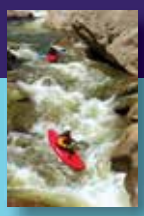

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Managing Editor: Kristen "Kea" Giles, kgiles@geosociety.org, gsatoday@geosociety.org

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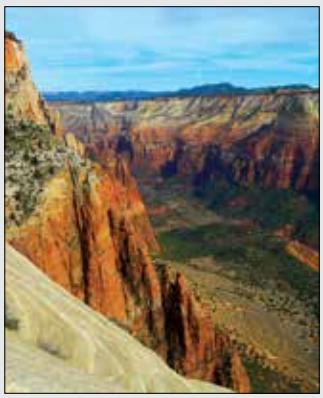

Cover: View upstream into Zion Canyon with The Sentinel (source area for the landslide) at left and deposits of the Sentinel rock avalanche at bottom center. Photo by Sarah Meiser, used with permission. See related article, p. 4–9.

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Dynamics and legacy of 4.8 ka rock avalanche that dammed Zion Canyon, Utah, USA

Jessica J. Castleton, Jeffrey R. Moore*, *University of Utah, Dept. of Geology and Geophysics, 115 South 1460 East, Salt Lake City, Utah 84112, USA;* ***Jordan Aaron,*** *University of British Columbia, Dept. of Earth, Ocean and Atmospheric Sciences, 2020-2207 Main Hall, Vancouver, Canada V6T 1Z4;* ***Marcus Christl,*** *Laboratory of Ion Beam Physics, ETH Zurich, Otto-Stern-Weg 5, 8093 Zurich, Switzerland; and* ***Susan Ivy-Ochs,*** *Laboratory of Ion Beam Physics, ETH Zurich, Otto-Stern-Weg 5, 8093 Zurich, Switzerland, and Dept. of Geography, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland*

ABSTRACT

The Sentinel rock avalanche blocked the mouth of Zion Canyon, Utah, USA, over a distance of 3.3 km and created a large lake that filled the canyon floor with sediment, transforming this iconic desert landscape. However, key questions remain regarding the size, timing, and dynamics, as well as the geomorphic effects of this prominent landslide. Reconstructing topography before and after the failure, we calculate an original deposit volume of 286 million m^3 with maximum thickness of 200 m. New cosmogenic nuclide surface exposure ages of 12 boulders from across the deposit reveal a mean age of 4.8 ± 0.4 ka and are consistent with single-event emplacement. Results of 3D numerical runout simulations agree well with mapped deposit boundaries and thickness, affirming our hypothesized failure scenario and indicating an average runout velocity of 50 m/s. Following partial breach of the landslide dam, we estimate that water levels stabilized for ~700 yr until the lake filled with sediment. Deposited lacustrine clays reveal a period when Zion Canyon was filled by the 3 km^2 Sentinel Lake extending more than 7 km upstream. Today the Virgin River incises alluvial and lacustrine deposits still stranded behind remnants of the rock avalanche dam, attesting to the long-lasting geomorphic and ecological impacts of large landslides in steep desert landscapes.

INTRODUCTION

> To the visitor viewing Zion National Park for the first time, there is a tantalizing similarity in shape between the sheer-walled gorge of Zion Canyon and the Yosemite Valley … The impression is so pronounced that the explanation of this similarity is a daily task for the members of the naturalist staff. —R.K. Grater (1945, p. 117)

Zion National Park, Utah, USA, receives millions of visitors annually, but few appreciate that the tranquil and inviting flat valley floor of Zion Canyon set amidst towering sandstone cliffs owes its origin to a large, prehistoric landslide (Fig. 1A). Many visitors identify deposits of smaller slides as they enter Zion Canyon (e.g., one that damaged the main road in 1995), climbing a winding roadway through blocky rock avalanche debris incised by the Virgin River (Fig. 1B). The scale of the Sentinel rock avalanche, however, evades easy perception—with visible deposits >2 km long, 1 km wide, and up to 200 m thick, the slide is approximately five times larger than the largest historic, non-volcanic landslides in North America (Grater, 1945; Pankow et al., 2014). Remnant clay beds and fossil mollusks preserved throughout the canyon reveal a period when Sentinel Lake occupied Zion Canyon for several centuries until eventually filling with sediment (Hamilton, 1976).

Catastrophic rock avalanches represent an extreme-magnitude natural hazard. Case histories illustrate the devastating consequences as millions of cubic meters of rock travel kilometers distance in only seconds, reaching peak velocities of ~100 m/s with flow-like characteristics (e.g., Crosta et al., 2004; Dunning et al., 2007). Beyond the immediate hazard, however, rock avalanches also have long-lasting geomorphic and ecological consequences, blocking river valleys and controlling local base-level for millennia, while facilitating human habitation and cultivation of otherwise steep terrain (Korup, 2006; Hewitt et al., 2011). This juxtaposition of modern-day hazard and geomorphic transformation is ideally captured in Zion Canyon; however, the related effects of transient landscape disturbance can be found in a wide range of environments (Korup et al., 2010), and the ecological effects of altered river courses may be especially relevant in desert canyons of the Colorado Plateau.

Previous efforts to date the Sentinel rock avalanche relied on radiocarbon from charcoal found in lacustrine and alluvial sediments. Hamilton (1976) determined an age of 3.4–4.5 cal. k.y. B.P. (recalculated calibrated 1σ range using IntCal13; Reimer et al., 2013) for charcoal found in post-lake sand overlying clay beds. The Utah Geological Survey (UGS) reported ages of 7.2–9.0 and 7.0–8.3 cal. k.y. B.P. for charcoal found in lacustrine clay at 4 m and 10 m below ground level, respectively (Doelling et al., 2002) (see Fig. 2A). Most recently, Hamilton (2014) obtained a luminescence age of 4.3 ± 1.3 ka for sand between lacustrine clays near the top of the lake sequence. Taken together, these ages imply a nearly 4000-yr lifespan for Sentinel Lake. However, calculations of modern sediment flux for the Virgin River suggest that the lake filled with sediment in only 600–800 yr (Hamilton, 1976, and our new value described herein).

In this paper, we report new mapping of Sentinel rock avalanche deposits and select lacustrine sediments. We approximate the topography of Zion Canyon before and after the slide to generate refined estimates of the rock avalanche volume and to comment on failure kinematics. We then use cosmogenic nuclide surface exposure dating to provide the first direct date of the rock avalanche deposit and constrain the age of Sentinel Lake.

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* Corresponding author e-mail: jeff.moore@utah.edu

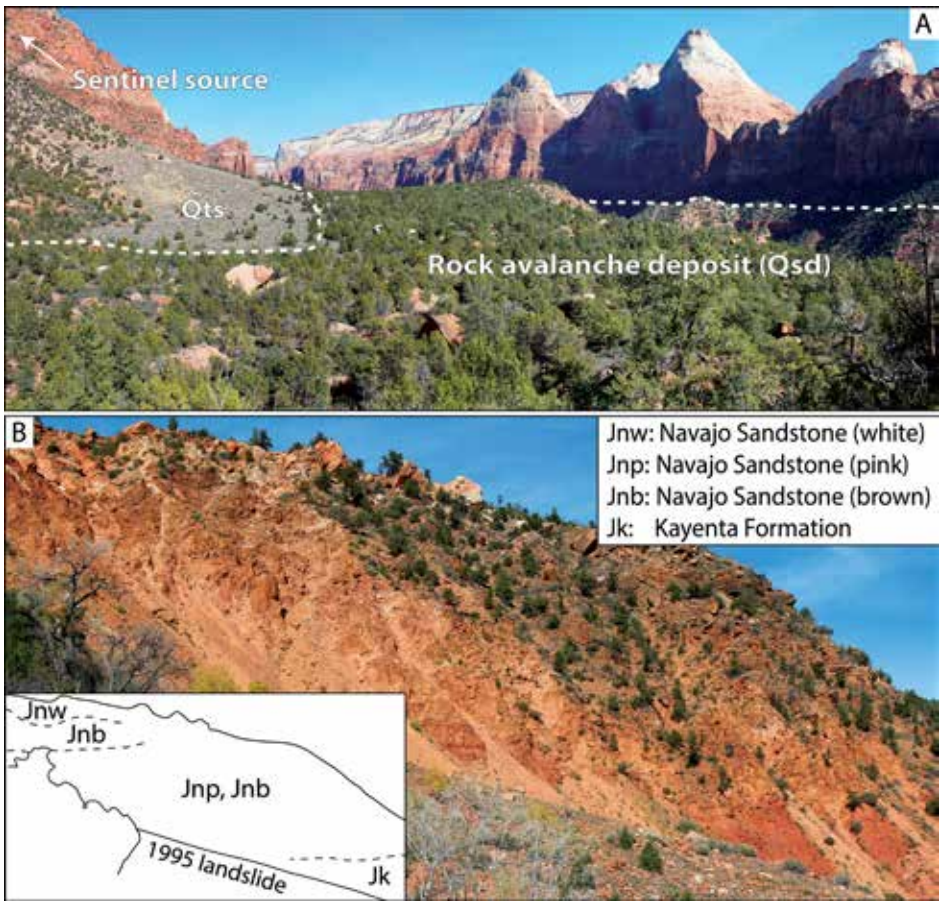

Figure 1. (A) View northeast (looking upstream into Zion Canyon) over the surface of the Sentinel rock avalanche deposit; incised gorge of the Virgin River at far right. Qsd—Sentinel rock avalanche deposits; Qts—sandy talus (see Fig. 2). (B) Rock avalanche deposits exposed by river incision, showing constituent rock types assessed from remote mapping; height of exposure is ~150 m. The upper part of the deposit consists primarily of Navajo Sandstone debris, which is characteristically shattered and compact, while the basal portion of the deposit consists of Kayenta material that has been deformed and tilted but often retains small-scale structure. See Figures 2 and 3 for composition of the source.

Numerical runout simulation helps confirm the hypothesized single-event, catastrophic failure scenario. Long-lasting geomorphic and ecological effects contributing to the iconic setting of Zion National Park attest to the diverse impacts of large rock avalanches in steep desert landscapes.

SENTINEL ROCK AVALANCHE

Deposits of the Sentinel rock avalanche are deeply incised by the Virgin River, providing exceptional exposures over a distance of ~2 km (Figs. 1 and 2). We observed large-scale remnant stratification reflecting the composition of the source: Kayenta Sandstone from the base of the source is generally found along the basal portion of the deposit, while Navajo Sandstone from the top of the source forms the upper part of the deposit (for details of these lithologies see Doelling et al., 2002). Moreover, the two materials exhibit strong textural differences caused by rock avalanche emplacement: the Kayenta Sandstone, with higher clay content, is highly deformed but frequently retains remnant centimeter-scale sedimentary structure, while the massive and relatively homogenous Navajo Sandstone exhibits compact and shattered, clast-supported deposits. Navajo Sandstone in Zion Canyon appears white in the upper part of the formation, transitioning to pink and brown below through diagenetic leaching of iron (Nielsen et al., 2009). Boulders of each diagenetic facies are found within the deposit (Fig. 1B).

To quantify the volume of the rock avalanche, we reconstructed topography beneath the deposit and immediately after failure. Our reconstruction is based on field assessments, exposed outcrops, and extrapolation from nearby slopes. A key marker is a ~30 m thick bed of Springdale Sandstone, a member of the Moenave Formation, which dips gently (~2°) to the northeast (Fig. 2A) (Doelling et al., 2002). We assume the failure surface did not penetrate this layer, because in-place outcrops are exposed at the base of the rock avalanche deposit. Another key element in our reconstruction is a large bedrock arm flanking the southwestern end of the deposit; here we mapped bedrock along the river gorge and under thin colluvium on two knobs above rock avalanche debris (see Fig. 2A). Aided by long-profile extrapolation of the Virgin River underneath the slide (Fig. 3A), we approximated the topography below deposits of the Sentinel rock avalanche (Fig. 3B). To reconstruct the top of the slide debris, we extrapolated existing surfaces across the incised Virgin River gorge.

