert Fahnestock, a 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

Mark Stelten, *University of California at Davis*

The Lipman Research Fund was established in 1993 and is supported by gifts from the Howard and Jean Lipman Foundation; the current president of the Lipman Foundation, Peter W. Lipman, was the recipient of a GSA research grant in 1965. This award promotes and supports student research grants in volcanology and petrology.

Bruce L. "Biff" Reed Scholarship Award

Kelly Ferguson, *California State University–Fullerton*

This scholarship fund was established to provide research grants to graduate students pursuing studies in the tectonic and magmatic evolution of Alaska, primarily, and can also fund other geologic research.

Alexander Sisson Research Award

Amy Dethlefs, *Alaska Pacific 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

Tyler Brown, *University of Wyoming*

Kristin Morell, *Pennsylvania State University*

Harold Stearns established this award in 1973 to support student research on aspects of the geology of the Pacific Islands and the circum-Pacific region.

John Montagne Fund

Amina Margreth, *Dalhousie University*

This fund was established in 2000 to support student research in the field of Quaternary geomorphology.

Alexander & Geraldine Wanek Fund

Joseph Giovinazzo, *Northern Arizona University*

The Wanek Fund was established in 2002 to support 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

Phoebe Chan, *University of Toronto*

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 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) changes in climate and the effects of those climate changes on Earth's inhabitants through geologic time.

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

Kristin Cooke, *University of Victoria*

This award supports field-oriented graduate student research that contributes to the understanding of the geologic processes and history of the Pacific Northwest convergent margin and/or to the evaluation of its hazard or resource potential.

Minority Award

Meredith Petrie, *University of Iowa*

The Minority Award was established to promote and support minority students in the geosciences.

Diversity in the Geosciences Minority Research Grant Awards

Two research grant submissions from minority graduate students were deemed of exceptionally high merit in conception and presentation by GSA's Diversity in the Geosciences Committee. Each recipient will be given an additional cash award of US$500.

Michael Kennedy, University of Wisconsin–Milwaukee, *for* "Testing extinction as a cause for environmental disruption at the K-Pg boundary, Montana, USA."

Jessica Watkins, University of California at Los Angeles, *for* "Emplacement mechanisms of recent Martian landslides and their geologic implications."

Farouk El-Baz Student Research Grants

These grants were established to encourage and support desert studies by students worldwide, either in their senior year of their undergraduate studies or at the masters or Ph.D. level. Each student will receive a cash award of US$2,500 at the GSA Annual Meeting in Minneapolis, Minnesota, USA, in October.

Ahmed El-Sayed Gaber, Tohoku University, *for* "Assessing the natural resources at some localities in Egypt by using the optical/microwave remote sensing and 3D GPR."

Jessica R. Norman, University of South Florida, *for* "The role of biogenic versus lithogenic carbon in pedogenic carbonate formation."

The Maurice "Ric" Terman Fund

This fund provides one-year grants to support the Ph.D. theses and post-doctoral research of East Asian scientists in Cambodia, China, Indonesia, Japan, Korea, Malaysia, Papua New Guinea, Thailand, and Vietnam. The 2011 recipient will be announced in the fall.

All 2011 GSA Research Grant Recipients

Sarah Able
Christopher Adcock
Eric Allen
George Allen
Rafael Almeida
Monica Arienzo
Karen Aydinian
Allan Bacon
Michael Badding
Andrea Balbas
Natalie Beckman
Kevin Befus
Neil Bennett
James Berglund
Tedros Berhane
Emily Beverly
Curtis Bixler
Liana Boop
Tyler Brown
Jessica Buckles
Mason Burgess
Blair Burgreen
Patrick Burns
Chris Burrows
Emily Cahoon
Keely Campbell
Robin Canavan
Jacob Carnes
Monica Carvalho
Angeline Catena
Phoebe Chan
Hilary Christensen
Adam Clark
Lauren Colwell
Kristen Cooke
Angela Cota
Erika Crespo
Joshua Cuzzone
Justin Davis
Kathryn De Rego
Rebecca Deal
William Defliese
Franklin Dekker
Meredith Dennis
Ashlee Dere
Amy Dethlefs
Matthew Dettinger
Kelly Deuerling
Robert Dietz
Ashley Dineen
Dennis Donaldson
Rocio Duchesne Onoro
Kallina Dunkle
Regan Dunn
Jordan Eamer
Laura Eastham

All 2011 GSA Research Grant Recipients, *continued*

Sara Elliott
Amy Eschberger
Kristopher Felt
Kelly Ferguson
Kelsey Feser
Erin Fitch
Justin Fitch
Frank Forcino
Ryan Frazer
Elizabeth Freedman
Isis Fukai
Sean Gallen
Joshua Garber
Pablo Garcia Del Real
Joseph Giovinazzo
Eva Gladish
Michael Griffin
Kyle Grimsley
Stephanie Grocke
Julie Gross
Victor Guevara
Kellen Gunderson
Jeffre Hamlin
Emily Hammer
Ryan Haupt
Mark Hausner
Dawn Hayes
Brendan Headd
Andi Heard
Breanna Hennessy
Justin Herbert
Eric Hoffnagle
Eliya Hogan
Benjamin Hook
Johanna Hoyt
Ben Hutchins
Yadira Ibarra
Alex Ireland
Samuel Johnstone
Faith Justus
Sarah Keenan
Samuel Kelley
James Kessler
Subodha Khanal
Susan Kilgore
Yuri Kimura
Meghan King
Michael King
Katherine Knierim
Kory Konsoer
Alexandros Konstantinou
Jeff La Frenierre
Ethan Lake
Nicholas Legg
Carolyn Levitt
Anna Lindquist
Agathe Lisé-Pronovost
Joshua Lively
Rebecca Lloyd
Colleen Long
Jason Luke
Yini Ma
Jonathan Malzone
Agnieszka Marchlewska
Tomasz Marchlewski
Annina Margreth
Linda Martin
Jessica Matthews
Daniel McInnis
Sharon McMullen
Benjamin Melosh
John Metzger
Craig Millard
Brendan Miller
Theo Mlynowski
Seul Gi Moon
John Moore
Kristin Morell
Jesse Morris
Keith Morrison
Katherine Mouzakis
Erin Murphy
Kendra Murray
Carl Nagy
Laura Neser
Michelle Newcomer
Beth Novak
Kenneth O'Donnell
Jonathan Obrist
Zachery Oestreicher
Lindsay Olinde
Diana Ortega-Ariza
Todd Parr
Randall Paylor
Nathaniel Pepe
Mauricio Perillo
Meredith Petrie
Michael Pickell
Noah Planavsky
Mitchell Prante
Jonathan Pratt
Philip Prince
Ian Putnam
Brian Rankin
Sean Regan
Christopher Reinhard
Roxanne Renedo
Jason Ricketts
Wendy Robertson
Rebecca Rodriguez
Joshua Rosera
Ashley Russell
Kimberly Samuels
Eugenio Santillan
Jennifer Schmitz
Zachary Seligman
Christopher Seminack
Glenn Sharman
Lauren Sherson
Aaron Shultis
Maija Sipola
Alison Sloat
Martin Smith
Jacob Smokovitz
James Smotherman
Kristin Sorota
Trisha Spanbauer
Andrew Sparks
Christopher Spencer
Arron Steiner
Mark Stelten
Melanie Stine
Philip Stokes
Stephanie Stotts
Sarah Strano
Daniel Sturgis
Jonathon Syrek
Kenneth Takagi
Lidya Tarhan
Allison Teletzke
Mussie Tewelde
Drew Thomas
Brian Tillquist
Scott Tipple
Rebecca Tortorello
Tabitha Trosper
Olivia Turner
Sheldon Turner
Marc Vankeuren
Heather Veasey
Nicholas Venti
Laura Vietti
Ross Waldrip
Fan Wang
Meghan Weaver
Heather Weismiller
James Wilson
Ian Winkelstern
Julia Wise
Andrea Wolfowicz
Terry Workman
Peter Zamora
Xavier Zapata-Rios
Jennifer Zyczynski