Subtracting the reconstructed basal topography from the top-of-slide debris surface, we calculated a mean and maximum deposit thickness of 95 m and 200 m, respectively (see Fig. 4F). The original deposit was 3.3 km long and 1.4 km wide, covered an area of 3 million m^2, and had an estimated total volume of 286 million m^3 (volume presumed accurate to within ±20% from trial solutions using alternate topographies). A minimum fahrboeschung angle (i.e., the ratio of fall height to path length along flow lines) of 20° for the Sentinel slide indicates relatively low mobility for this volume compared to other terrestrial events (Lucas et al., 2014). This may be related to the cross-valley flow orientation. Comparing the original volume of rock avalanche deposits to the volume of material found today, we estimate that approx. 131 million m^3, or ~45%, of debris has been eroded by the Virgin

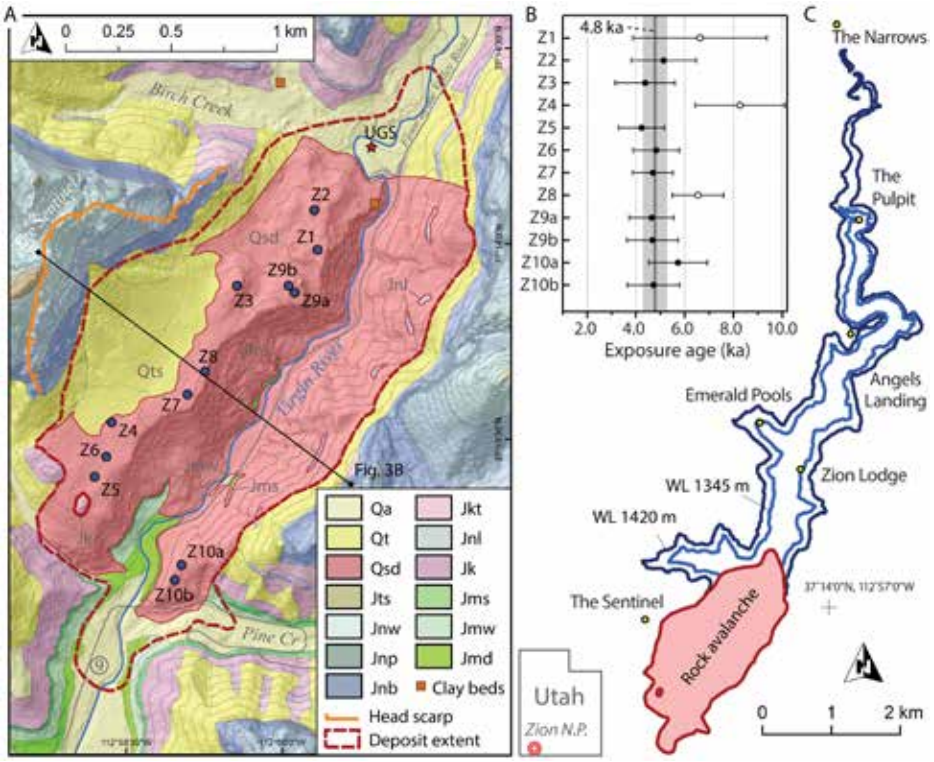

Figure 2. (A) Geological map of the study area (modified from Doelling et al. [2002] in the landslide area). Units: Qa—Quaternary alluvium; Qt—Quaternary talus (Qts—sandy talus cone at base of source); Qsd—deposits of the Sentinel rock avalanche (in places with >1 m of alluvium or colluvium cover); Jts—Temple Cap Formation; Jnw—Navajo Sandstone, white; Jnp—Navajo Sandstone, pink; Jnb—Navajo Sandstone, brown; Jkt—Kayenta Formation, Tenney Canyon Tongue; Jnl—Navajo Sandstone, Lamb Point Tongue; Jk—Kayenta Formation; Jms—Moenave Formation, Springdale Sandstone; Jmw—Moenave Formation, Whitmore Point Member; Jmd—Moenave Formation, Dinosaur Canyon Member. Orange squares are select exposures of Sentinel Lake clay beds; star shows location of Utah Geological Survey (UGS) core. Circles are cosmogenic exposure age sample locations. Contour interval is 30 m. (B) Results of cosmogenic surface exposure dating showing individual ages and errors, mean age (solid line) of 4.8 ka, and associated standard deviation (gray bar). Samples with open circles were deemed outliers (see text). (C) Estimated extents of Sentinel Lake at its initial high-stand (water level ~1420 m) and later stable level (~1345 m).

River. We also estimate that ~5 million m^3 have been added to the deposit in the sandy debris cone at the base of the source area (Fig. 2A), although the timing of this addition is uncertain.

The rock avalanche source is revealed by the craggy, unweathered east face of the Sentinel; a series of broken pinnacles help delineate the scarp. The form of the original cliff, however, is not well constrained. We model the source form loosely after nearby Abraham Peak, which shares the same stratigraphy and regional joint patterns. We allow the source area to extend to 2150 m above sea level and assume common slope angles for the different lithologies (Fig. 3B). The kinematics of the release are similarly unknown. Based on topographic reconstruction, we place the lowest point of the failure surface near the base of the Kayenta Formation, which features alternating beds of sandstone and shale. Rotational or translational failure through the Kayenta likely exploited one or more weak shale layers. Our recreated source has a volume of 223 million m^3, yielding an estimated volume increase of 28% as intact rock was converted to debris (typical fragmentation volume increase is ~25%; Hungr and Evans, 2004). The relatively flat and hummocky surface of the rock avalanche deposit, combined with a lack of internal erosional or depositional surfaces visible in outcrops, suggest single-event catastrophic failure and emplacement.

Surface Exposure Dating

We sampled 12 boulders from across the rock avalanche deposit for cosmogenic ^{10}Be surface exposure dating (Fig. 2B; GSA Supplemental Data Repository[1] Table S1). The boulders, which were predominantly Navajo Sandstone of each coloration facies, exhibited a range of bedding orientations and had average dimensions of several meters. We avoided boulders that were excessively friable or showed evidence of slabbing, excavation, or movement after deposition (Ivy-Ochs and Kober, 2008). Iron concretions in several sampled boulders are weathering resistant, projecting 1–2 cm above the surrounding rock and allowing estimates of boulder surface erosion since deposition. Sample preparation followed the procedures of Ivy-Ochs et al. (2006). ^{10}Be/^{9}Be AMS measurements were performed at ETH Zurich (Christl et al., 2013). Sample ^{10}Be/^{9}Be ratios were normalized to the ETH in-house standard S2007N, which is calibrated to 07KNSTD. The weighted mean full-process, measured blank ^{10}Be/^{9}Be ratio of $(3.6 \pm 2.6) \times 10^{-15}$ was used for blank corrections. We calculated exposure ages with the CRONUS online calculator (Balco et al., 2008) using a spallation production rate of 3.93 ± 0.19 atoms g^{-1} a^{-1} of the northeast North America calibration data set (Balco et al., 2009) and a time-dependent spallation production model (Lal, 1991; Stone, 2000). Several of the quartz mineral separates had high B contents, leading to large AMS uncertainties for a few samples. Final exposure ages are shown in Figure 2B; input data and calculation results are reported in Supplemental Table S1 (see footnote 1).

Exposure dating revealed that boulders from across the surface of the slide were deposited simultaneously, indicating a single-event, massive, and catastrophic rock slope failure. We identified three outliers in our dating results: boulder Z1, which had large

[1] GSA Supplemental Data Item 2016070, including cosmogenic nuclide surface exposure dating sample details and results, as well as animation of the simulated Sentinel rock avalanche, is online at www.geosociety.org/pubs/ft2016.htm. You can also request a copy from *GSA Today*, P.O. Box 9140, Boulder, CO 80301-9140, USA; gsatoday@geosociety.org.

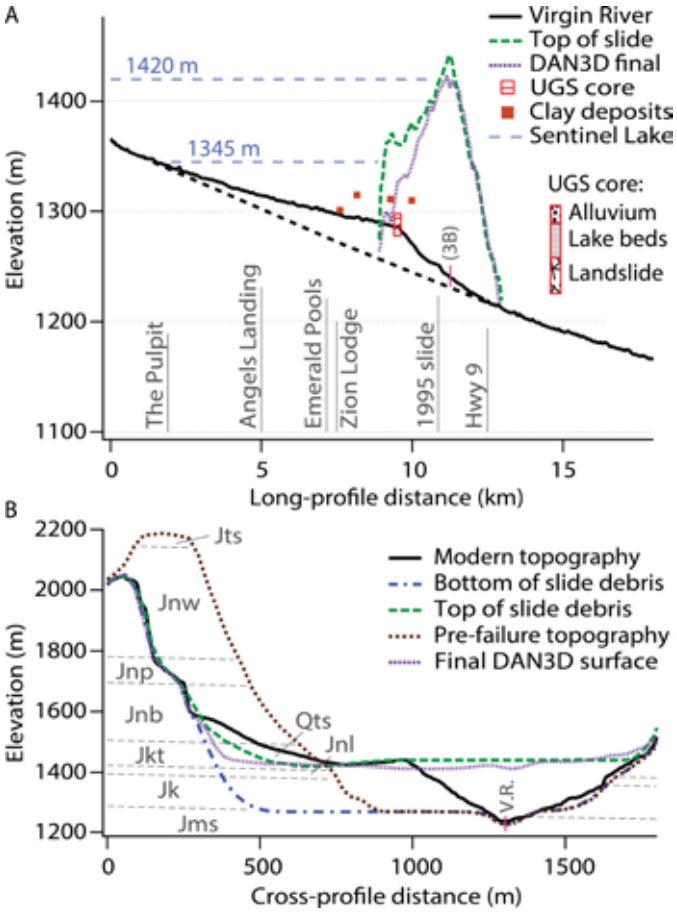

Figure 3. (A) Long-profile of the Virgin River (V.R.) from The Narrows to the town of Springdale, with extrapolated pre-slide profile (black dashed line). Reconstructed top of rock avalanche deposits is compared to modeled profile. Inset shows simplified schematic of the UGS core. Clay lake bed deposits are projected onto the long-profile. 36× vertical exaggeration. (B) Cross section through the Sentinel rock avalanche deposit showing reconstructed base of slide, top of slide, and original valley profile, compared to model results and modern topography. Qts—sandy talus cone at base of source; Jts—Temple Cap Formation; Jnw—Navajo Sandstone, white; Jnp—Navajo Sandstone, pink; Jnb—Navajo Sandstone, brown; Jkt—Kayenta Formation, Tenney Canyon Tongue; Jnl—Navajo Sandstone, Lamb Point Tongue; Jk—Kayenta Formation; Jms—Moenave Formation, Springdale Sandstone; no vertical exaggeration.

measurement uncertainty due to high boron content; Z4, with likely inheritance from pre-slide exposure; and Z8, which was highly weathered with possible inheritance. The remaining nine ages are consistent, indicating a mean age of 4.8 ± 0.4 ka (error: ±1σ). No evidence for a concurrent paleo-seismic event in the area has been identified, which might have triggered the rock avalanche (Stenner et al., 1999).

Runout Modeling

We performed numerical runout simulation of the Sentinel rock avalanche using the equivalent-fluid code DAN3D (McDougall and Hungr, 2004). Our goal was to reproduce the observed deposit extents and thickness, and in doing so validate the hypothesized single-event failure scenario. DAN3D allows modeling of rock avalanche motion over 3D terrain based on input of slide path topography, source thickness, and material properties. We used a modified version of DAN3D that allows initial rigid-body motion (Aaron and Hungr, 2014). We selected a Voellmy rheology for basal shear resistance and assigned uniform material properties across the runout path. The best-fitting input parameters were (1) Voellmy friction coefficient $f = 0.27$ and turbulence parameter $\zeta = 200$; (2) unit weight $\gamma = 20$ kN/m^3; and (3) an internal friction angle $\varphi_i = 35°$. The relatively high Voellmy friction coefficient for the Sentinel rock avalanche (cf. Hungr and Evans, 1996) indicates comparably low mobility, which is due in part to the cross-valley flow orientation and likely dry rock avalanche and substrate materials.

Runout modeling results for the Sentinel rock avalanche are shown in Figure 4 (see also animation in the Supplemental Data Repository [see footnote 1]). After 4.5 s of initial rigid-body displacement (~20 m southeast), the mass collapses, fluidizes, and rapidly accelerates. The ensuing rock avalanche travels predominantly southeast, crossing Zion Canyon in less than 20 s with maximum velocity of 90 m/s and energetic runup on the opposite valley wall. Debris then spreads laterally up and down canyon. After ~50 s, the distal ends of the deposit have been reached and most of the material has come to rest, traveling a maximum source-toe path distance of 2.4 km at an average velocity of ~50 m/s. The modeled deposit boundaries match well with those mapped in the field (Figs. 4E and 4F), although our simulated deposit exceeds the mapped boundaries in areas to the east and southwest. Excessive material spreading in the initial part of our simulation may account for some of this discrepancy. The thickness and overall distribution of mass within the simulated deposit also match well with our topographic reconstruction. Independent velocity constraint can be obtained from estimated runup (h) on the opposing valley wall as: $V = (2gh_{max})^{0.5}$ (Jibson et al., 2006), where g is gravity and $h_{max} = 200$ m, indicating a minimum velocity needed to achieve this runup of 62 m/s (value does not account for basal shear resistance).

SENTINEL LAKE

The Sentinel rock avalanche blocked Zion Canyon over a distance of more than 3 km, damming the Virgin River and creating a lake. We estimate an initial breach elevation of the landslide dam of 1420 m, which is lower than the maximum height of ~1445 m and corresponds to a topographic low in the northern-central region of the deposit. At this initial level, Sentinel Lake would have covered an area of ~6.2 km^2 (Fig. 2C). Assuming that discharge of the Virgin River was similar to modern mean values (USGS, 2014), we estimate that ~5–10 yr were required to fill the lake to this high-stand.

Preserved clay beds and mollusks indicate that a calm, deep-water environment was sustained by Sentinel Lake for several centuries (Hamilton, 1976, 2014). Lake-bed deposits are found as low as 1285 m (UGS core log data) and as high as 1315 m (Fig. 3), representing at least 30 m maximum thickness. Core and surface observations show that these clay beds are gray and yellow in color and layered at the centimeter scale. We estimate an approximate stable water elevation for Sentinel Lake of 1345 m based on the maximum elevation of identified clay deposits and morphology of the landslide dam. Field evidence of debris slumps and clay-filled channels indicates that this elevation varied slightly over time.

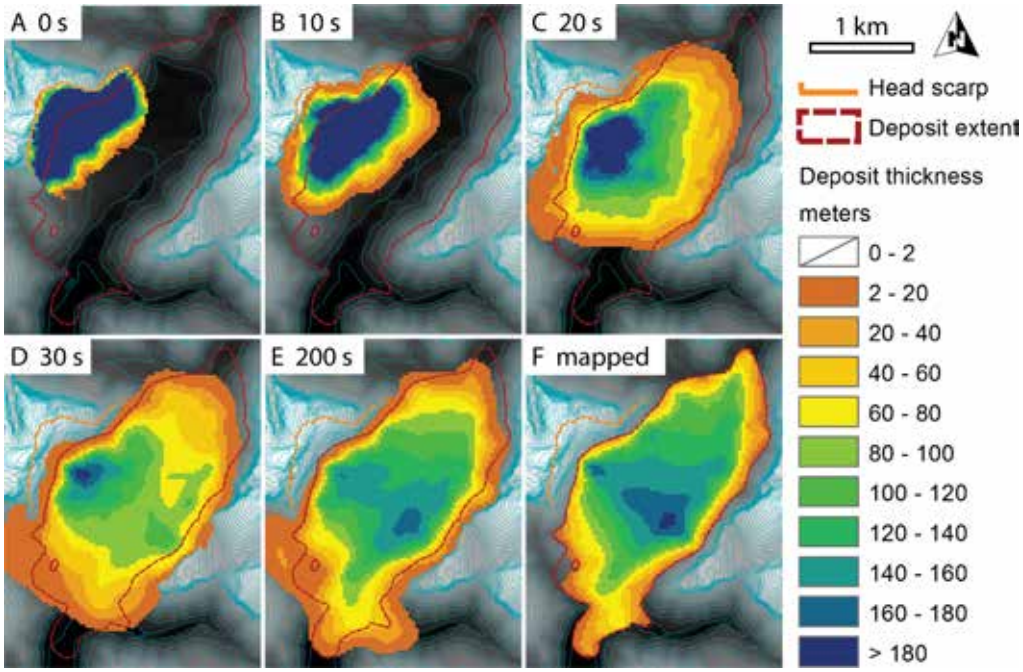

Figure 4. DAN3D runout simulation of the Sentinel rock avalanche. Panels (A–E) show snapshots of the runout at indicated times. Thickness at 200 s represents final modeled values and has been bulked by 28% for comparison with mapped and reconstructed values (F). See the GSA Supplement Data Repository (see footnote 1) for animation. Shaded relief map and 30 m contours show recreated sliding surface topography. Thickness values <2 m have been omitted for clarity.

At this water level, Sentinel Lake would have covered an area of ~3 km^2, extending >7 km upstream (Fig. 2C).

Deposition of sediment behind the rock avalanche dam began to fill Sentinel Lake. Using modern sediment yields measured at the nearby East Fork of the Virgin River (Andrews, 2000), rescaled for the (nearly identical) North Fork drainage area, we calculate that Sentinel Lake would have filled with sediment in ~600–800 yr. This value matches a previous estimate by Hamilton (1976), which was generated from different data. Thus, from its formation at 4.8 ka, we estimate that Sentinel Lake occupied Zion Canyon for ~700 yr until ca. 4.1 ka. This timing is consistent with Hamilton's (2014) OSL age of 4.3 ka, as well as Hamilton's (1976) median radiocarbon age of 4.0 cal. k.y. B.P. for post-lake deposition of sand. Our results are not consistent with UGS radiocarbon ages, measured from extremely small charcoal samples in cored lake sediments, which placed the date of lake formation at ca. 8 ka.

Continued incision of the rock avalanche dam has resulted in erosion of alluvial and lacustrine sediments deposited up to 7 km upstream (Fig. 3A). In the area of Zion Lodge, the river now lies ~25 m below the highest alluvial sediments associated with the slide. As local base level continues to drop, this material will ultimately be lost, and the canyon will return to the steep and narrow form seen in nearby tributaries. Based on observed rates of post-slide erosion, this process is expected to require several millennia. The transient disturbance to the Virgin River drainage basin created by the Sentinel rock avalanche may thus control upstream base-level and prohibit fluvial incision of bedrock for >10 ka (cf. Hewitt et al., 2011).

CONCLUSIONS

The flat valley floor of modern Zion Canyon owes its origin to a 286 million m^3 rock avalanche at 4.8 ka arising from the catastrophic collapse of a nearly 900-m-high wall of predominantly Navajo Sandstone. Aided by weak layers in the underlying Kayenta Formation, the failure sent material across the canyon at speeds possibly reaching 90 m/s; some deposits retain portions of their original stratigraphy although in a highly deformed state. Field mapping, runout modeling, and cosmogenic nuclide dating support our hypothesis of single-event, catastrophic emplacement of rock avalanche debris. Zion Canyon was blocked over a distance of 3.3 km, damming the Virgin River and creating a lake. At its high-stand, Sentinel Lake may have covered more than 6 km^2, including all of Zion Canyon to The Narrows, but this water level was short-lived as incision of slide debris lowered the breach elevation to ~1345 m. There Sentinel Lake stood relatively stable for ~700 yr until filling with sediment. Today, incision of the rock avalanche dam continues, lowering the base-level of the Virgin River and causing erosion of lacustrine and alluvial materials upstream in Zion Canyon.

Large rock avalanches represent an infrequent but extreme-magnitude hazard in Zion National Park. Our study helps address the dynamics and timing of one such event in the densely utilized area of Zion Canyon; however, deposits of several other large valley-blocking landslides have been documented in the park (Hamilton, 2014). One similar event is the Hop Valley rock avalanche, with an estimated volume in the range of 50 million m^3 and minimum age constrained by radiocarbon dating as ~2.6 k.y. B.P. The consequences of a similar event occurring today, especially within the narrow confines of Zion Canyon, could be disastrous. Moreover, smaller recent landslides have caused notable damage; for example, the 1995 Virgin River slide (Figs. 1A and 3A) affected Zion Canyon's access road, requiring extensive repairs, while the 1990 Middle Fork Taylor Creek slide dammed a remote canyon, which drained suddenly three years later, creating a debris flow that impacted vehicles on a nearby interstate (Lund et al., 2010). Recognition of these hazards, combined with detailed field investigation, dating, and runout analysis, are the first steps toward mitigating landslide risks.

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Manuscript received 12 Oct. 2015; accepted 11 Jan. 2016. ❧

National Park Service Geoscientists-In-the-Parks (GIP) Opportunities

FALL/WINTER 2016–2017

The NPS GIP program places college students and early career professionals (18–35 years old) in National Park Service units for three months to one year to assist with geology and integrated science projects. This program is a partnership between the National Park Service, the Geological Society of America, and Environmental Stewards. Opportunities for fall/winter are posted online and open for applications. **Deadline: 1 July.**

www.geosociety.org/gip

GeoCorps™ America

FALL/WINTER 2016–2017

The next GeoCorps America fall/winter season runs from September 2016 through May 2017. All fall/winter GeoCorps positions are posted on the GeoCorps website and open for applications. **Deadline: 1 July.**

GeoCorps provides paid geoscience opportunities in partnership with government agencies and other organizations committed to science and stewardship, including the U.S. Forest Service and the Bureau of Land Management (BLM). All levels of geoscientists—students, educators, professionals, retirees, and others—are encouraged to apply.

www.geosociety.org/geocorps

www.facebook.com/GeoCorps

GSA 2016 ANNUAL MEETING & EXPOSITION

25–28 SEPTEMBER

GSA 2016

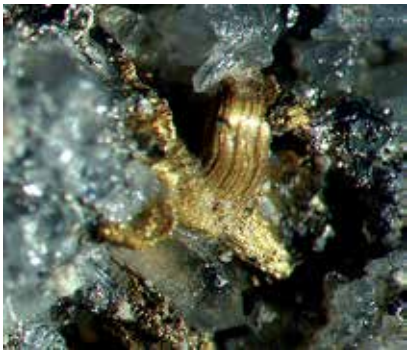
Denver, Colorado, USA

Share your science, network, and explore Colorado

Photo courtesy of the Denver Metro Convention & Visitors Bureau.

THE GEOLOGICAL SOCIETY OF AMERICA®

Contents



Wire gold from the Cash Mine, Gold Hill District, Boulder County, Colorado, USA.

Message from the Annual Meeting General Chair

GSA 2016 Denver Glows with Gold

Pack up your camera and head out to Denver for the annual GSA meeting and fall aspen display that sets the gold standard for leaf gazing. You don't have to go far to find mountainsides ablaze with brilliant orange and yellow.

If you prefer the view of golden hops in a frosty mug, Denver is your dream destination. Colorado is home to more than 230 artisan breweries and is credited with perfecting the art of craft beer. Left Hand Brewing Company and GSA will be unveiling a golden brew specially crafted for conference participants. I'm pretty excited about this year's selection and hope I can avoid spilling the hops before September.

Jed Clampett might have discovered "black gold" in Tennessee, but Colorado is ranked eighth among the states in proven oil reserves. Several field trips will explore the stratigraphy of the Denver Basin and its prime unconventional reservoirs. One field trip will explore Denver's energy grid and look at the role coal, gas, solar, wind, and other renewables play in keeping the lights on. Other field trips will explore the cultural history, legacy, and geology of Colorado's gold and mineral belt.

Need more to keep you busy? With 230 topical sessions, 32 short courses, five Pardee sessions, and 35 field trips throughout the Rocky Mountain region, you can sample a wide variety of spectacular scenery, geology, and topics in the earth sciences.

Even if you have been to Denver before, there is always something new to see and taste. The organizing committee is looking forward to an outstanding conference, and we hope to see you in September.

Karen Berry, Colorado Geological Survey
GSA 2016 General Chair

Thank You GSA 2016 Organizing Committee

GENERAL CHAIR:
Karen Berry, Colorado Geological Survey

TECHNICAL PROGRAM CHAIR:
Paul Baldauf, Nova Southeastern University

TECHNICAL PROGRAM VICE-CHAIR:
Dick Berg, Illinois State Geological Survey

CO-FIELD TRIP CHAIR:
Steve Keller, Colorado Geological Survey

CO-FIELD TRIP CHAIR:
Matt Morgan, Colorado Geological Survey

EDUCATION & OUTREACH CHAIR:
Rick Aster, Colorado State University

K–12 CHAIR:
Samantha Richards, Denver Museum of Nature & Science

Student Committee

Charles Shobe, University of Colorado
Rachel Glade, University of Colorado
Annette Patton, Colorado State University
Jay Merrill, Colorado State University
Sean Smith, Colorado School of Mines
Hank Matthew Cole, Colorado School of Mines
Rania Eldam, Colorado School of Mines

Schedule At-a-Glance

Field Trips and Short Courses, along with a variety of business meetings, will take place between Mon., 12 Sept., and Sat., 1 Oct.

Sunday, 25 September

1. Oral Technical Sessions: 8 a.m.–noon
2. Poster Sessions: 9 a.m.–5:30 p.m.
3. **GeoCareers Day:** 8 a.m.–2 p.m.
4. Lunch Break: noon–1:30 p.m.
5. **GSA Presidential Address and Awards Ceremony:** noon–1:30 p.m.
6. Oral Technical Sessions: 1:30–5:30 p.m.
7. **Exhibits Open:** 2–7 p.m.
8. **Exhibits Opening Reception:** 5:30–7 p.m.

Monday, 26 September

1. Oral Technical Sessions: 8 a.m.–noon
2. Poster Sessions: 9 a.m.–6:30 p.m.
3. **Exhibits:** 10 a.m.–6:30 p.m.
4. Lunch Break: noon–1:30 p.m.
5. **Feed Your Brain:** 12:15–1:15 p.m. *(Lunchtime Enlightenment, buy your food and take it in)*
6. Oral Technical Sessions: 1:30–5:30 p.m.
7. **Libations & Collaborations—Posters & Conversations:** 4:30–6:30 p.m.
8. **Alumni Receptions:** evening hours

Tuesday, 27 September

1. Oral Technical Sessions: 8 a.m.–noon
2. Poster Sessions: 9 a.m.–6:30 p.m.
3. **Exhibits:** 10 a.m.–6:30 p.m.
4. Lunch Break: noon–1:30 p.m.
5. **Feed Your Brain:** 12:15–1:15 p.m. *(Lunchtime Enlightenment, buy your food and take it in)*
6. Oral Technical Sessions: 1:30–5:30 p.m.
7. **Libations & Collaborations—Posters & Conversations:** 4:30–6:30 p.m.

Wednesday, 28 September

1. Oral Technical Sessions: 8 a.m.–noon
2. **Exhibits:** 10 a.m.–2 p.m.
3. Poster Sessions: 9 a.m.–6:30 p.m.
4. Lunch Break: noon–1:30 p.m.
5. **Feed Your Brain:** 12:15–1:15 p.m. *(Lunchtime Enlightenment, buy your food and take it in)*
6. Oral Technical Sessions: 1:30–5:30 p.m.
7. **Libations & Collaborations—Posters & Conversations:** 4:30–6:30 p.m.

Action Dates

▶ Abstracts deadline	12 July
▶ Speaker notifications	Early August
▶ Early registration deadline	22 August
▶ GSA Sections travel grants deadline	22 August
▶ Registration cancellation deadline	29 August
▶ Housing reservations deadline	31 August

Seeking OTF Annual Meeting Mentors

Make a positive impact:
Help an On To the Future student navigate his or her first GSA meeting. Mentors provide real-world information and insight to students and early career professionals at GSA's Annual Meeting. Mentoring can range from one-on-one mentor pairs for the duration of the meeting to short-term mentoring opportunities.

- Learn more at **community.geosociety.org/otf/annualmeetingprogram/mentors.**

50th Anniversary

Association of Earth Science Editors, Annual Meeting

September 28–October 1, 2016 | Boulder, Colorado, USA

Fifty years of excellence in earth science communications

Mark your calendars to attend AESE's 50th anniversary event. The annual meeting is open to AESE members and nonmembers: anyone interested in earth science or science editing and communication.

Photo courtesy of www.colorado.edu

Abstract deadline: July 31
Early Registration: September 1
www.aese.org

Information
John Keith, Technical Program Chair (jkeith@usgs.gov)
Sara Pratt, Host Chair (sepratt@earthmagazine.org)

Visit the AESE booth #714 at GSA2016 Denver!

AESE is an organization of editors, journal managers, and others concerned with publication in the earth sciences. The goals of the organization are to strengthen the profession of earth science editing; to foster education and improve communication in the earth sciences that will lead to more effective dissemination of earth science information to the scientific community, educators and students, and the public.

Accommodations

▶ **Reservation deadline:** 31 August

GSA has negotiated special hotel rates for GSA 2016 attendees. We appreciate your support by staying in the official GSA hotels; your patronage enables GSA to secure the meeting space at a greatly reduced cost, which in turn helps lower the cost of the meeting and your registration fees.

Orchid Event Solutions (OES) is GSA's only official housing company for this meeting—to be included in the GSA room block and receive GSA rates, you must make your reservations through OES. Reservations are taken on a first-come, first-served, space-available basis. We recommend that you make your request early for the best opportunity to get the hotel of your choice.

Booking through OES means you will receive:

- An immediate e-mail acknowledgment of your hotel assignment;
- Free access to the Internet in your guest room; and
- Protection if the hotel has oversold guest rooms.