2011 Alternates

Jessica Errico
William Jacobson
Philip Kenroy
Yanbin Lu
Conor McKinley
Zach Mergenthal
Claude Morissette
Jeffrey Oalmann
Christopher Pantano
Megan Pickard
Eric Prokocki
Ryan Quinn

2011 SUBARU MINORITY STUDENT SCHOLARSHIP RECIPIENTS

Subaru of America, Inc., in partnership with the GSA Foundation, has generously funded a scholarship program to benefit minority undergraduates considering a degree in the geosciences. The Subaru Minority Student Scholarship Program provides US$1,500 to one student in each of GSA's six North American regional Sections and to one student in a low-income country from GSA's International Section (nominated by a GSA Campus Representative). The student also receives free registration to attend the GSA Annual Meeting and a one-year complimentary membership in GSA.

The purpose of this scholarship is to encourage minority students to continue studies in the geosciences as a degree choice. Nomination forms for the 2012 program will be e-mailed to GSA Campus Reps later this year. *Questions?* Contact Diane Lorenz-Olsen, awards@geosociety.org.

Christine Chesley, University of Miami (Southeastern Section)*

Lisa Kant, University of Puget Sound (Cordilleran Section)

Jena Long, Miami University (North-Central Section)

Ethan John Rice, Colorado State University (Rocky Mountain Section)

Sriparna Saha, Jadavopur University (International Section)

Natalie Sievers, University of Maryland (Southeastern Section)

Sabrina Tucker, Kent State University (Northeastern Section)

*No nominations were received from the South-Central Section. As a result, the second highest rated student from all Sections was selected to receive this scholarship.

2011 GSA DIVISION & SECTION STUDENT RESEARCH AWARDS

Six GSA Divisions and three GSA Sections have recognized the following graduate student research grant recipients proposals of exceptionally high merit in conception and presentation in their fields. These students will be honored at the 2011 GSA Annual Meeting in Minneapolis, Minnesota, USA, in October.

DIVISIONS

GEOPHYSICS

Allan V. Cox Student Research Grant
Drew Thomas, University of Missouri–Columbia
Geophysics Student Research Grant Award
James A. Wilson, University of South Florida

HYDROGEOLOGY

Hydrogeology Division Student Research Grant Awards
Mark Hausner, University of Nevada–Reno
Colleen Long, University of North Carolina–Chapel Hill
Daniel McInnis, University of Notre Dame
Peter Zamora, University of Texas at Austin

MINERALOGY, GEOCHEMISTRY, PETROLOGY, AND VOLCANOLOGY

MGPV Division Student Research Grant Awards
William F. Defliese, University of Michigan
Stephanie B. Grocke, Oregon State University

QUATERNARY GEOLOGY AND GEOMORPHOLOGY

J. Hoover Mackin Student Research Award
Linda Martin, Rutgers University
J. Hoover Mackin Student Research Award Honorary Mention
Jessica Zinger, University of Illinois Urbana–Champaign
Arthur D. Howard Student Research Award
Philip Prince, Virginia Tech
Arthur D. Howard Student Research Award Honorary Mention
John Gartner, Dartmouth College
Marie Morisawa Student Research Award
Kristen Cooke, *University of Victoria*
Marie Morisawa Student Research Award Honorary Mention
Jessica Zinger, University of Illinois Urbana–Champaign

SEDIMENTARY GEOLOGY

Sedimentary Geology Division Student Research Grant Award
Theo Mlynowski, University of Northern British Columbia

STRUCTURAL GEOLOGY AND TECTONICS

Structural Geology and Tectonics Division Student Research Grant Awards
Benjamin Melosh, McGill University
Kristin Morell, Pennsylvania State University
Meredith Petrie, University of Iowa
Jonanthan Pratt, University of South Carolina

SECTIONS

SOUTHEASTERN

Md. Iftekhar Alam, Auburn University
Nikolaos Apsilidis, Virginia Tech
Lori Babcock, University of Georgia
Edwin Cadena, North Carolina State University
Kristin Dorfler, Virginia Tech
Robert W. Hunter, University of Tennessee
Louis Infante, Mississippi State University
Jessica R. Norman, University of South Florida
Catherine Skees, University of Kentucky

NORTHEASTERN

Alexandria Brannick, Lafayette College
Brian Butts, SUNY Potsdam
Erin Donaghy, Bucknell University
Jared Lefkowitz, Wesleyan University
Sidney Mattocks, Mount Holyoke College
Lily Pfeifer, Bucknell University
Amber Scoufos, University of Rhode Island
Leah Toms, Pennsylvania State University

NORTH-CENTRAL

Ryan Bleess, Minnesota State University at Mankato
Cathrine Botzum, University of Wisconsin–Whitewater
Ian Freeman, University of Wisconsin–Eau Claire
Nicholas John Heim, Winona State University
Kiel Jenkin, Winona State University
Kase Knochenhauer, Grand Valley State University
Kendra Lynn, Winona State University
Joel Main, The Ohio State University
Candice Phillips, University of Wisconsin–Oshkosh
Andrew Simmons, Winona State University
Cody Wendt, Winona State University

GSA/EXXONMOBIL FIELD CAMP AWARD RECIPIENTS

GSA/ExxonMobil Field Camp Excellence Award

This award recognizes one geology field camp based on safety awareness, diversity, and technical excellence. The following field camp leader has been awarded $10,000 to assist with his summer field camp.

John P. Hogan, Missouri University of Science and Technology

GSA/ExxonMobil Field Camp Scholars Award

This award funds summer field camp attendance for the following 12 undergraduate students, who will receive US$2,000 each, based on diversity, economic/financial need, and merit, to attend the field camp of their choice.

Michelle Aigner, Arizona State University

Daniel Ashe, University of Memphis

Shan Bi, Missouri University of Science and Technology

Assonman Degny, Mississippi State University

Megan Drinnan, Sacramento State University

Calista Guthrie, Mississippi State University

Kimmaree Horvath, University of Akron

Christopher Keefe, State University of New York–College at Oneonta

Heather Krivos, Kent State University

Jena Long, Miami University

Alexander Rytel, Ohio State University

Junzhe Sun, Missouri University of Science and Technology

THE GEOLOGICAL SOCIETY OF AMERICA®

ExxonMobil

GSA/ExxonMobil Bighorn Basin Field Award

The following students and faculty will receive scholarships to participate in the third annual GSA ExxonMobil Field Seminar in the Bighorn Basin of north-central Wyoming, which emphasizes multidisciplinary integrated basin analysis.