When rooms are booked at hotels that are not within GSA's official hotel block and/or you do not use OES:

- GSA is exposed to penalties for not fulfilling our room block commitments;
- GSA risks losing the ability to re-book preferred meeting hotels and receive reduced rates in the future; and
- GSA could possibly lose its qualification for the amount of space allowed at the convention center.

Critical Dates

22 Aug.: Last day to cancel rooms without a penalty.

31 Aug.: Reservations *must* be received by this date in order to guarantee rooms at discounted meeting rates.

After 31 Aug.: Reservations will be taken based on availability, and hotels can charge higher rates. Inclusion in GSA's hotel block cannot be guaranteed.

15 Sept.: All changes, cancellations, and name substitutions must be finalized through Orchid Event Solutions.

After 15 Sept.: You must contact the hotel directly with any changes or for new reservations.

Reserving with Orchid Event Solutions

1. **Online at https://resweb.passkey.com/go/GSA16ANNUAL** (for new reservations, modifying an existing reservation, or cancelling).
2. **Phone:** Agents will be available Mon.–Fri., 7 a.m.–6 p.m. MST at +1-855-657-0547 (U.S. toll-free) or +1-801-433-0661 (international).
3. **Print** the hotel reservation form and fax (+1-801-355-0250; do not mail after faxing) or mail the completed form to Orchid Event Solutions, 175 S. West Temple, Suite 30, Salt Lake City, UT 84101, USA.

Special Requests

Please contact OES at +1-855-657-0547 or help@orchideventsolutions.com if you have special requests, including if you need to book a hotel suite. Some requests are not guaranteed and hotels will assign specific room types upon check-in, based on availability.

Acknowledgments

OES will send reservation acknowledgments within 24 hours via email if you booked online or by telephone; fax and mail acknowledgments will be sent within 72 hours of receipt. If you do not receive your acknowledgment in this time frame, contact OES. **You will not receive a confirmation from the hotel.**

Deposits, Cancellations & Changes

All reservation requests must be accompanied by a credit card guarantee or check equaling the amount of one night's room rate plus tax for each room reserved. Reservations cancelled after 22 Aug. OR *prior to* 72 hours of your scheduled arrival will be subject to a US$25 fee for each room cancelled. Your deposit will be forfeited entirely if you cancel *within* 72 hours of your arrival date. Through 15 Sept., please send requests for changes and cancellations via email to OES at help@orchideventsolutions.com or in writing by fax to +1-801-355-0250. After 15 September, contact your hotel directly.

Upgrade/Suite Raffle

To thank you for booking your hotel through OES, you will be entered into a raffle to win a room upgrade for your entire hotel stay. This is valid for reservations booked with a three-night stay or longer. Your reservation must be made by 11 July in order to qualify. Winners will be notified via email 7–10 days after 11 July.

Room Sharing

Use the GSA Travel & Housing Bulletin Board **community.geosociety.org/gsa2016/roomates** to share housing, airport shuttles, and/or carpool. You can also use this service to make arrangements to meet up with your colleagues.

Hotels & Rates (in U.S. dollars; does not include 14.85% tax)

Hotel	Rate (single/double)	More than 2 adults	Distance to CCC	Parking Daily/24-hr**
Hyatt Regency Denver at CCC (HQ Hotel)	$223	$25	Adjacent	$29 self/$39 valet
Grand Hyatt (co-HQ Hotel)	$205	$25	3 blocks	$37 valet
Crowne Plaza Denver Downtown	$179	$10	2 blocks	$27 self
Denver Marriott City Center	$199	$15	3 blocks	$37 valet
Hampton Inn & Suites Denver/Downtown-Conv. Ctr.*	$199	$10	1 block	$30 valet
Hilton Garden Inn Denver Downtown	$195	$10	1 block	$39 valet
Holiday Inn Express Denver Downtown	$161	$10	5 blocks	$35 valet
Homewood Suites Denver/Downtown-Conv. Ctr.	$199	$10	1 block	$39 valet
Hyatt House Denver/Downtown*	$199	$10	2 blocks	$39 valet
Hyatt Place Denver/Downtown*	$199	$10	2 blocks	$39 valet
Sheraton Denver Downtown Hotel	$199	$15	3 blocks	$37 self/$45 valet

*Breakfast included in rate (check hotel websites for specifics regarding breakfast menu).
**Parking rates subject to change; additional fees for oversized vehicles.
Note: All rates are in U.S. dollars.

If you are contacted by a vendor that claims to represent GSA, notify the GSA Meetings Department at meetings@geosociety.org. Please do not make hotel arrangements or share any personal information through any means other than a trusted, secure source. Help make this meeting a success—book early and with **Orchid Event Solutions.**

TRAVEL & TRANSPORTATION

Denver International Airport (DIA; **www.flydenver.com**) is about 35 minutes from downtown Denver. Light rail ("RTD University of Colorado A Line"; US$9) runs from the airport to downtown Denver's Union Station. Union Station is about 1.3 miles from the convention center. Learn more at **www.rtd-denver.com/a-line.shtml.**

Amtrak arrives at Union Station daily via the California Zephyr enroute to and from Glenwood Springs, Salt Lake City, Reno, San Francisco, Omaha, and Chicago. The California Zephyr is among the most scenic train routes in the United States. Connecting Amtrak thruway bus service is also provided for Amtrak's Southwest Chief for rail service to Los Angeles, Grand Canyon, Flagstaff, and Albuquerque. For more information, go to **www.amtrak.com** and or call +1-800-USA-RAIL.

The public transit for metropolitan Denver/Boulder is called "RTD" (for Regional Transportation District). One-day and five-day passes can be purchased for unlimited travel for bus and light rail service in the Denver metro area, along with SkyRide service to/from DIA. Learn more at **www.rtd-denver.com.**

Local Tours

The following local tours are open to all registered GSA Annual Meeting attendees and guests. For short visits and historical tours, it is valuable to have an experienced and knowledgeable tour guide to assist you as you tour the city. Our tour groups are small and provide guests with an opportunity to ask questions and get off the beaten path!

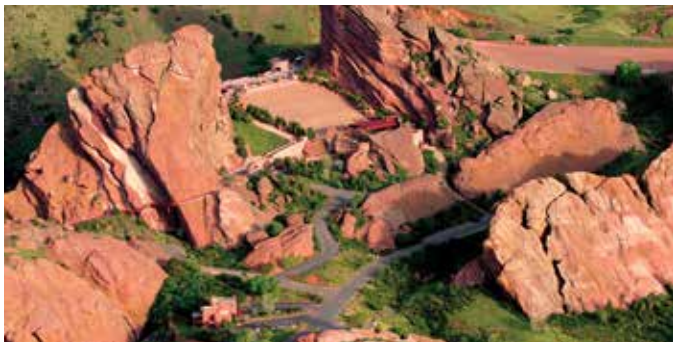


Photo courtesy of the Denver Metro Convention & Visitors Bureau.

101. **A Colorado Hike**

Sun., 25 Sept., 8 a.m.–noon. US$150; min. 20 participants.

Hike at Matthews/Winter Park and Red Rocks Amphitheatre. A creek that winds past wild plum and willow trees greets visitors to Matthews/Winters Park, offering a bucolic setting for picnickers and a starting point for reaching the City of Denver's Red Rocks Park by trail. Across State Highway 93, the Hogback offers a different recreation experience, with a steep climb up to the hulking ridge between plains and foothills. The group will start this beautiful trail together and then can split off into beginner and intermediate trail options. Snacks and water are included.

102. **Denver Bike Bar Microbrewery Tour**

Mon., 26 Sept., 2 p.m.–4 p.m. US$76; min. 15 participants.

The Denver Microbrew Tour is a two-hour guided tour through downtown Denver's historic LoDo (lower downtown), and Ballpark Neighborhood districts on a Bike Bar! Experience the city in a whole new way, pedaling to each brewery to discover why Denver has been dubbed the "Napa Valley of Beer." Taste multiple beers and learn more about the history of beer, how it's made, the different types and how they differ, as well as the history of Denver and how it became the city it is today. This tour is sure to be the most fun you've had in years!

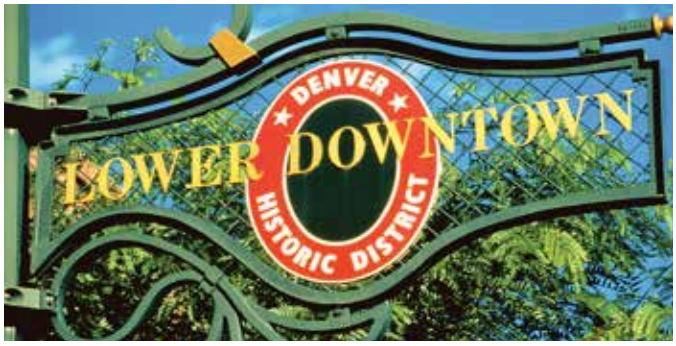


Photo courtesy of the Denver Metro Convention & Visitors Bureau.

103. **Denver "Foodie" Tour**

Tues., 27 Sept., 11 a.m.–2 p.m. US$99; min. 20 participants.

The Mile High City restaurant scene has exploded in recent years with celebrity chefs joining creative Denver chefs to create amazing culinary creations. Experience some of the best Denver "foodie" restaurants with a walking tour that takes you through the Theater District, Lower Downtown (LoDo), and historic Larimer Square, stopping at four restaurants to enjoy samples of their delicious fare and unique beverages. Our tour guide stops at interesting locations along the way to share the unique history of this fascinating part of the city.

Photo courtesy of the Denver Metro Convention & Visitors Bureau.

104. **Denver City Swing**

Wed., 28 Sept., 9 a.m.–noon US$55; min. 20 participants.

The "Mile High City" has many unique and vibrant neighborhoods that guests will experience on a Denver City Swing. You'll tour the downtown finance and business district as well as the revitalized areas of "old" Denver that have been creatively combined with powerful skyscrapers. See the spectacular State Capitol building, one of the many "oohs and ahs" stops. Drive by the spectacular architecture of the Denver Art Museum and Civic Center Park. On the way to Denver's City Park, the city's gem that showcases over 370 lush acres of outdoor space, you'll enjoy driving through trendy Uptown Denver.

GUEST PROGRAM

Penrose Guest Hospitality Suite

Hours: Sun.–Wed., 25–28 Sept., 8 a.m.–5:30 p.m.

We warmly welcome all members of the GSA community to Denver! As part of that welcome, we offer registered guests and Penrose Circle invitees a comfortable Hospitality Suite for rest and relaxation while technical sessions are going on. As a registered guest, you are welcome to attend your companion's technical session(s), and you will have admission to the Exhibit Hall. Activities in the suite include complimentary refreshments, entertaining and educational seminars, and local experts ready to answer your questions about Denver. Local tours and activities will also be offered for an additional fee. We hope that you take advantage of the tours to learn about the area from one of the knowledgeable tour guides.

Seminars

Introduction to Smartphone Photography

Sun., 25 Sept., 10 a.m., Penrose Guest Hospitality Suite

In this workshop, a professional blogger and photographer will advise attendees on how to take pictures that are frame worthy using nothing more than a smartphone, a few simple accessories, and a mix of recommended apps. You'll learn the basics of photography composition, exposure, and lighting using a smartphone as a tool, as well as how to use some basic and inexpensive tools to improve your photos.

Cherry Creek Shuttle

Mon., 26 Sept., 10 a.m.–3 p.m., Penrose Guest Hospitality Suite

A fabulous day of shopping begins with a brief transfer to the Cherry Creek Shopping Center. After meeting in the hospitality suite, the tour will head to one of Colorado's most affluent and distinguished shopping areas. The shopping extravaganza begins with your Passport to Shopping, which offers discounts and savings to more than 60 shops and restaurants. Your group can browse through some of the world's most exclusive shops. Guests will then have the day to shop and enjoy lunch on their own in one of the many excellent restaurants.

Life Cleanse

Wed., 28 Sept., 10 a.m., Penrose Guest Hospitality Suite

This workshop is designed to help you grow and heal in a multitude of areas, including parenting, emotional well-being, balance and fulfillment, relationships, careers, and so much more. This workshop is both informative and interactive in a comfortable and non-judgmental setting.

Registration

- **Early registration deadline:** 22 August
- **Cancellation deadline:** 29 August

Interested in Helping Students Participate in the Meeting?

Every year, a large percentage of students who apply for travel grants do not receive them because funds are limited. You can help by donating as little as US$10 via your registration form; 100% of the money goes to student attendees.

Events Requiring Tickets/ Advance Registration

Several GSA Divisions and Associated Societies will hold breakfasts, lunches, receptions, and awards presentations that require a ticket and/or advance registration (see the meeting website for a complete list). Ticketed events are open to everyone, and tickets can be purchased in advance when you register. If you are not attending the meeting but would like to purchase a ticket to one of these events, please contact the GSA Meetings Department at meetings@geosociety.org.

Continuing Education Credits

The Annual Meeting offers an excellent opportunity to earn CEUs toward your general continuing education requirements for your employer or K–12 school. Credits are available for technical sessions, short courses, and field trips. Ten contact hours are required for one CEU; for example, one day (eight hours) of technical sessions = 0.8 CEUs. We'll post a link on the Annual Meeting website after the meeting so you can print out your CEU certificate.

REGISTRATION FEES (all fees are in U.S. dollars)

	EARLY	STANDARD/ ONSITE
	June–22 Aug.	after 22 Aug.
Member: Professional, full meeting	$399	$485
Member: Professional, one day	$245	$285
Member: Professional, 70+, full meeting	$285	$370
Member: Professional 70+, one day	$185	$210
Nonmember: Professional, full meeting	$575	$650
Nonmember: Professional, one day	$350	$425
Member: Early Career Professional, full meeting	$250	$320
Member: Early Career Professional, one day	$150	$190
Member: Student, full meeting	$125	$160
Member: Student, one day	$79	$89
Nonmember: Student, full meeting	$175	$215
Nonmember: Student, one day	$115	$130
High School Student	$45	$45
K–12 Professional, full meeting	$55	$65
Field Trip or Short Course only	$40	$40
Guest or spouse	$85	$90
Low Income Country*	50%	50%

*Participants from countries classified as "Low or Lower Middle Income Economies" by the World Bank need only pay 50% of the category fee for full meeting or one day registration. Online registration is not available for "Low or Lower Middle Income Economy" registrants. Please fill out a printable version of the registration form and mail it to GSA, 3300 Penrose Place, Boulder, CO 80301, USA. IMPORTANT: Fees for onsite registration will be collected in U.S. dollars and credit cards only.

25-28 SEPTEMBER
GSA 2016
Denver, Colorado, USA

Don't forget to…

- ✔ Register for tours, special events, field trips, and short courses;
- ✔ Bring a copy of your meeting confirmation with you;
- ✔ **STUDENTS:** Be sure to apply for the travel grant program by 22 August;
- ✔ Make your hotel reservation; and
- ✔ Book your travel.

Special Requirements

GSA strives to create a pleasant and rewarding experience for every attendee. Let us know in advance of the meeting if you have needs that require further attention. Most dietary considerations can be met without any extra charge. Be sure to **check the appropriate box** when registering online, and a GSA staff member will contact you. GSA will also have a self-care room on-site for nursing mothers and other needs.

Travel Grants

Various groups, including GSA's Sections, Divisions, and Associated Societies are offering grants to help defray registration, field trip, and travel costs. Eligibility criteria and deadline dates may vary by grant. Go to **attendeeinfo/travel** page on the meeting website to learn more.

For meeting attendees who reside outside of North America, check the International Travel Grant page **www.geosociety.org/GSA_International/travelGrants.htm.** The application deadline for international grants is **17 June.**

Student Members

Volunteer! Earn FREE meeting registration when you volunteer for ten hours, plus get an insider's view of the meeting. Sign up on the **students/volunteers** page of the meeting website and then register for the meeting as a student volunteer. Most jobs will be posted this month, but more may be added as we get closer to the meeting, so check back often.

Media Registration

Complimentary meeting registration is available to journalists from bona fide news organizations as well as public information officers from geoscience-related organizations. Media registration provides access to all scientific sessions, the exhibits area, and the newsroom. Check **community.geosociety.org/gsa2016/press/mediareg** for details.

Event Space Request

You still have time to reserve a room for your business meetings, luncheons, award ceremonies, parties, alumni receptions, and more. Please complete and submit the event space request form via the link at **community.geosociety.org/gsa2016/spacerequest** along with your payment (if applicable). Your request will also allow GSA to include your event listing on the personal scheduler and mobile app. So please let us know about your event—even if it's being held at a restaurant or other venue in the city.

THE GEOLOGICAL SOCIETY OF AMERICA®

Childcare by KiddieCorp

Location: Colorado Convention Center.

Hours: Sat.–Wed., 7 a.m.–6 p.m. daily.

Ages: Six months to 12 years.

Cost: US$9 per hour per child with a consecutive 2-hour min. per child. At least one parent must be registered for the meeting.

Late pick-up fee: US$5 per child for every five minutes the parent is late.

More info: www.kiddiecorp.com/parents.html

Register securely at https://form.jotform.com/KiddieCorp/gsakids

Cancellations: For a full refund, cancellations must be made to KiddieCorp prior to 22 Aug. Cancellations made after 22 Aug. will incur a 50% fee. No refunds after 7 Sept.

Contact: KiddieCorp: +1-858-455-1718, info@kiddiecorp.com

GSA Meetings: meetings@geosociety.org

About: KiddieCorp is a nationally recognized company that provides onsite children's activities for a comfortable, safe, and happy experience for both kids and parents! GSA has used their service for more than 10 years. Childcare services are a contractual agreement between each individual and the childcare company. GSA assumes no responsibility for the services rendered.

Discipline Sessions are created by pooling together abstracts submitted to a particular discipline category.

Topical Sessions are topically focused for a motivating exchange of science. Review the list at science-careers/sessions/topical on the meeting website to see if you'd like to submit an abstract to one of these sessions.

Pardee Keynote Symposia represent leading-edge, interdisciplinary science and address broad, fundamental geoscience issues and/or areas of public policy. Speakers are of high standing in their fields.

Submitting an Abstract

Submission deadline: Tuesday, 12 July

To begin your submission, go to community.geosociety.org/gsa2016/science/sessions. An **abstract submission fee** of US$50 for professionals and US$25 for students will be charged during the submission process.

Two-Abstracts Rule

You may submit two volunteered abstracts, as long as one of the abstracts is for a poster presentation. Each submitted abstract must be different in content; and if you are invited to submit an abstract in a Pardee Keynote Symposium or a topical session, the invited abstracts do not count toward the two-abstract rule.

Abstract Content and Presentation

Abstracts **must describe recent findings** in the realms of science, pedagogy, or their applications. All abstracts undergo **peer review.** Common **reasons for rejection** include dubious conclusions, questionable methodologies, poorly written prose, and incomplete or outdated information. The **Joint Technical Program Committee** (JTPC) will do its best to honor the authors' designations of topical session, discipline, or presentation mode (oral or poster), but **final assignments** remain at the discretion of the Technical Program Chair. Session scheduling and presentation modes are firm once assigned. Please familiarize yourself with and adhere to the **GSA Code of Ethics** for abstract publication and meeting presentation (p. 23).

Authors

Enhance your professional reputation by submitting a refined abstract. Then, deliver an admirable presentation.

Please adhere to the **Code of Ethics** (p. 23) regarding content, authorship, and scholarship.

Presenting authors can deliver two abstracts during the meeting, which can consist of one volunteered oral presentation and one volunteered poster presentation, or two poster presentations.

The only exemption to this policy is if an author is also invited to give a presentation in either a Pardee Keynote Session or a Topical Session, because invited abstracts are not counted. Invited presenters will receive a PIN to exempt that abstract.

If the session to which a presenting author is invited is cancelled, that abstract will lose its exempted status.

All presenting authors, including invited speakers, **must pay their registration fees** plus any other expenses they might incur in association with the GSA meeting.

Co-Authors can be listed on any number of additional abstracts, just not as the presenting co-author.

Acceptance notifications will be delivered within three weeks after the abstract deadline to allow sufficient time to make travel arrangements.

Poster Presenters

Once your abstract is approved, you will be assigned a date for your presentation. Please hang your posters in accordance with the following schedule:

Sunday: On display 9 a.m.–5:30 p.m.; authors present 3:30–5:30 p.m.

Monday–Wednesday: On display 9 a.m.–6:30 p.m.; authors present 4:30–6:30 p.m.

We'll provide one horizontal, freestanding 8-ft-wide × 4-ft-high display board and Velcro for hanging your poster; a shared (with one other poster) 6-ft-long × 30-inch-wide table; and Wi-Fi.

Complementary electricity will not be available this year, so please plan your presentation accordingly.

Want to present your poster digitally? As a poster presenter, you will be given the opportunity to present your poster in a

Learn what makes a story newsworthy at
community.geosociety.org/gsa2016/science-careers/sessions/requestpr.

Submit a press release request at **http://google/forms/oTc51UbRXB.**

digital format. More information will be provided with the acceptance notices. Presenters are responsible for all fees associated with this type of presentation.

Oral Presenters

The normal length of an oral presentation is 12 minutes, plus three minutes for questions and answers. All technical session rooms will be equipped with a PC using MS Office 2013. You must visit the Speaker Ready Room at least 24 hours before your scheduled presentation to run through your talk and make sure it is compatible with the convention equipment.

Request a Press Release

Each year, GSA works to highlight scientific presentations from the Annual Meeting that may be of wider interest beyond the GSA community.

If you are presenting new research that you would like to share with science journalists and the audiences they write for, please e-mail us at communications@geosociety.org. Adequate lead-time is important; we cannot generate publicity for papers that come to our attention during the last days leading up to the meeting.

When submitting an abstract, you will be asked for your agreement to the following:

GSA Code of Ethics for Abstracts Publication and Meeting Presentation

Working together as a community of geoscientists, we will continue to advance the finest science in a respectable, professional manner. Authors will display integrity in disseminating their research. Presentations will adhere to the content and conclusions of abstracts, as submitted and reviewed. Listed co-authors will have made a bona fide contribution to the project. Conversely, the presenter should remain gracious by offering collaborators the opportunity for recognition as a co-author. All co-authors must be aware of their inclusion and have accepted that recognition. Presenters must be diligent in preparing a polished product that conveys high-quality scholarship. Submission of an abstract implies a sincere intent to attend the meeting.

PROGRAMS

The Geological Society of America®

GEOCAREERS

community.geosociety.org/gsa2016/science-careers/careers

GSA 2016 offers opportunities for career development—no matter where you are in your career. **Just getting started?** Get a well-rounded introduction to industry and government careers by attending this program in its entirety.

GEOCAREERS DAY • Sunday, 25 Sept., 8 a.m.–2 p.m.

Registration is required and space is limited. BEST VALUE all-inclusive fee: US$25. Sign up when you register for the meeting or contact GSA Sales & Service at gsaservice@geosociety.org or +1-800-443-4472.

Career Workshop: 8–9 a.m. US$10 fee if attending separately.

Successfully prepare for a career in the industry and government sectors. This workshop will be divided into 20-minute power sessions, reviewing résumés for industry, USA jobs, and Q&A.

Career Information Session: 9 a.m.–11 a.m. This is your opportunity to ask questions and talk one-on-one with corporate and government representatives. You'll learn about their unique work cultures and the types of careers available.

Career Mentor Roundtables: 11 a.m.–2 p.m. Mentors from a variety of sectors will answer your career questions at table stations around the room.

Career Pathways Panel (includes lunch): noon–1 p.m. Representatives from government and industry sectors will answer questions and offer advice in preparation for a career in these fields. Lunch ticket provided, but lunch is limited to first come, first served. All-day participants receive priority. *GeoCareers Day events may be attended separately, but why not make a day of it?*

NETWORKING AND PANEL EVENTS

Women in Geology Career Pathways Reception: Sun., 25 Sept., 5:30–7 p.m. This informal gathering begins with remarks from a few key women speakers who will address issues faced by women in geology. A roundtable mentoring session follows, providing time for networking, sharing ideas, and getting to know other women geoscientists.

The Paleontological Society Mentors in Paleontology Careers Luncheon: Mon., 26 Sept., noon–1 p.m. This student luncheon features a panel of mentors representing a variety of colleges, universities, museums, and government agencies.

MORE WORKSHOPS

Science Communication: "Be Heard & Be Interesting" Sat., 24 Sept., 8 a.m.–noon. Professionals: US$35; students: US$25; includes continental breakfast. Limited seating. Sign up when you register or call GSA Sales & Service at +1-800-443-4472.

Hone your public communication skills and practice in a safe and comfortable setting. Learn to create clear and concise messages that are targeted to your audience, as well as how to prepare for a media interview. Develop strategies for using social media, identify opportunities for speaking in your community, and gain an understanding of how to approach policy makers on scientific issues.

Publishing: "What's Your Problem; What's Your Point?" Sun., 25 Sept., 11:30 a.m.–2 p.m. Experienced GSA science editors will explain the process of preparing your research for submission to scholarly journals. An application is required; find complete information at **www.geosociety.org/pubs/writersResource.htm.**

EMPLOYMENT ASSISTANCE

Résumé Clinic: Sun., 25 Sept., 9 a.m.–5 p.m. US$10; registration required (sign up when you register for the meeting). Reserve your 30-minute private consultation with a geoscience professional to review your résumé and discuss strategies to better market yourself to potential employers. Please bring a copy of your current résumé. Space is limited; sign up early to guarantee a spot.

Geoscience Job Board: Check the on-site job board for open opportunities and the online Geoscience Job Board (www.geosociety.org/classiads/) for employment, fellowship, and student opportunities.

Scientific Field Trips

Descriptions and leader bios are online. ECP—early career professional.

Before the Meeting

401. **GSA International Student Field Trip to National Parks in the Western U.S.** Sixteen days: Wed.–Thurs., 7–22 Sept. US$1,000. Cosponsor: GSA International. Leader: Anke Friedrich.

402. **A Visit to the Regional Aluminum Silicate Triple-Point Metamorphic Rocks of Northern New Mexico: A Field Trip to Honor the Career Contributions of Lincoln Hollister to Petrology and Tectonics.** Four days: Wed.–Sat., 21–24 Sept. US$499; limited student/ECP price: US$250. Cosponsors: GSA Structural Geology & Tectonics Division; GSA Mineralogy, Geochemistry, Petrology and Volcanology Division. Leaders: Christopher G. Daniel; Christopher L. Andronicos.

403. **Transect of Mesoproterozoic Belt Basin, Glacier National Park, Montana.** Two days: Thurs.–Fri., 22–23 Sept. US$275; limited student/ECP price: US$145. Leaders: James W. Sears; John S. MacLean.

404. **Dynamic Topography, Regional Uplift, and Integration History of the Colorado–Green River Systems.** Four days: Wed.–Sat., 21–24 Sept. US$585; limited student/ECP price: US$325. Cosponsor: GSA Quaternary Geology and Geomorphology Division. Leaders: Andres Aslan; Karl E. Karlstrom; Eric Kirby.

405. **Sequence Stratigraphy, Stratal Patterns, and Hydrodynamics of the Upper Cretaceous Iles (Mount Garfield) and Williams Fork (Hunter Canyon) Formations, Grand Junction Area, Colorado.** Four days: Wed.–Sat., 21–24 Sept. US$495; limited student/ECP price: US$250. Leaders: Diane L. Kamola; Jesse Thompson; Benjamin Campanaro.

406. **Getting to the Bottom of the High Plains Aquifer: New Insights into the Depositional History, Stratigraphy, and Paleoecology of the Cenozoic High Plains.** Three days: Thurs.–Sat., 22–24 Sept. US$399; limited student/ECP price: US$200. Cosponsors: GSA Sedimentary Geology Division; SEPM (Society for Sedimentary Geology); GSA Soils and Soil Processes Interdisciplinary Interest Group; GSA Geology and Public Policy Committee; GSA Geology and Society Division. Leaders: Jon J. Smith; Anthony L. Layzell; William E. Lukens; Matthew L. Morgan; Stephen M. Keller.