UNDERGRADUATE STUDENTS

Hehewutei Amakali, Appalachian State University

Carolyn Ball, University of Florida

James Carrigan, University of Massachusetts

Adam Davis, Grand Valley State University

Erin Donaghy, Bucknell University

Tawnya Hildabrand, California State University–Long Beach

Erik Munson, Illinois State University

John Murphy, St. Lawrence University

Jesse Pisel, Western State College of Colorado

Carson Richardson, Ball State University

Monica Rolls, Smith College

Harry Rudo, Bucknell University

Lily Seidman, Smith College

Heather Strickland, California State University–Long Beach

Alexandre Turner, University of North Carolina–Chapel Hill

GRADUATE STUDENTS

Ayrat Abdullin, Colorado State University

Dustin Cote, University of Rochester

Elizabeth Denis, Pennsylvania State University

Justin Fitch, The University of Texas at Austin

Bryan Hunt, The University of Alabama

PROFESSORS

Martin Acaster, Portland Community College

Richard Behl, University of California at Santa Cruz

Prajukti Bhattacharyya, University of Wisconsin–Whitewater

Brian Currie, Miami University

Daniel Eastmond, Mira Costa College

GSA Foundation Update

Donna L. Russell, *Director of Operations*

New Foundation Fund Established

The GSA Foundation is pleased to announce the establishment of the **David M. Diodato Hydrogeology Student Travel and Beer Fund.** David Diodato has created this fund to provide hydrogeology students with travel grants to attend GSA's annual meetings, to afford student memberships, and for beer for the annual Hydrogeology Division student reception. The GSA Foundation will manage the fund in order to carry forward Diodato's legacy of selfless service to student and professional members of GSA's Hydrogeology Division.

As a hydrogeologist, Diodato has focused his work on the qualitative and quantitative analysis of hydrogeological and engineered geologic systems, including field and computational approaches to evaluating groundwater resources; the use of probabilistic risk assessment in decision making and public policy; and the communication of complex scientific and technical issues to non-technical audiences. He has also served as senior professional staff for the U.S. Nuclear Waste Technical Review Board, a federal agency that performs independent scientific and technical oversight for the U.S. Congress Dept. of Energy programs that manage and dispose of high-level nuclear waste and spent nuclear fuel. In 2009, he was appointed senior sustainability officer for the board and is responsible for supporting an executive order to reduce U.S. government greenhouse gas emissions.

A GSA Fellow since 2006 and former chair of the GSA Geology and Public Policy Committee, Diodato is a 2011 recipient of the Hydrogeology Division's Distinguished Service Award.

You can contribute to the David M. Diodato Hydrogeology Student Travel and Beer Fund by writing "Diodato fund" on the coupon below and returning it with your check, payable to the GSA Foundation, to P.O. Box 9140, Boulder, CO 80301-9140, USA. For further information, go to **www.gsafweb.org/funds/diodato-fund.html.**

GSA Research Grants—International Program

GSA has initiated a non–North American-based Graduate Student Research Grants Program to include GSA's international student members. We are asking for your help with the funding of this exciting new program.

The current North American Program is one of the largest and most prestigious funding programs for geoscience graduate students in this arena. The Program helps fund field and laboratory costs of geoscience projects conducted by masters and doctoral students at universities in the United States, Canada, Mexico, and Central America. Since its inception in 1933, GSA has awarded over US$11.6 million to nearly 10,000 students. This program is an essential element in supporting the education and training of future geoscientists, while instilling in our student members a sense of loyalty to the Society.

In order to support this program, we need your help. You can contribute in one of two ways: (1) note it on the coupon below and return it with your check, payable to the GSA Foundation, to P.O. Box 9140, Boulder, CO 80301-9140, USA; or (2) go to gsafweb.org and click on the "Make a Donation" tab. Follow the directions and select "GSA Research Grants—International Program" from the pull-down menu. The GSA Foundation thanks you in advance for your interest in growing GSA's support for student research.

Donate Today!

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Welcome New GSA Members

The following individuals submitted their applications for GSA membership between October 2010 and January 2011 and were approved by GSA Council at its April 2011 meeting.

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Syed Ajaz Ahmad
Girma Abiyu Alemu
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Alvin D. Anderson
Jack Banttari
William N. Barbat
Gwendolyn D. Bart
Travis Bauer
Heather D. Bays
Stefani Jade Bennett
Timothy Best
John C. Bird
Timothy Donald Bird
David T. Blewett
Everton M. Bongiolo
Karen R. Brantl
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Curt Burbach
Wm John Camier
Karen Lyn Canter
Samantha Caputi
Drew Ryan Carlock
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Brian D.E. Chatterton
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Gregory Houseman
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Ahmad Jahangiri
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Charlie Johlgren
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Roberta M. Johnson
Ebenlyns M. Jones
Rasha Mohamed Kamal
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Sujay Kaushal
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Pallab Chatterjee
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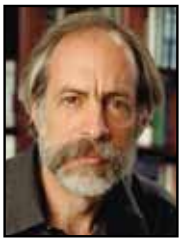

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Tectonic Crossroads:

Evolving Orogens of Eurasia–Africa–Arabia

Ankara, Turkey • 4–8 October 2010

The October 2010 "Tectonic Crossroads: Evolving Orogens of Eurasia-Africa-Arabia" meeting, a collaboration of the Geological Society of America, the Chamber of Geological Engineers of Turkey, and the Turkish Association of Petroleum Geologists, was hosted by Middle East Technical University (METU) in their magnificent Cultural and Convention Centre. The meeting's co-conveners, whose efforts were appreciated by all in attendance, were Yildirim Dilek of Miami University and Erdin Bozkurt of METU.

This global meeting was the first sponsored by GSA's new International Section. Nearly 400 geoscientists from more than 30 countries presented 180 talks and 100 posters divided into 50 sessions. The participants included ~150 students.

The purpose of the meeting was to provide a forum for earth scientists to exchange and discuss their recent research on crustal structure, mantle dynamics, and landscape evolution of active orogens around the world with a focus on the recent interactions between the African, Arabian, and Eurasian plates. Morning and afternoon sessions on Mon.–Tues., 4–5 Oct., and Thurs.–Fri., 7–8 Oct., were led off by invited keynote lecturers who provided state-of-the-art global perspectives on the topics related to the main themes of the meeting. These were followed by three or four smaller concurrent sessions of contributed talks. Each day, new poster sessions were established; time after the talks was devoted to viewing and discussion with authors present. Lunch hours were scenes of fine dining, with a wide variety of traditional Turkish cuisine. A celebratory dinner on Thursday evening was held in the convention center and featured Turkish music.

Monday sessions focused on landscapes and climate, ophiolites and blueschists, and strike-slip and transform tectonics. Tuesday sessions focused on crustal motions and mantle dynamics, magmatism in orogenic belts, and mélange-forming processes. Thursday sessions focused on Aegean geodynamics, paleomagnetics, the seismology and archaeoseismology of the Mediterranean region, collisional orogenies, and petroleum geology. Friday sessions focused on modern accretionary wedges and ancient analogues, with third and fourth sessions on ophiolites, blueschists, collisional orogeny, and mélange-forming processes.

Field trips were major highlights of the meeting. Two pre-meeting trips featured the active faulting of western Anatolia and blueschists and ophiolites of northwest Anatolia. Two postmeeting trips featured the Ankara mélange and the Cappadocian volcanic province. On Wednesday, nearly all attendees went on field trips to geological and historical sites near Ankara. This mid-meeting excursion ensured that all international attendees had the opportunity to see some of the wonders of Turkey.

At the request of the Turkish Association of Petroleum Geologists, GSA sponsored the travel of two distinguished scientists to the meeting: Terry Engelder, who gave a keynote presentation on the Devonian-Mississippian black shales of the Appalachian Basin as a model for global exploration for shale gas; and Mark Rowan, who gave a keynote presentation on fold-and-thrust belts detached on salt.