407. **Exploring the Ancient Volcanic and Lacustrine Environments of the Oligocene Creede Caldera and Environs, San Juan Mountains, Colorado.** Three days: Thurs.–Sat., 22–24 Sept. US$325; limited student/ECP price: US$175. Leaders: Daniel Larsen; Peter W. Lipman.

408. **Depositional Systems of the Rockies.** Three days: Thurs.–Sat., 22–24 Sept. US$560; limited student/ECP price: US$295. Cosponsor: Energy and Geoscience Institute, University of Utah. Leaders: R. William Keach II; Tom Anderson.

409. **From Terraces to Terroir: Exploring Geology and Wineries on Colorado's Western Slope.** Three days: Thurs.–Sat., 22–24 Sept. US$390. Leaders: Terri L. Cook; Lon D. Abbott.

410. **Geomorphic Evolution of the San Luis Basin and Rio Grande.** Three days: Wed.–Fri., 21–23 Sept. US$290; limited student/ECP price: US$145. Cosponsor: GSA Quaternary Geology and Geomorphology Division. Leaders: Cal Ruleman; Michael N. Machette; Ren Thompson.

411. **Geoheritage along the Gold Belt Byway, Colorado: Initiatives to Promote the Legacy of Geologic History for Local Communities.** Two days: Fri.–Sat., 23–24 Sept. US$345; limited student/ECP price: US$175. Cosponsors: William Smith Bicentenary Committee; GSA History and Philosophy of Geology Division. Leaders: Herb Meyer; Melissa Smeins.

412. **Cretaceous Ocean-Climate Perturbations Revealed in Cenomanian-Campanian Strata of Colorado: Field Trip Associated with Symposium Honoring the Scientific Contributions of Michael A. Arthur.** Two days: Fri.–Sat., 23–24 Sept. US$299; limited student/ECP price: US$150. Leaders: Bradley B. Sageman; R. Mark Leckie; Richard Barclay; Christopher M. Lowery.

413. **Stromatolite Variability in the Nash Fork Formation, Southeastern Wyoming: A Walking Tour across a Paleoproterozoic Carbonate Shelf.** Two days: Fri.–Sat., 23–24 Sept. US$325; limited student/ECP price: US$175. Leaders: David R. Lageson; Donald W. Boyd.

414. **Overview of the Eocene Castle Rock Conglomerate, East-Central Colorado: Remapping the Fluvial System and Implications for the History of the Colorado Piedmont and Front Range.** One day: Sat., 24 Sept. US$89; limited student /ECP price: US$45. Cosponsor: Colorado Geological Survey. Leaders: Stephen M. Keller; Matthew L. Morgan.

415. **Unconventional Reservoirs and Stratigraphy of the Southern Denver Basin: Graneros, Greenhorn, Carlile, and Niobrara Formations.** Two days: Sat.–Sun., 24–25 Sept. US$425; limited student/ECP price: US$225. Cosponsor: GSA Energy Geology Division. Leaders: Jeffrey Allyn May; Russell "Tofer" Lewis.

416. **Geology along the Colorado Front Range near Morrison and Golden.** One day: Sat., 24 Sept. US$99; limited student/ECP price: US$50. Cosponsor: GSA Members of the Friends of Dinosaur Ridge. Leaders: Norb Cygan; Tim Connors; Lou Taylor.

417A. **An Accessible Journey through Geologic Time in Central Colorado.** For higher education students with disabilities and geoscience faculty. One day: Sat., 24 Sept. US$50; limited student/ECP price: US$25. Cosponsors: GSA Geoscience Education Division; International Association for Geoscience Diversity. Leaders: Christopher L. Atchison; Brett H. Gilley; Cheryl L.B. Manning; Julie Maxson; Carla McAuliffe; Aisha R. Morris; Leilani Arthurs; Wendi J.W. Williams.

417B. **An Accessible Journey through Geologic Time in Central Colorado.** For middle and high school students with disabilities and science teachers. One day: Sat., 24 Sept. *Link will be provided on GSA registration website to apply* Cosponsors: GSA Geoscience Education Division; International Association for Geoscience Diversity. Leaders: Christopher L. Atchison; Brett H. Gilley; Cheryl L.B. Manning; Julie Maxson; Carla McAuliffe; Aisha R. Morris; Leilani Arthurs; Wendi J.W. Williams.

418. **Geology, Hydrology, Water Rights, and History of the Mineral Waters of Manitou Springs**. One day: Sat., 24 Sept. US$120; limited student/ECP price: US$60. Leaders: Ralf Topper; Christine Siddoway; Melissa A. Peterson.

419. **Management of Acid Mine Drainage in the Colorado Mineral Belt.** One day: Sat., 24 Sept. US$195; limited student/ECP price: US$99. Cosponsor: Hatch Associates Consultants, Lakewood, Colorado, USA. Leaders: Devin Castendyk; Kato T. Dee; Garret Rue.

420. **Pinedale Glacial History of the Upper Arkansas River Valley: New Moraine Chronologies, Modeling Results, and Geologic Mapping.** One day: Sat., 24 Sept. US$85; limited student/ECP price: US$45. Cosponsor: GSA Quaternary Geology and Geomorphology. Leaders: Avriel D. Schweinsberg; Jason P. Briner; Ralph R. Shroba; Joseph M. Licciardi; Eric M. Leonard; Keith A. Brugger.

421. **Restoring the Headwaters of the Arkansas River: A Bike and Underground Tour of the Leadville Mining District and Modern Reclamation Efforts to Minimize the Effects of Acid Mine Drainage.** One day: Sat., 24 Sept. US$99; limited student/ECP price: US$50. Cosponsor: Colorado Mountain College, Leadville, Colorado, USA. Leader: Jacob Mohrmann.

422. **Roadside Faults, Folds, Fossils, Crystals, and Diamond Pipes—Sampling the Geologic Diversity of Northern Colorado.** One day: Sat., 24 Sept. US$99; limited student/ECP price: US$50. Leaders: Uwe Kackstaetter; Barbara EchoHawk.

423. **The Consequences of Living with Geology.** One day: Sat., 24 Sept. US$110; limited student/ECP price: US$55. Cosponsors: American Institute of Professional Geologists; Association of Engineering and Environmental Geologists. Leaders: David M. Abbott Jr.; David C. Noe.

During the Meeting

424. **Kirk Bryan Field Trip: Quaternary Landslides, Fluvial Terraces, and Recent Geomorphic Events along the Colorado Front Range.** One day: Tues., 27 Sept. US$99; limited student/ECP price: US$50. Cosponsors: GSA Quaternary Geology and Geomorphology Division; Boulder Creek Critical Zone Observatory; Colorado Scientific Society. Leaders: Melissa A. Foster; Robert S. Anderson.

After the Meeting

425. **Late Holocene Landscape Evolution in the White River Badlands.** Four days: Fri.–Sun., 29 Sept.–2 Oct. US$525; limited student/ECP price: US$275. Leaders: Patrick Burkhart; Paul Baldauf.

426. **Middle to Late Cenozoic Geology and Geomorphology of the Laramie Mountains, Wyoming.** Two days: Thurs.–Fri., 29–30 Sept. US$199; limited student/ECP price: US$99. Cosponsor: Colorado Scientific Society. Leader: Emmett Evanoff.

427. **Progressive Development of Basement-Involved Foreland Thrust Belts: Results from the NSF/EarthScope Bighorn Project Applied to the Laramide Orogeny in the Colorado Front Range.** One day: Thurs., 29 Sept. US$75; limited student/ECP price: US$40. Leaders: Eric A. Erslev; Karen Aydinian; Laura E. Kennedy.

428. **South Park: Complex Structure and Stratigraphy Create One of Colorado's Crown Jewels.** One day: Thurs., 29 Sept. Cosponsors: Colorado Geological Survey; Colorado Scientific Society; Coalition for the Upper South Platte. US$99; limited student/ECP price: US$50. Leaders: Peter Barkmann; Marieke Dechesne; Edward J. Sterne; Karen J. Houck.

429. **Large Hydrothermal Systems above the Yellowstone Magma Chamber.** Five days: Thurs.–Mon., 29 Sept.–3 Oct. US$599; limited student/ECP price: US$300. Leaders: Lisa A. Morgan; W.C. Pat Shanks; Robert A. Sohn.

430. **New Perspectives on a 140-Year Legacy of Mining and Abandoned Mine Cleanup in the San Juan Mountains, Colorado.** Four days: Thurs.–Sun., 29 Sept.–2 Oct. US$650; limited student/ECP price: US$325. Cosponsors: U.S. Geological Survey Central Mineral and Environmental Resources Science Center; Navarro Research and Engineering Inc. (contractor to the U.S. Department of Energy Office of Legacy Management). Leaders: Douglas B. Yager; Raymond H. Johnson; David L. Fey.

431. **Slime, Redbeds, and Evaporites in an Eolianite Sandwich: The Permian-Triassic of Colorado & Southeastern Wyoming.** One day: Thurs., 29 Sept. US$85; limited student/ECP price: US$45. Leaders: James W. Hagadorn; Karen R. Whiteley; Bonita L. Lahey; Woods J. Alee.

432. **Conodonts and Early Fish in Colorado's Shallow, Early Paleozoic Seas.** One day: Thurs., 29 Sept. US$110; limited student/ECP price: US$55. Leaders: F. Nicole Peavey; Ivan J. Sansom Sr.

433. **Sandstones and Utah's Canyon Country: Deposition, Diagenesis, Exhumation, and Landscape Evolution.** Four days: Thurs.–Sun., 29 Sept.–2 Oct. US$575; limited student/ECP price: US$295. Cosponsor: SEPM (Society for Sedimentary Geology). Leaders: David B. Loope; Richard M. Kettler; Peter W. Reiners; Kendra Murray; Joel L. Pederson.

434. **U.S. Geological Survey Collections: Understanding the Past to Create a Future—Tour Three Federal Repositories, Paleontological Collections, Core Research Center, National Ice Core Laboratory.** One day: Thurs., 29 Sept. US$10; limited student/ECP price: US$5. Cosponsor: U.S. Geological Survey. Leaders: Natalie E. Latysh; Kevin C. McKinney.

435. **How to Make the Lights Turn on with a Clap—A Tour of Colorado's Energy Grid.** One day: Thurs., 29 Sept. US$99; limited student/ECP price: US$50. Cosponsors: Colorado School of Mines Energy and Minerals Field Institute; Colorado Geological Survey. Leaders: Barry Martin; Tom Sladek; Karen A. Berry.

Photo by Bret Webster.

Meet Us in the Social Media–Sphere

Twitter: https://twitter.com/geosociety
Follow hashtag #GSA2016

Facebook: https://www.facebook.com/GSA.1888

LinkedIn: https://www.linkedin.com/company/geological-society-of-america

GSA's Connected Community: community.geosociety.org

Associated Society Field Trip

Society of Economic Geologists (SEG)

Mineral Deposits and Geology of the Silver City Mining District and Owyhee Mountains, Southwestern Idaho. Three and a half days: Arrive Tuesday evening, 20 Sept., in Silver City, Idaho, USA; depart 9 a.m. Saturday, 24 Sept. Note: This field trip begins and ends at the Boise, Idaho, USA, airport (BOI). Leaders: Jim Saunders, saundja@auburn.edu; Matt Brueseke; Virginia Gillerman. Register via the SEG website: **www.segweb.org/events.**

5th International EarthCache Event

Saturday, 24 Sept. 2016 | Denver, Colorado, USA

EarthCaching gets people out in the field to learn about their planet first-hand. Participants in this annual event will learn all about EarthCaching, interact with EarthCachers from around the globe, meet EarthCache developers and reviewers, find local EarthCaches, and engage in many other exciting and educational activities. The 2016 event will be held in conjunction with the GSA Annual Meeting, which provides a unique opportunity for GSA members to connect with the EarthCaching and Geocaching communities! For details, go to www.earthcache.org, www.facebook.com/earthcache, or contact Matt Dawson at mdawson@geosociety.org.

Let the Earth be your teacher!

THE GEOLOGICAL SOCIETY OF AMERICA®

Short Course Topics

for Professionals, Students, Faculty, & K–12 Teachers

- **Early registration deadline:** 22 August
- **Registration after 22 August** will cost an additional US$30.
- **Cancellation deadline:** 29 August

The following short courses are open to everyone. Early registration is highly recommended to ensure that courses will run.
Can I take a short course if I am not registered for the meeting? YES! You're welcome to—just add the meeting nonregistrant fee (US$40) by 22 Aug. to your course enrollment cost. Should you then decide to attend the meeting, your payment will be applied toward meeting registration.
GSA K–12 teacher members: You are welcome to take short courses without registering for the meeting or paying the nonregistrant fee.
Continuing Education Units (CEUs): Most professional development courses and workshops offer CEUs. One CEU comprises 10 hours of participation in an organized continuing education experience under responsible sponsorship, capable direction, and qualified instruction.

See **community.geosociety.org/gsa2016/science-careers/courses** or contact Jennifer Nocerino, jnocerino@geosociety.org, for course abstracts and additional information.

501. **Introduction to Terrestrial Laser Scanning (Ground-Based LiDAR) for Earth Science Research and Education.** Fri., 23 Sept., 8 a.m.–5 p.m. US$50; lunch included. Limit: 20. CEU: 0.8. **Instructors:** Christopher Crosby, UNAVCO; Marianne Okal, UNAVCO. **Cosponsor:** UNAVCO.

502. **Sequence Stratigraphy for Graduate Students.** Fri.–Sat., 23–24 Sept., 8 a.m.–5 p.m. $US25. Limit: 55. CEUs: 1.6. **Instructors:** Bret Dixon, Anadarko; Morgan Sullivan, Chevron. **Cosponsor:** Anadarko.

503. **Structural and Stratigraphic Concepts Applied to Basin Exploration.** Fri.–Sat., 23–24 Sept., 8 a.m.–5 p.m. US$25, includes lunch. Limit: 30. CEUs: 1.6. **Instructors:** Bob Stewart, ExxonMobil Exploration Co.; Tonya Brami, ExxonMobil Exploration Co. **Cosponsors:** ExxonMobil Exploration Co.; GSA Sedimentary Geology Division.