The meeting was a great scientific success. A broad cross section of geoscientists from around the world made presentations that contrasted regional geology and processes with local experts working in this extraordinarily active region—so active that it is one of the world's great natural geological laboratories. Conference participants not only learned about and directly examined the geology of the Turkey, but they and their guests enjoyed the vibrant culture of Ankara.

All participants thank co-conveners Dilek and Bozkurt for their time and hard work to make the meeting so successful. Jack Hess, Melissa Cummiskey, and the rest of the staff at GSA Headquarters are thanked for their work to make this first meeting of the new GSA International Section a benchmark event. The geoscience students of METU expertly assisted in registration and posters organization and provided professional service in running the computers and projectors in the session and speaker ready rooms. Dunder Caglan, president of the Chamber of Geological Engineers of Turkey, and Ismail Bahtiyar, chairman of the Turkish Association of Petroleum Geologists, are thanked for their endorsement and sponsorship of this meeting—a meeting so exceptional that the fond remembrances will ensure most participants will return to Turkey for geology and tourism. We all look forward to the next great international collaboration.

Mark Cloos, *GSA International Section Secretary*




Photos by Yildirim Dilek.

Penrose Conference Report

Neotectonics of arc-continent collision

Manizales, Colombia • 17–21 January 2011

CONVENERS

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INTRODUCTION

Collisions of arcs with continents are some of the most significant tectonic processes on Earth, leading to crustal accretion, continental growth, formation of sedimentary basins, large areas of regional uplift and deformation, complex interactions between continuous and torn subducted slabs and the surrounding mantle, and large regions of large earthquakes and seismic, volcanic, and landslide hazards that can threaten the lives of millions.

The objective of this conference was to bring together an international group of scientists to discuss the neotectonics and seismic hazards of shallow slab subduction in areas of arc-continent collisions. Important questions included the following:

1. How do the plate tectonic settings and crustal structures of ongoing arc-continent collisions in different parts of the world (e.g., Taiwan, Papua New Guinea, Japan, Kamchatka, Italy, Alaska) control the pattern of surface deformation and the geometry of shallowly subducted slabs? Are plate-driving forces the main control on the regional deformation patterns or do mantle forces acting on subducted or broken off slabs also play a role?
2. How do arc collision and shallow subduction generate anomalously broad crustal zones of deformation as seen in areas like the Andes, Taiwan, the Banda arc, and the Himalayas? Are these broad zones of crustal deformation "thin-skinned" and deforming on shallow detachments with large amounts of shortening or "thick-skinned" and rooted on older fault surfaces and reactivated rifts?
3. The process of vertically detaching slabs or "slab breakoff" and torn slabs shown by areas of strong slab dip change is common to many areas of arc-continent collision and shallow subduction, yet the tectonic mechanisms and timing of this process are not well understood. How have recent advances in seismology, tomography, and geodynamic modeling improved our imaging and understanding of slab subduction and breakoff, and how do these observed breakoffs affect the pattern of observed earthquakes and slab-related volcanism?
4. Is coupling of the subducted slab and arc in arc-collision zones any greater than that observed along non-collisional subduction boundaries and therefore linked to higher levels of larger and more destructive earthquakes? How can this improved level of academic understanding of arc collision and shallow subduction at all levels in the crust and upper mantle help improve maps of seismic hazard and be communicated to the public living in broad plate boundary zones?
5. How can this tectonic and geologic data be used to better inform policy makers and planners about the potential seismic, volcanic, and landslide hazards of those inhabitants living in arc-continental collisional zones?

VENUE

The Cordillera Central of Colombia, 130 km to the west of Bogotá, was chosen as the meeting venue because it is the setting for many of the tectonic, volcanic, and sedimentary processes related to arc-continent collision discussed at the meeting. From the late Cretaceous to Miocene, accretion of arcs and oceanic plateaus has shaped the active margin. Since the middle Miocene (ca. 12 Ma), the Panama arc has been colliding with the continental margin of the northwestern South American plate and has superimposed earlier tectonic events. This cumulative tectonic history has produced many features illustrative of the conference themes: (1) formation of the widest area of the Andean mountain chain (500 km) over its entire >8000-km length from Colombia to Tierra del Fuego; (2) shallow subduction of the Caribbean slab beneath the northern Andes with active slab tears defining distinct slabs seen with tomographic studies and "breakoff" occurring along the downdip edge of the slab; (3) large, historic earthquakes produced by strong coupling at the shallow subduction interface; and (4) thick Miocene to present sedimentary basins that provide a record of structural events.

Manizales was also an ideal location for the meeting because of its location near the major transverse Caldas slab tear separating a steeper dipping Nazca slab in southern Colombia from a more shallowly dipping slab beneath northern Colombia.

The alpine setting, interesting geology, active tectonics, and many interesting interactions all made for a stimulating meeting. We greatly appreciate the financial support of Ecopetrol-ICP for making this meeting possible.

Presentations and Field Trips

The five-day Penrose meeting, the first meeting of its type to be held in Colombia, was divided into five parts. Paul Mann

opened the meeting with an overview of the deformational and rotational effects produced by colliding arcs and buoyant ridges as compiled in a summary of geologic and GPS effects by Wallace et al. (G3, v. 10, May 2009).

The morning talk session focused on the crustal response to arc-continent and buoyant ridge collision that included descriptions of different active collisional zones found along the length of the Andes, using geologic and thermochronologic studies of basement rocks and overlying basins (Victor Ramos, Richard Spikings, German Bayona, Joel Saylor, Mauricio Parra); the Banda arc, using a combination of GPS and geologic studies (Ron Harris); and Taiwan, using a combination of earthquake studies and deep geophysical profiling (Wu-Cheng Chi).

In the case of the Banda arc and Taiwan, there is no question about the driver of collision, because the colliding block is well defined. However, the subsurface geometry of the subducted slabs within the collisional zone is less clear due to the limits of imaging to depths of 50–100 km using reflection and refraction methods. One issue is the fate of the forearc basin during the collisional process. In the Andes, the relative importance of colliding ridges is less obvious, and there was much discussion about the relative effects of the various ridges on the Andes themselves.

The afternoon talk session focused on lithospheric responses to arc-continent collision and included talks on the possible causes of flat-slab subduction, including its impact on plate coupling and great earthquakes along the length of the Andes (Marc-Andre Gutscher); deep crustal imaging of the Taiwan arc-continent collision, including recent tomographic data (Kirk McIntosh); the application of deep seismic imaging to the Himalayas from a passive geophysical experiment (Anne Sheehan); tomographic methods from the BOLIVAR study applied to the southern Caribbean and northern Andes (Gary Pavlis, Alan Levander, Carlos Vargas); and stratigraphic effects in the northern Andes of collision (Hermann Duque-Caro). The afternoon session was followed by presentation of 15 posters on the crustal and lithospheric responses mainly in the northern Andes.

Tuesday was an all-day field trip to Nevado del Ruiz volcano, led by Carlos Borrero, that combined outcrop stops of volcanic rocks up the flank of the 5300-m-high snow and glacially capped volcano. A highlight was Borrero's investigation of post-glacial stratigraphy of interbedded paleosols and tephra deposits that document ~11 minor eruptive events in the past 11,000 years. The group visited the headwaters of a massive lahar (mud and debris flows) that buried the downstream town of Armero and caused an estimated 23,000 deaths on 13 Nov. 1985. Discussions included how to better protect the surrounding towns from future eruption-related floods and the volcano's tectonic setting near the northern projection of the Caldas slab tear, which is proposed to separate the steeper dipping Nazca plate to the south from the more shallowly dipping Panama arc indentor to the north.

Talks on Wednesday addressed the measurement and modeling of fault motions, paleoseismology, and determination of seismic risk in areas of arc-continent collision and shallow subduction. Serge Lallemand began the session with a discussion of active tectonics and seismic risk in Taiwan using a combination of reflection and refraction data with earthquake data. These data suggest that the slab is being torn in the collisional area beneath Taiwan. Ross Stein provided an overview of the utility of Coulomb stress models for understanding the large 2010 Haiti and Chile events. Hector Mora summarized his work with James Kellogg on the 20-year-long CASA GPS study of the northern Andes and more recent permanent GPS receiver installation toward a denser GPS array. Tom Rockwell discussed the deformation of Panama as a consequence of its collision with northern South America using both paleoseismologic and GPS data. Hans Diederix summarized the state of paleoseismologic work on Holocene fault scarps in Colombia. Franck Audemard summarized GPS and paleoseismologic data for the northward motion of the Maracaibo block that includes faults in both Venezuela and Colombia. This refined work indicates ca. 5 Ma inception of right lateral slip on the Bocono system responsible for ~30 km of cumulative displacement. Carlos Costa introduced a perspective from the southern Andes in Argentina and Chile on the distribution and style of late Quaternary faults and folds in that area. Sergio Lopez and Cristina Dimate summarized earthquake and GPS data for Colombia showing evidence for strain partitioning, and Omar Cardona described the CAPRA (Central American Probabilistic Risk Assessment) plan for probabilistic risk assessment in Colombia and other parts of the world. Afternoon talks included a session on volcanism in the arc-continent collisional zone of Panama (Camillo Montes, David Farris) and Colombia (Maria Luisa Monsalve, Carlos Borrero). Seven afternoon posters addressed issues of active deformation and volcanism in Colombia.

The field trip on Thursday, led by Alvaro Nivia, Carlos Vargas, and Andreas Kammer, provided a regional structural transect from Manizales in the Cordillera Central to the Cordillera Oriental of western Colombia, which is adjacent to the modern Colombian trench. The main features examined included highly deformed rocks along the broad zone of the Romeral fault zone—the suture between oceanic rocks and continental rocks of South America. We discussed the active versus ancient origin of prominent topographic basins in western Colombia, such as the Cauca, given their setting in the zone of convergence of the impinging Panama arc. Our final stop was near the town of Salento to observe tectonic geomorphology suggestive of Holocene faulting. The group agreed that much work remains to be done on mapping of Holocene faults and tectonic geomorphology in Colombia.

Discussion Theme 1: Global plate tectonic setting and crustal structures; group leaders: Marc-Andre Gutscher and Ron Harris. This group compiled a list of all arc-continent collisions and attempted to show which processes are shared and which processes appear unique.

Discussion Theme 2: Deformation zones associated with arc collision and shallow slab subduction; group leaders: Paul Mann and Victor Ramos. This group compiled a list of arc-continent collisions around the world and used information from the Thursday field trip to construct a regional cross section from the colliding Panama arc to the meeting venue

in Manizales, Colombia. A broad consensus emerged on the nature of the belts within the collisional zone and their tectonic origins.

Discussion Theme 3: Imaging and modeling slab tears in arc-collisional areas; group leaders: Carlos Vargas and Anne Sheehan. This group attempted to better define the terms *slab breakoff* and *slab tear* and to identify specific examples of each feature. Geophysical field experiments for determining breakoffs and tears were also summarized.

Discussion Theme 4: Geohazards assessment in regions of arc-continent collision; group leaders: Ross Stein and Omar Cardona. This group outlined three main strategies for improving the next generation of seismic hazard maps in Colombia: (1) use GPS and paleoseismology to better define fault slip rates; (2) focus on faults that are closer to large urban areas like Bogota; and (3) improve understanding of seismic sources using magnitudes, b-values, and recurrence intervals. The CAPRA and GEM (Global Earthquake Model) programs are the first step in developing standards for fault compilations and training and to gain visibility on an international scale.

Participants: Tricia Alvarez, Mónica Arcilla, Franck Audemard, German Bayona, Gabriel Bernal, Rocio Bernal-Olaya, Carlos Borrero, Andrex Calle, Henry Campos, Alexandar Caneva, Omar Cardona, Fabio Cediel, John Ceron, Wu Cheng Chi, German Chicangana, Martin Cortes, Carlos Costa, Ruth Costley, Hans Diederix, Yildrim Dilek, Christina Dimate, Herman Duque-Caro, Juan Sebastian Echeverri, David Farris, Christian Gonzalez, Marc-Andre Gutscher, Ron Harris, Andreas Kammer, Suzanne Kay, Serge Lallemend, Alan Levander, Sergio Lopez, Paul Mann, Carlos Marcillo Jaramillo, Mabel Marulanda, Kirk McIntosh, Carlos Molindres, Gasper Monsalve, Hugo Monsalve, Maria Luisa Monsalve, Camillo Montes, Hector Mora-Paez, Freddy Nino, Alvaro Nivia, German Ojeda, Mauricio Parra, Gary Pavlis, Maria Prieto, Victor Ramos, Andres Reyes Harker, Tom Rockwell, Geovanni Romero, Mario Salgada, Joel Saylor, Anne Sheehan, Richard Spikings, Ross Stein, Javier Tamara, Mike Taylor, Roelant Van der Lelij, Carlos Vargas, Gabriel Veloza, and Caroline Whitehill.

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FIELD FORUM REPORT

Structure and Neotectonic Evolution of Northern Owens Valley and the Volcanic Tableland, California

13–19 September 2009 • Bishop, California, USA

CONVENERS:

David A. Ferrill, *Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78238-5166, USA, dferrill@swri.org*

Alan P. Morris, *Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78238-5166, USA, amorris@swri.org*

Nancye H. Dawers, *Tulane University, New Orleans, Louisiana 70118, USA, ndawers@tulane.edu*

This GSA Field Forum was held in Bishop, California, and the surrounding regions of northern Owens Valley, USA, on 13–19 September 2009. Owens Valley is one of the most tectonically active transtensional basins in the United States. Superb exposure, rapid deformation, and the presence of the ca. 758,000 year old Bishop Tuff as a key marker horizon make this an ideal area for investigating the structure and neotectonic evolution of an actively forming, continental transtensional basin. Moreover, the distributed nature of faulting, particularly in the exposure of Bishop Tuff, known as the Volcanic Tableland, makes this an ideal natural laboratory for studies of fault growth, scaling, interaction, and linkage. The past two decades have seen a virtual explosion of this research, and lessons from northern Owens Valley have proven relevant to other evolving fault populations around the world.

We organized this Field Forum to gather investigators from diverse disciplines to share results and explore the relationships between long-term deformation, geodetic measurements, seismicity, fault growth and interaction, geochronology, and extensional and transtensional basin development. Our goals for the field forum were to (1) consolidate recent research in northern Owens Valley, (2) elevate the level of understanding of the structure and neotectonics of northern Owens Valley and the Eastern California shear zone–Walker Lane region, (3) foster collaboration between researchers working in the area and elsewhere, and (4) spark new ideas and stimulate new investigations.