504. **Advanced Sequence Stratigraphic Applications for Exploration**. Fri.–Sat., 23–24 Sept., 8 a.m.–5 p.m. US$ 322. Limit: 25. CEUs: 1.6. **Instructor:** Vitor Abreu, Consultant.

505. **GIS-Based Spatial Mathematical Modeling for Mineral Exploration**. Fri.–Sat., 23–24 Sept., 8 a.m.–5 p.m. US$ 207. Limit: 20. CEUs: 1.6. **Instructors:** Alok Porwal, Indian Institute of Technology Bombay Mumbai; Bijal Chudasama, Indian Institute of Technology Bombay Mumbai.

506. **Facilitating Effective STEM Learning and Public Engagement in Paleontology.** Fri., 23 Sept., 1–5 p.m. US$25. Limit: 30. CEU: 0.4. **Instructors:** Bruce MacFadden, Florida Museum of Natural History; Kent Crippen, Univ. of Florida; Ronny Leder, Florida Museum of Natural History; Eleanor Gardner, Florida Museum of Natural History; Lisa Lundgren, Univ. of Florida; Victor Perez, Univ. of Florida. **Cosponsor:** The FOSSIL Project.

507. **Digital Technology across the Earth Science Curriculum—A Short Course for Preservice and In-Service Teachers and Undergraduate Instructors**. Sat., 24 Sept., 8 a.m.–4 p.m. US$25. CEU: 0.7. Limit: 25. **Instructors:** Declan De Paor, Old Dominion Univ.; Steve Whitmeyer, James Madison Univ.; Callan Bentley, Northern Virginia Community College; Bill Richards, North Idaho College; Kristen St. John, James Madison Univ.; Barb Tewksbury, Hamilton College. **Cosponsors:** GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geoinformatics Division; GSA Geology and Society Division; GSA Geophysics Division; GSA Geoscience Education; GSA Hydrogeology Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Planetary Geology Division; GSA

Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; GSA Structural Geology and Tectonics Division. **EXTRA!** Upon completion of the course, participants will receive a US$25 coupon redeemable at GSA's onsite bookstore.

508. **Ground-Penetrating Radar: Principles, Practice, and Processing.** Sat., 24 Sept., 8 a.m.–5 p.m. US$70. Limit: 24. CEU: 0.8. **Instructors:** Greg Johnston, Sensors & Software Inc.; Troy De Souza, Sensors & Software Inc. **Cosponsor:** Sensors & Software Inc.

509. **Using Laser Ablation Split Stream (LASS) Geochronology and Petrochronology to Address Tectonic & Petrologic Questions.** Sat., 24 Sept., 8 a.m.–5 p.m. US$50, includes lunch. Limit: 35. CEU: 0.8. **Instructors:** John Cottle, Univ. of California Santa Barbara; Bradley Hacker, Univ. of California Santa Barbara; Andrew Kylander-Clark, Univ. of California Santa Barbara. **Cosponsors:** Nu Instruments; Teledyne CETAC; Agilent.

510. **Geochemical Applications of pXRF: Environmental, Exploration, and Geology.** Sat., 24 Sept., 8 a.m.–5 p.m. US$40, includes lunch. Limit: 40. CEU: 0.8. **Instructors:** Ross Knight, Geological Survey of Canada; Bruce Kjarsgaard, Geological Survey of Canada; Lawrence Lemke, Wayne State Univ.; Samuel Mutiti, Georgia College and State Univ. **Cosponsors**: GSA Environmental and Engineering Geology Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; Bruker Scientific.

511. **Practical Techniques for Using Temperature as a Tracer in Hydrological Research.** Sat., 24 Sept., 8 a.m.–5 p.m. US$150. Limit: 20. CEU: 0.8. **Instructors:** Jeffrey McKenzie, McGill Univ.; Barret Kurylyk, Univ. of Calgary; Laura Lautz, Syracuse Univ.; Dylan Irvine, Monash Univ.

512. **Acid Rock Drainage (ARD) Characterization: A Critical Component of Life Cycle Planning and Management of Metal Mines.** Sat., 24 Sept., 8 a.m.–5 p.m. US$125. Limit: 20. CEU: 0.8. **Instructors:** Madhumitha Raghav, Freeport-McMoRan Inc.; Sarah Doyle, Integral Consulting Inc.; Erick Weiland, Freeport-McMoRan Inc.

513. **Vapor Intrusion: Scientific, Regulatory, and Field Perspectives.** Sat., 24 Sept., 8 a.m.–5 p.m. US$249. Limit: 30. CEU: 0.8. **Instructors:** Stephen Van der Hoven, Genesis Engineering & Redevelopment Inc.; Tissa Illangasekare, Colorado School of Mines.

514. **The Essentials to Building Realistic and Reliable 3D Geological Models.** Sat., 24 Sept., 8 a.m.–5 p.m. US$130, includes lunch. Limit: 40. CEU: 0.8. **Instructors:** Kelsey MacCormack, Alberta Geological Survey; Harvey Thorleifson, Minnesota State Geological Survey; Richard Berg, Illinois State Geological Survey.

515. **Organic, Light, and Clumped Stable Isotope Geochemistry in the Twenty-First Century: Principles, Practices and Novel Applications.** Sat., 24 Sept., 8 a.m.–5 p.m. US$50; lunch included. Limit: 30. CEU: 0.8. **Instructors:** Katie Snell, Univ. of Colorado, Boulder; Brett Davidheiser-Kroll, Univ. of Colorado, Boulder; Sebastian Kopf, Univ. of Colorado, Boulder; Julio Sepulveda, Univ. of Colorado, Boulder. **Cosponsors:** Thermo Scientific; Univ. of Colorado, Boulder, Geological Sciences; INSTAAR.

516. **Preparing for a Career in the Geosciences.** Sat., 24 Sept., 8 a.m.–noon. US$50. Limit: 40. CEU: 0.4. **Instructors:** Paul Klipfel, Mineral Resource Services Inc.; Heather Houlton, American Geosciences Institute; Christopher Keane, American Geosciences Institute. **Cosponsor:** American Geosciences Institute.

517. **Teaching about Climate Change and Hazards: Data-Rich Teaching Modules for Introductory Courses.** Sat., 24 Sept., 8 a.m.–noon. US$25. Limit: 30. CEU: 0.4. **Instructors:** Becca Walker, Mount San Antonio College; Beth Pratt-Sitaula, UNAVCO. **Cosponsors:** GETSI (GEodetic Tools for Societal Issues); UNAVCO; National Association of Geoscience Teachers.

518. **Teaching the Anthropocene: Controversial Issues 1.** Sat., 24 Sept., 8 a.m.–noon. US$35. Limit: 40. CEU: 0.4. **Instructors:** Don Duggan-Haas, Paleontological Research Institution and its Museum of the Earth; Mark Nielsen, Howard Hughes Medical Institute; Minda Berbeco, National Center for Science Education; Glenn Dolphin, Univ. of Calgary; Robert Ross, Paleontological Research Institute and its Museum of the Earth. **Cosponsors:** National Association of Geoscience Teachers; GSA Geoscience Education Division.

519. **Interactive Strategies for the Classroom: A How-To Guide Using Examples about Igneous Rocks**. Sat., 24 Sept., 8 a.m.–noon. US$35. Limit: 40. CEU: 0.4. **Instructors:** Karen Kortz, Community College of Rhode Island; Jessica Smay, San Jose City College. **Cosponsors:** National Association of Geoscience Teachers (NAGT); Geo2YC Division of NAGT; National Science Foundation.

520. **Making Plate Reconstructions with GPlates: Applications for Teaching and Research**. Sat., 24 Sept., 8 a.m.–noon. US$75. Limit: 30. CEU: 0.4. **Instructors:** Chris Scotese, PALEOMAP Project; Michael Tetley, California Institute of Technology.

521. **Top Tips for Publishing Success.** Sat., 24 Sept., 8 a.m.–noon. US$10. Limit: 40. CEU: 0.4. **Instructors:** Matt Cannon, Taylor & Francis; Lauren Herman, Taylor & Francis. **Cosponsor:** Taylor & Francis journals.

522. **Using Terrestrial Laser Scanning (TLS) and Structure from Motion (SfM) in Undergraduate Field Courses**. Sat., 24 Sept., 8 a.m.–noon. US$25. Limit: 35. CEU: 0.4. **Instructors:** Bruce Douglas, Indiana Univ.; Christopher Crosby, UNAVCO. **Cosponsors:** UNAVCO; GEodetic Tools for Societal Issues (GETSI); National Association of Geoscience Teachers.

523. **U-Th-Pb Geochronology Using ET_Redux (Data Reduction) and Geochron (Database).** Sat., 24 Sept., 9 a.m.–5 p.m., US$30. Limit: 40. CEU: 0.7. **Instructors:** George Gehrels, Univ. of Arizona; Jim Bowring, College of Charleston; Noah McLean, Univ. of Kansas; Doug Walker, Univ. of Kansas.

524. **Introduction to Numerical Modeling of Lithospheric Deformation in Matlab.** Sat., 24 Sept., 9 a.m.–5 p.m. US$20. Limit: 25. CEU: 0.7. **Instructors:** Eric Mittelstaedt, Univ. of Idaho; Jean-Arthur Olive, Columbia Univ.; John Naliboff, Univ. of California Davis. **Cosponsor:** Computational Infrastructure for Geodynamics. **EXTRA!** Upon completion of the course, participants will receive a US$20 coupon redeemable at GSA's onsite bookstore.

525. **Introduction to Structure from Motion (SfM) Photogrammetry for Earth Science Research and Education.** Sat., 24 Sept., 9 a.m.–5 p.m. US$30, includes lunch. Limit: 40. CEU: 0.7.
Instructors: Edwin Nissen, Colorado School of Mines; Ramon Arrowsmith, Arizona State Univ.; Christopher Crosby, UNAVCO. **Cosponsor:** UNAVCO.

526. **High-Resolution Site Characterization (HRSC) for Complex Contaminant Sites.** Sat., 24 Sept., 1–5 p.m. US$110. Limit: 40. CEU: 0.4. **Instructors:** Todd Halihan, Oklahoma State Univ.; Marcy Bogren, Aestus LLC; Stuart McDonald, Aestus LLC.

527. **Analyzing Active Tectonics with LiDAR, InSAR, and GPS: Using Geodetic Data in Major-Level Courses.** Sat., 24 Sept., 1–5 p.m. US$25. Limit: 30. CEU: 0.4. **Instructors:** Bruce Douglas, Indiana Univ.; Vince Cronin, Baylor Univ.; Beth Pratt-Sitaula, UNAVCO. **Cosponsors:** GETSI (GEodetic Tools for Societal Issues); UNAVCO; National Association of Geoscience Teachers.

528. **Teaching the Evolution of Life & Earth: Controversial Issues 2.** Sat., 24 Sept., 1–5 p.m. US$35. Limit: 40. CEU: 0.4. **Instructors:** Don Duggan-Haas, Paleontological Research Institution and its Museum of the Earth; Mark Nielsen, Howard Hughes Medical Institute; Minda Berbeco, National Center for Science Education; Glenn Dolphin, Univ. of Calgary; Robert Ross, Paleontological Research Institute and its Museum of the Earth. **Cosponsors:** National Association of Geoscience Teachers; GSA Geoscience Education Division.

529. **Microbially Induced Sedimentary Structures (MISS)—Introduction to Reconnaissance and Interpretation.** Sat., 24 Sept., 1–5 p.m. US$91. Limit: 30. CEU: 0.4. **Instructor:** Nora Noffke, Old Dominion Univ. **Cosponsor:** GSA Geobiology & Geomicrobiology Division.

530. **Introductory-Level InTeGrate Geoscience Classroom Activities that Blend Student Decision-Making with Important Societal Issues.** Sat., 24 Sept., 1–5 p.m. US$45. Limit: 40. CEU: 0.4. **Instructors:** Elizabeth Nagy-Shadman, Pasadena City College; Kyle Gray, Univ. of Northern Iowa. **Cosponsors:** National Association of Geoscience Teachers; GSA Geoscience Education Division.

531. **Ethics on the Edge: Scientific Integrity and Geoethics for a Changing World.** Sat., 24 Sept., 1–4 p.m. US$10. Limit: 40. CEU: 0.3. **Instructors:** Linda Gundersen, Earth Science, Ethics, and Art; David Mogk, Montana State Univ. **Cosponsors:** American Geosciences Institute; GSA Geology and Society Division; GSA Geology and Health Division; GSA Geoscience Education Division. **EXTRA!** Upon completion of the course, participants will receive a US$10 coupon redeemable at GSA's onsite bookstore.

532. **Bridging Science to Society in the Classroom: Tectonic Motions, Earthquakes, and Shake-Resistant Buildings**. Sat., 24 Sept., 1–5 p.m. US$25. Limit: 30. CEU: 0.4. **Instructors:** Shelley Olds, UNAVCO; Roger Groom, Mount Tabor Middle School; RobertMichael de Groot, SCEC (Southern California Earthquake Center). **Cosponsors:** UNAVCO; National Association of Geoscience Teachers.

Associated Society Course

Paleontological Society

Virtual Paleontology. Sat., 24 Sept., 9 a.m.–6 p.m. FREE, with no registration needed and no course attendance limit.

Instructors: Leif Tapanila, Idaho State Univ.; Imran A. Rahman, Univ. of Oxford.

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Make sure that your company, organization, or university is represented at GSA 2016. Time is running out, and space is filling up.

Exhibiting at GSA 2016 puts you or your organization in the spotlight for more than 7,000 geoscientists from around the globe.

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For information on exhibiting or to reserve your space now, please contact Corcoran Expositions Inc. at david@corcexpo.com or +1-312-541-0567 (or fax +1-312-541-0573).

Photos courtesy of Denver Metro Convention & Visitors Bureau.