The overall approach of the forum was to begin in an area where fundamental processes of fault evolution are easily elucidated. Therefore, we chose to focus first on the extensional faulting across the Volcanic Tableland, where displacement dis tributions along faults are well preserved. General concepts of fault growth, interaction, and linkage provided the underlying framework for discussion of large evolving fault systems.

The first and last days of the week were reserved for travel to and from eastern California. Thus, a total of 5 full days were spent in the field.

The general itinerary for the Field Forum is summarized as follows:

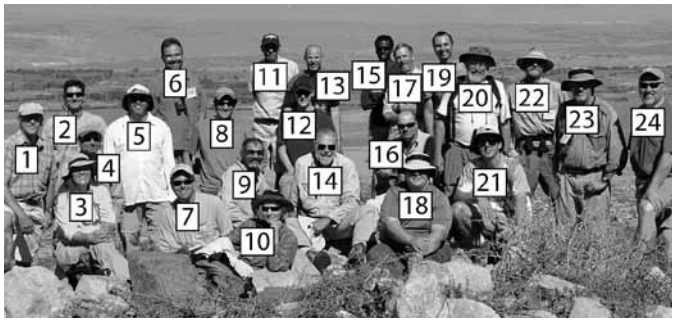
- **Monday began with a general overview** of the regional fault architecture of the northern Owens Valley from an overlook on the side of the valley west of Bishop. We then headed toward the Volcanic Tableland. By visiting key exposures at the lower end of the Owens River Gorge, the group was introduced to the eruptive and emplacement processes of the Bishop Tuff and the collapse of Long Valley caldera. Fault zone deformation was then examined in cross section along an exposure of tuff and volcaniclastic sedimentary strata known as Chalk Bluff.
- **On Tuesday,** we proceeded onto the plateau area of Volcanic Tableland to examine along-strike displacement distributions. This included a discussion of the various studies that have utilized faults exposed here for determining displacement-length scaling relations and unraveling patterns of fault interaction and linkage. The day concluded with travel around the Tableland to look at typical displacement gradients across a range of fault scales and spatial patterns. From the vantage point of the Tableland, we viewed and discussed larger nearby fault systems, such as the Fish Slough fault and the White Mountains fault along the eastern margin of Owens Valley.
- **Wednesday morning** was spent following an incised Pleistocene channel across overlapping faults and up a relay ramp; we were able to unravel the relative timing of activity on the faults and relate channel slope and fault-related knickpoints to the evolution of fault linkage. In the afternoon, we traveled east to the White Mountains fault and looked at evidence of normal and oblique (right-lateral) slip, and discussed temporal variations in the kinematics and rate of faulting there.
- **On Thursday morning** we looked at a succession of terraces along the Owens River, south of the Volcanic Tableland. An assessment of distributed strain was made by summing fault displacements across these post–Bishop Tuff geomorphic surfaces. The remainder of the day focused on the Round Valley fault, which marks the western margin of Owens Valley and is a major segment of the Sierra Nevada frontal fault system. We looked at localities in the vicinity of Pine Creek and Elderberry Canyon and had a lively discussion about constraining the dip of this important range-front system.
- **Friday was our last field day.** From Bishop, we headed south to the area surrounding the Big Pine volcanic field. In

the Red Mountain area, we looked at displacements of several volcanic units, including Fish Springs cinder cone, and discussed the strain budget for northern Owens Valley. We concluded the Field Forum by visiting the Poverty Hills, which has been interpreted as either a manifestation of a restraining bend along the Owens Valley fault or a landslide block derived from Inyo Range.

The Field Forum benefited from having a diverse group of participants, which included researchers from academia, industry, and federal agencies. Students, both graduate and undergraduate, played an active role and contributed greatly. In addition to the discussions held in the field, many of the participants shared results of their research via evening poster sessions and short talks. The exchange of ideas and the recognition of the different perspectives of the geomorphologists, volcanologists, geochronologists, geophysicists, and structural geologists attending the forum were particularly instructive. The overarching goals of the Field Forum were achieved, and several specific remaining issues were identified for further study.

A special issue of the GSA journal *Lithosphere* titled "Structure and Neotectonic Evolution of Northern Owens Valley and the Volcanic Tableland, California" is in preparation. The special issue is being developed following a new model whereby accepted articles are published in regular journal issues as they are completed. The papers are designated as special issue papers when they are published and will be assembled into an online special issue.

Acknowledgments: The University of California White Mountain Research Station provided a venue for evening discussions and presentations.



Participants: Guleed Ali (15), Callan Bentley (7), Kim Bishop (11), Douglas Burbank (17), Nancye Dawers (3), David Ferrill (24), Kurt Frankel (8), Douglas Goff (13), Wes Hildreth (14), Simon Kattenhorn (19), Eric Kirby (5), Jeff Lee (9), Peter Lovely (12), Lisa Majkowski (18), Margaret Mangan (10), Alan Morris (2), Thomas Neely (21), Fred Phillips (23), Robert Phinney (20), Jeffrey Schaffer (1), Gregor Schoenborn (6), Dave Stockton (22), Markos Tranos (16), John Weber (4).

DRAFT

GSA Position Statement Draft

Expanding and Improving Geoscience in Higher Education

GSA members are invited to submit comments and suggestions regarding the following *Position Statement draft* by **15 August 2011** at **www.geosociety.org/geopolicy/.** Go to **www.geosociety.org/positions/** to learn more.

Position Statement: The Geological Society of America (GSA) affirms the need for strong support to geoscience departments and programs at all institutions of higher learning. This commitment will help ensure that future generations of students receive the Earth-science education they will need to address crucial societal issues that have the potential to impact global economic security and the well-being of human populations over the next century or more. More broadly, sustaining strong geoscience programs accessible to all higher education students is vital to developing the Earth-science literacy that all global citizens need to make informed decisions about the significant challenges facing the planet.

Purpose: The purpose of this position statement is to (1) summarize the consensus views of the GSA on the role of geoscience education in institutions of higher learning; (2) highlight future environmental and resource issues that will provide great impetus and opportunity for geoscience programs to significantly increase enrollments; (3) stress the importance of investment from governments, the private sector, and higher education institutions in collegiate Earth-science education; and (4) provide a communication tool for use by GSA and its members to discuss why a strengthened commitment to geoscience education is critical to global future prosperity.

Rationale: Natural and human-induced events in the early twenty-first century have significantly increased the visibility of the Earth sciences to the general public. Events such as Hurricane Katrina in 2005, the March 2011 Tohoku-Oki earthquake, and the 2010 Deepwater Horizon oil spill have enhanced the recognition and understanding of the role of geologists in a spectrum of hazard and natural resource issues of global importance. Awareness of the implications of climate change, sea-level rise, and natural hazards, the availability of affordable energy, and the dwindling supplies of clean water has increased among citizens and our representatives. These issues challenge our technology and infrastructure and require solutions by integrated teams that rely on highly educated geoscientists. All these concerns have raised the stakes for education across the Earth sciences and underscore the importance of geoscience literacy among all citizens.

The importance of geoscience education in institutions of higher education (2-year college through 4-year college/university level) is multifaceted.

- All graduates should have at least some foundation in geoscience so they are equipped to make informed decisions about key environmental problems facing Earth.
- Geoscience education is essential to prepare the next generation of skilled geoscience workers to address important societal needs for natural resource development and management, natural hazards mitigation, environmental protection, and ecosystem restoration. The majority of geoscientists in the workforce are within 15 years of retirement age, indicating that there will be a particularly critical need for new geoscientists in the coming two decades.
- Geoscience courses are essential for educating pre-service K–12 science teachers and for their continued professional development. These teachers will in turn use an updated and informed integrated approach to educating their students.
- Geoscience education is important in related fields, including civil and environmental engineering, environmental studies, agricultural sciences, atmospheric and ocean sciences, life sciences, materials research, homeland security and emergency services, medicine, law, and public administration.
- Geoscience also plays an increasing role in disciplines such as public health and economics, fields that have not traditionally relied on geoscience expertise but that recognize the dependence of a healthy society on our soils, rocks, and water.

SOCIETAL AND PUBLIC POLICY ASPECTS OF EARTH-SCIENCE EDUCATION

As the challenges facing Earth increase in magnitude and urgency, there will be a pressing need for science-based decisions to maintain the well-being of citizens, sustainability of vital resources, and the economic security of all nations. Geoscientists play an important role in helping solve these problems through innovative research, public awareness, and interdisciplinary work with specialists in other fields. GSA supports strong and increasing public investment in geoscience education by government. Current public investment in geoscience education is insufficient to meet future demands for skilled geoscientists. State and federal governments have a responsibility to increase funding for Earth-science education to ensure that the necessary expertise exists in the future. Higher institution geoscience education is crucial for workforce development in key fields that face a significant shortage of highly qualified geologists ready for employment:

- Geologists play a vital role in the petroleum industry, including identifying and assessing potential hydrocarbon reservoirs and overseeing the drilling and production of oil and gas wells. As oil and gas become scarcer, identification of exploration opportunities is becoming

increasingly challenging, and resources are becoming more difficult to recover.

- Geologists are essential to the mining industry, providing the underlying geologic mapping, geophysics, and geochemistry to identify and understand critical mineral deposits. As the development of green technology and clean energy advances, the need for specialty minerals, such as radionuclides, rare earths, and precious metals, will increase.
- Hydrogeologists are critical in indentifying and preserving clean drinking water. Aquifers are coming under increasing pressure as population grows and climate change leads to slow replenishment in arid parts of the country. Environmental geologists play a vital role in clean-up efforts for contaminated aquifers.
- Geological engineers perform many vital tasks, including locating facilities, such as dams, toxic waste repository sites, and nuclear power plants. An area of great future potential for geological engineers will be locating sites for carbon capture and sequestration, as well as upgrading aging infrastructure, such as highways, bridges, and water systems.
- Geologists play a lead role in understanding how to best mitigate natural hazards, such as earthquakes, floods, volcanic eruptions, tsunamis, landslides, and avalanches. Natural hazards pose an especially large threat for vulnerable urban areas, where the economic and human risk is potentially catastrophic.
- Geologists, geochemists, soil geologists, and geomicrobiologists provide the basic understanding needed to support ecosystem and agricultural sciences, which underpin maintaining a robust food supply and a healthy environment needed for our basic survival.
- Geoscience education is very important for college students studying to become K–12 teachers. Faculty educated in Earth sciences can promote appreciation and respect for our natural resources, leading to more students deciding to pursue geoscience careers and to an increase in overall public awareness of the key issues involving Earth science.
- Geoscientists and geoscience education have a role in informing students and citizens about the geoscience implications of Earth hazards and resource supplies.

RECOMMENDATIONS

1. College and university administrators must sustain geoscience programs so that they can educate non-majors and the general public, train future Earth-science educators at all levels, from K–12 to collegiate, as well as educate the next generation of the geoscience workforce. Administrators should view geoscience education and literacy as an essential component of higher education given its clear relevance in many aspects of society.
2. Policy makers must make available new sources of funding for programs to educate the next generation of Earth scientists that will be vital to the economy, security, and health of our nation.
3. Industries in the private sector, such as oil and natural gas companies, minerals extraction, and environmental and engineering companies rely heavily on the expertise developed by geoscience programs in institutions of higher education. These industries must advocate for increased funds which are critical for the continuation and enhancement of geoscience education, and, whenever possible, directly support the geoscience departments and initiatives that are responsible for training their future workforce.

OPPORTUNITIES FOR GSA AND GSA MEMBERS TO HELP IMPLEMENT RECOMMENDATIONS

To strengthen geoscience programs at colleges and universities, The Geological Society of America recommends that:

1. Faculty continually stress the importance of geoscience awareness and literacy across the student body, among the general public, and to university administrators and elected officials, by focusing courses, curricula, and outreach activities on the crucial issues that will face the planet in coming decades, including climate change, natural and water resources issues, and natural hazards.
2. All stakeholders (faculty, students, and alumni) educate policy makers and university administrators about changing demographics in the geoscience workforce and the increasing potential for employment.
3. Stakeholders advocate for public support and public investment in geoscience programs at institutions of higher education.
4. Identify legislation that affects public investments in Earth-science education and alert GSA's Geology and Public Policy Committee, GSA's Geology and Society Division, and GSA's Associated Societies if action by the GSA membership and affiliated organizations can help improve the scientific basis for any particular decision. The Geology and Public Policy Committee, Geology and Society Division, and Director for Geoscience Policy, often working with GSA members, can also bring this Position Statement to the attention of lawmakers when legislation affects public investments in Earth-science education.

In Memoriam

The Society notes with regret the deaths of the following members (notifications were received between 21 Dec. 2010 and 25 May 2011).

Kodjopa Attoh
Ithaca, New York, USA
Notified 14 March 2011

Thomas D. Barrow
Houston, Texas, USA
27 January 2011

James R. Beerbower
Washington, D.C., USA
27 September 2010

Gilbert T. Benson
Lake Oswego, Oregon, USA
6 April 2011

Phillip F. Brease
Healy, Alaska, USA
Notified 11 May 2011

Alice A. Cardenas
Tucson, Arizona, USA
Notified 28 April 2011

Stephen E. Clabaugh
Spicewood, Texas, USA
2 December 2010

William R. Farrand
Ann Arbor, Michigan, USA
1 March 2011

Fred W. Farwell
Stamford, Connecticut, USA
1 February 2011

Gordon A. Gross
Ottawa, Ontario, Canada
14 March 2011

Eugene Thornton Herrin Jr.
Dallas, Texas, USA
20 November 2010

Jasper L. Holland
Portland, Oregon, USA
8 March 2011

Robert A. Loney
Cupertino, California, USA
1 April 2009

Monzell R. Louke
Bend, Oregon, USA
5 April 2011

James C. MacLachlan
Lakewood, Colorado, USA
26 June 2010

Gordon C. McKeague
Galena, Illinois, USA
Notified 11 April 2011

Robert S. Merkel
Socorro, New Mexico, USA
18 November 2010

Ronald R. Moore
Van Nuys, California, USA
Notified 12 April 2011

Melville R. Mudge
Lakewood, Colorado, USA
2 December 2009

Jack E. Oliver
Ithaca, New York, USA
5 January 2011

James F. Olmsted
East Aurora, New York, USA
24 March 2011

Donald F. Reaser
Arlington, Texas, USA
29 December 2009

Kingsley W. Roth
Pine, Colorado, USA
26 March 2010

Kelvin Norman Sachs Jr.
Madison, Connecticut, USA
29 January 2011

Stanley A. Schumm
Fort Collins, Colorado, USA
11 April 2011

George R. Tilton
Santa Barbara, California, USA
22 October 2010

Edward T. Tozer
Vancouver,
British Columbia, Canada
26 December 2010

Franklyn B. Van Houten
Bethlehem,
New Hampshire, USA
Notified 21 January 2011

Barry N. Watson
Tucson, Arizona, USA
29 January 2011

Robert F. Yerkes
Walnut Creek, California, USA
1 August 2008

About People

GSA Fellow **Naomi Oreskes** has been named Climate Change Communicator of the Year (the "4C Award") by the George Mason University Center for Climate Change Communication.

The American Geological Institute (AGI) has awarded GSA Fellow **Robert H. Dott Jr.**, professor emeritus at the University of Wisconsin–Madison, its 2011 Marcus Milling Legendary Geoscientist Medal in recognition of his "long history of scientific achievement and exceptional service to the geoscience profession."

GSA Fellow and 1992 Penrose Medalist **John Dewey** has been honored by the Australian Academy of Science by being elected as a "Corresponding Member." Corresponding Members are "eminent scientists residing overseas who have developed links with scientific institutes in Australia and maintain strong ties with Australian scientists."

The Geochemical Society and The European Association of Geochemistry have bestowed the honorary title of Geochemistry Fellow to the following GSA members, honoring them as outstanding scientists who have made major contributions to the field of geochemistry: GSA Fellow **Samuel Bowring** of MIT; GSA Fellow **Katherine Freeman** of Penn State; GSA Fellow **Terry Plank** of the Lamont Doherty Earth Observatory; and GSA Fellow **John W. Valley** of the University of Wisconsin–Madison.

GSA Fellow and 2000 Day Medalist **Stephen J. Sparks** of Bristol University has been awarded the Geological Society's (London) highest honor: the Wollaston Medal, given to geologists who have had a significant influence by means of a substantial body of excellent research in "pure" and/or "applied" aspects of the science. GSA Fellow **Christopher Paola** of the University of Minnesota–Twin Cities has been recognized with the Geological Society's Murchison Medal, given to geoscientists who have made a significant contribution to the science by means of a substantial body of "hard rock" research. The Geological Society also awarded GSA Member **Alexander Densmore** of Durham University with the Bigsby Medal, given to a geoscientist under 45 years of age who studies American geology.

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Positions Open

TENURE-TRACK ASSISTANT PROFESSOR GEOLOGY (MINERALOGY/PETROLOGY) FORT HAYS STATE UNIVERSITY

The Dept. of Geosciences at Fort Hays State University invites applications for a tenure-track position as Assistant Professor of Geology (Mineralogy/Petrology). Responsibilities include teaching undergraduate and graduate courses, overseeing labs, student recruitment, and advising, supervising student research and theses, and grant writing and research. PhD required; ABD considered. Starting date: 1 Aug. 2011. For additional details, see www.fhsu.edu/geo or www.fhsu.edu/faculty-and-staff/employment-and-benefits/. FHSU is an AA/EO Employer. Screening of applications will begin immediately and continue until the position is filled. Final candidate must consent to and successfully complete a criminal background check. Send letter of application, curriculum vitae, statements of teaching and research philosophies, transcripts, three letters of reference, and visa status (if applicable) to Dr. John F. Heinrichs, Chair, Dept. of Geosciences, Fort Hays State University, 600 Park Street, Tomanek Hall 233, Hays, KS 67601.

TENURE TRACK ASSISTANT OR ASSOCIATE PROFESSOR TECTONOPHYSICS, UNIVERSITY OF UTAH

The Dept. of Geology and Geophysics at the University of Utah seeks applicants for a tenure track position at the Assistant or Associate Professor level in Tectonophysics. Scientists from all subdisciplines of tectonophysics are welcome to apply, but preference will be given to candidates with research interests that complement existing geophysical strengths in the department. These include seismic imaging of Earth's deep interior, earthquake seismology and hazard assessment as carried out by the University of Utah Seismograph Stations, active source seismology, electromagnetic studies of Earth's interior, and tectonics.

The successful candidate must be committed to excellence in geophysics teaching at both the undergraduate and graduate levels, and should have either the proven ability or potential to attract external funds and to build an internationally recognized research program involving students and post-docs. Applicants must hold a Ph.D. in geophysics, or a closely related discipline.

Applicants should e-mail an application package describing research, teaching, and career interests, a curriculum vitae, and the names and contact information for three referees, all in a single PDF document to tectonophysics-search@lists.utah.edu. Review of applicants will begin 15 August 2011 and continue until the position is filled.

The University of Utah is fully committed to affirmative action and to its policies of nondiscrimination and equal opportunity in all programs, activities, and employment. Employment decisions are made without regard to race, color, national origin, sex, age, status as a person with a disability, religion, sexual orientation, gender identity or expression, and status as a protected veteran. The University seeks to provide equal access for people with disabilities. Reasonable prior notice is needed to arrange accommodations. Evidence of practices not consistent with these policies should be reported to: Director, Office of Equal Opportunity and Affirmative Action, +1-801-581-8365 (V/TDD).

The University of Utah values candidates who have experience working in settings with students from diverse backgrounds, and possess a commitment to improving access to higher education for historically underrepresented students.

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Deadline: 15 July 2011

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Last Call for Applications and Nominations for

GSA COMMITTEE SERVICE

Deadline: 15 July 2011

2012 Committee Vacancies

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Nominations
Penrose Conference and Field Forums
Penrose Medal Award
Professional Development
Research Grants
Young Scientist Award (Donath Medal)
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GSA Rep. to North American Commission on Stratigraphic Nomenclature
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Coming to *GSA Today*

Science Articles

August: E.W. Portenga and P.R. Bierman, "Understanding Earth's eroding surface with ^{10}Be"

September: Special issue! Four brief articles highlight science related to the 2011 GSA Annual Meeting & Exposition in Minneapolis, Minnesota, USA, 9–12 October: S. Stein et al., "Learning from failure: The SPREE Mid-Continent Rift Experiment"; K. Gran et al., "Landscape evolution in south-central Minnesota and the role of geomorphic history on modern erosional processes"; K. Bradbury and A. Runkel, "Recent advances in hydro-stratigraphy of Paleozoic bedrock in the Midwestern United States"; and C. Manduca, "Improving undergraduate science education."

Groundwork articles:

August: J.C. Libarkin et al., "Revisiting the Geoscience Concept Inventory: A call to the community"

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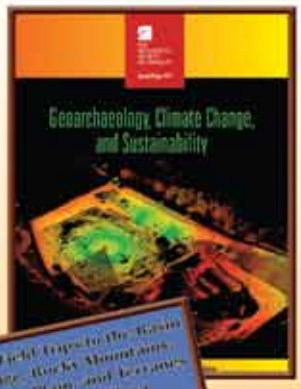

Geoarchaeology, Climate Change, and Sustainability

edited by Antony G. Brown, Laura S. Basell, and Karl W. Butzer

This volume provides a broad survey of recent advances in geoarchaeology with particular attention to environmental change. The fourteen chapters include methodologically innovative research, case studies valuable for teaching, and the use of geological techniques to answer archaeological questions from lower Paleolithic hunting to the location of Homer's Ithaca. *Geoarchaeology, Climate Change, and Sustainability* also includes a major position paper and, unusually, two papers on the management of the geoarchaeological resource. Both the geographical and chronological coverage are broad ranging from the Lower Paleolithic (lower Pleistocene) to the Iron Age (late Holocene), and from rural Iran to urban Manhattan. The research presented here clearly demonstrates the value and practical application of geoarchaeological techniques from sediment-based dating to geographic information systems.

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compiled by Diane Clemens-Knott

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