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- Contact with thousands of the best and brightest geoscience students soon to be entering the workforce—This meeting provides a convenient place to visit with students from numerous schools outside your company's usual recruiting areas.

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★ LAST CHANCE ★

CALL FOR COMMITTEE SERVICE

THE GEOLOGICAL SOCIETY OF AMERICA®

Impact the Future of Geoscience: Volunteer for Service on a GSA Committee

Deadline: 15 June 2016

Terms begin 1 July 2017 (unless otherwise indicated)

If you are looking for the opportunity to work toward a common goal, give back to GSA, network, and make a difference, then we invite you to volunteer (or nominate a fellow GSA member) to serve on a Society committee or as a GSA representative to another organization.

Key: B—meets in Boulder or elsewhere; E—communicates by phone or electronically; M—meets at the Annual Meeting; T—extensive time commitment required during application review period (15 Feb.–15 Apr. 2017).

Learn more and access the nomination form at **www.geosociety.org/aboutus/committees/.** Use the online form or download a hard copy and mail it to Pamela Fistell, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA; fax: +1-303-357-1074; pfistell@geosociety.org.

ACADEMIC AND APPLIED GEOSCIENCE RELATIONS COMMITTEE

Vacancies: Two members-at-large (industry-related field) three-year terms (E, M)
What it does: Strengthens and expands relationships between GSA members in the applied and academic geosciences and proactively coordinates GSA's effort to facilitate greater cooperation between academia, industry, and government geoscientists.
Qualifications: Volunteers should work in academia, industry, or government and be committed to developing a better integration of applied and academic science in GSA meetings, publications, short courses, field trips, and education and outreach programs. Members must also be active in one or more GSA Division. Professional interests: environmental and engineering geology; hydrogeology; karst; Quaternary geology and geomorphology; structural geology and tectonics; and sedimentary geology.

ANNUAL PROGRAM COMMITTEE

Vacancies: One member-at-large three-year term; one student member-at-large two-year term (B, E, M)
What it does: Develops a plan for increasing the quality of the Annual Meeting and other Society-sponsored meetings in terms of science, education, and outreach; evaluates the technical and scientific programs annually to identify modifications necessary for accomplishing GSA's long-range goals; conducts short and long-range planning for the GSA meetings as a whole; and develops a long-term logistical plan/strategy for the technical programs of all GSA meetings and other Society-sponsored meetings.

ARTHUR L. DAY MEDAL AWARD COMMITTEE

Vacancies: Two member-at-large three-year terms (E, T)
What it does: Selects candidates for the Arthur L. Day Medal.
Qualifications: Volunteers should have knowledge of people who have made distinct contributions to geologic knowledge through the application of physics and chemistry to solve geologic problems.

DIVERSITY IN THE GEOSCIENCES COMMITTEE

Vacancies: Two member-at-large three-year terms; one student member-at-large three-year term (E, M)
What it does: Provides advice and support to GSA Council; initiates activities and programs that will increase opportunities for people of ethnic minority, women, and persons with disabilities; raises awareness in the geosciences community of the positive role these groups play within the geosciences; and recruits and promotes positive career development for these groups.
Qualifications: Volunteers must be familiar with the employment issues these groups face; expertise and leadership experience in such areas as human resources and education are helpful.

EDUCATION COMMITTEE

Vacancies: One graduate student two-year term; one member-at-large four-year term; one two-year college faculty member four-year term; and one pre-college educator (K–12) four-year term (B, E, M)
What it does: Works with GSA members representing a wide range of education sectors to develop informal, pre-college (K–12), undergraduate, and graduate earth-science education and outreach objectives and initiatives.
Qualifications: Volunteers must have the ability to work with other interested scientific organizations and science teachers' groups.

GEOLOGIC MAPPING AWARD COMMITTEE

Vacancy: One member-at-large (industry-related field) three-year term (E)
What it does: Generates, receives, and evaluates candidates for the Geologic Mapping Award. This award acknowledges contributions in published, high-quality geologic mapping that led the recipient to publish significant new scientific or economic-resource discoveries, and to contribute greater understanding of fundamental geologic processes and concepts. The objective is to encourage training and support toward the production of excellent, accurate, detailed, purposeful geologic maps and cross sections.

GEOLOGY AND PUBLIC POLICY COMMITTEE

Vacancies: Two member-at-large three-year terms; one international representative (citizen outside of the U.S.) three-year term (B, E, M)
What it does: Provides advice on public policy matters to GSA Council and GSA leadership by monitoring and assessing international, national, and regional science policy; formulating and recommending position statements; and sponsoring topical white papers. This committee also encourages the active engagement in geoscience policy by GSA members.
Qualifications: Members should have experience with public-policy issues involving the science of geology; the ability to develop, disseminate, and translate information from the geologic sciences into useful forms for the general public and for GSA members; and familiarity with appropriate techniques for the dissemination of information.

JOINT TECHNICAL PROGRAM COMMITTEE

Vacancy: One member-at-large (marine coastal geology field) two-year term starting 1 Dec. 2016 through 30 Nov. 2018 (E)
What it does: Helps finalize the technical program for GSA's annual meetings by participating in the Web-based selection and scheduling of abstracts, as well as topical session proposal review.
Qualifications: Members must have access to computers and the Web, be a specialist in one of the specified fields, and be available in late July to mid-August for organization of the annual meeting technical program.

MEMBERSHIP COMMITTEE

Vacancies: One member-at-large (academia); one member-at-large (industry-related field); and one student member-at-large; three-year terms (B)
What it does: This committee draws its members from academia, industry, and government; contributes to the growth of GSA membership; and attends to the changing needs of Society members by focusing on attracting and retaining students, professionals working in industry, and those studying and working outside the United States. This committee also reviews and makes Fellow recommendations to Council.
Qualifications: Members should have experience in benefit, recruitment, and retention programs.

NOMINATIONS COMMITTEE

Vacancies: Two member-at-large three-year terms (B, E)
What it does: Recommends nominees to GSA Council for the positions of GSA Officers and Councilors, committee members, and Society representatives to other permanent groups.
Qualifications: Members must be familiar with a broad range of well-known and highly respected geoscientists.

PENROSE CONFERENCES AND THOMPSON FIELD FORUMS COMMITTEE

Vacancy: One member-at-large three-year term (E)
What it does: Reviews and approves Penrose Conference and Thompson Field Forum proposals and recommends and implements guidelines for the success of these meetings.
Qualifications: Committee members must be past conveners of a Penrose Conference or Thompson Field Forum.

PENROSE MEDAL AWARD COMMITTEE

Vacancies: Two member-at-large three-year terms (E)
What it does: Selects candidates for the Penrose Medal Award. Emphasis is placed on eminent research in pure geology that marks a major advance in the science.
Qualifications: Members should be familiar with outstanding achievers in the geosciences worthy of consideration for the honor.

PROFESSIONAL DEVELOPMENT COMMITTEE

Vacancies: Two member-at-large three-year terms (E)
What it does: Directs, advises, and monitors GSA's professional development program; reviews and approves proposals; recommends and implements guideline changes; and monitors the scientific quality of courses offered.
Qualifications: Members must be familiar with professional development programs or have adult education teaching experience.

GSA PUBLIC SERVICE AWARD COMMITTEE

Vacancy: One member-at-large three-year term (E)
What it does: Generates, receives, and evaluates candidates for the GSA Public Service Award and the AGI Outstanding Contribution to the Public Understanding of the Geosciences Award, which are given in recognition of outstanding individual contributions to either public awareness of the earth sciences, or the scientific resolution of earth-science problems of significant societal concern.

PUBLICATIONS COMMITTEE

Vacancy: One member-at-large four-year term (B, E, M)
What it does: Recommends candidates to Council for editorship when positions become vacant; reviews the quality and health of each GSA publication; and provides an annual report to Council that includes recommendations on publishing matters on which Council must make a decision.

RESEARCH GRANTS COMMITTEE

Vacancies: Nine member-at-large three-year terms (B, T)
What it does: Evaluates student research grant applications and selects grant recipients.
Qualifications: Members should have experience in directing research projects and in evaluating research grant applications.
Extensive time commitment required 15 Feb.–15 Apr. 2017.

RESEARCH GRANTS COMMITTEE—ALTERNATES

Vacancies: Ten alternate member-at-large three-year terms (B, T)
Why: The alternate member will be called upon to review research grant applications on an "as-needed" basis if the number of submitted grant applications increases significantly in any given year.

YOUNG SCIENTIST AWARD (DONATH MEDAL) COMMITTEE

Vacancy: One member-at large three-year term (E)
What it does: Investigates the achievements of young scientists who should be considered for this award and makes recommendations to GSA Council.
Qualifications: Members should have knowledge of young scientists with outstanding achievement(s) in contributing to geologic knowledge through original research that marks a major advance in the earth sciences.

GSA INTERNATIONAL

Vacancies: Coordinator, International Travel Grants and Awards Program; International Representative to Geology & Public Policy Committee; International Representative to the Joint Technical Program Committee; Chair, International Distinguished Lectureship; and Chair, International Interest Group; all are 4-year terms (E, M)
What it does: GSA International is GSA's coordination and communication resource seeking to promote, create, and enhance opportunities for international cooperation related to the scientific, educational, and outreach missions shared by GSA and like-minded professional societies, educational institutions, and government agencies. Members will help build collaborative relationships with GSA Divisions and Associated Societies on international issues and serve as a channel for member-generated proposals for international themes.

GSA REPRESENTATIVE TO AAPG PUBLICATION PIPELINE COMMITTEE

Vacancy: One GSA Conferee three-year term (M, B)
What it does: Collects a broad spectrum of geological reference materials from the U.S. and Canada and distributes them overseas to universities in developing nations where they will be put to good use.

Committee, Section, and Division Volunteers:

Council Thanks You!

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

THE GEOLOGICAL SOCIETY OF AMERICA®

CALL FOR APPLICATIONS

The Kerry Kelts Student Research Award of the Limnogeology Division

▶ **Deadline:** 30 June, 11:59 pm. EST

GSA's Limnogeology Division is offering one award of US$1,000 for undergraduate or graduate student research related to limnogeology, limnology, or paleolimnology. Send your applications to Limnogeology Division Chair Joop Varekamp, jvarekamp@wesleyan.edu. Please include "Kelts Award Application" in the subject line.

The application consists of a research summary and a short CV (two pages max.). Prepare your application as a PDF that includes your last name in the file name. Your research summary (five pages max., including figures and captions; the list of references cited is not included in this limit.) must include a description of the proposed research, its limnogeological significance, why the award funds are needed for the project, and a brief description of your other funding sources. Be sure to include a title.

The Division hopes to increase the number of awards in succeeding years. If you are interested in supporting this program, please send your donations, designated for the Kerry Kelts Research Awards of the Limnogeology Division, to GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA, or donate online at https://www.gsafweb.org/funds-and-awards/.

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LIMNOGEOLOGY DIVISION

Geoscience Jobs & Opportunities

Ads (or cancellations) must reach the GSA advertising office no later than the first of the month, one month prior to the issue in which they are to be published. Contact advertising@geosociety.org, +1.800.472.1988 ext. 1053, or +1.303.357.1053. All correspondence must include complete contact information, including e-mail and mailing addresses.
Rates are in U.S. dollars.

Classification	Per Line for 1st month	Per line each addt'l month (same ad)
Positions Open	$9.20	$8.95
Fellowship Opportunities	$9.20	$8.95
Opportunities for Students		
First 25 lines	$0.00	$5.00
Additional lines	$5.00	$5.00

UNIVERSITY OF MANITOBA

TENURE-TRACK FACULTY POSITION IN SEDIMENTOLOGY DEPARTMENT OF GEOLOGICAL SCIENCES POSITION NUMBER: 20719

The Department of Geological Sciences at the University of Manitoba invites applications for a tenure-track position at the rank of Assistant Professor beginning as early as January 1, 2017 in the general area of clastic sedimentology. We especially welcome applications from candidates with research interests in resource geoscience or basin analysis. Particular attention will be given to candidates that complement on-going research and teaching activities in the Department. Qualified applicants must have a proven record of excellence in research and the potential for excellence in teaching. The successful applicant will be expected to teach undergraduate and graduate courses in sedimentology, basin analysis and field geology, and establish an internationally recognized, externally funded research program. Additional teaching may include courses in resource geoscience and stratigraphy.

The Department of Geological Sciences is home to 12 tenured and tenure-track faculty members in the Clayton H. Riddell Faculty of Environment, Earth, and Resources, and offers a range of undergraduate and graduate programs in Geology and Geophysics. It has a well-established national and international research reputation with strengths in mineralogy, geochemistry, sedimentary geology, paleontology, geophysics, and environmental geosciences. The department has over $10 million of equipment housed in major, multi-user laboratories. To learn more about the University of Manitoba and the Department of Geological Sciences, please visit: **http://umanitoba.ca/geoscience/**

Applications, as a single pdf file, should include: a cover letter outlining specific interests in the position, a detailed curriculum vitae, a statement of teaching philosophy and interests, a research plan, and the names and contact information for three references.

Applications must be sent electronically by **June 30, 2016** to **Ms. Pam Achtemichuk, Department of Geological Sciences at Pam.Achtemichuk@umanitoba.ca. Please refer to Position Number: 20719 in the application.**

Review of applications will begin July 2016.

The University of Manitoba is strongly committed to equity and diversity within its community and especially welcomes applications from women, members of racialized communities, Indigenous persons, persons with disabilities, persons of all sexual orientations and genders, and others who may contribute to the further diversification of ideas. All qualified candidates are encouraged to apply; however, Canadian citizens and permanent residents will be given priority.

Application materials, including letters of reference, will be handled in accordance with the protection of privacy provision of *"The Freedom of Information and Protection of Privacy Act"* (Manitoba). Please note that curriculum vitae may be provided to participating members of the search process.

For more information on this and other opportunities, please visit: umanitoba.ca/employment

Photo by Bret Webster.

"What a great discussion." [*Andrew Cullen*]

Get Connected…

"Thank you for joining in. … I believe this type of discussion is exactly what was intended by GSA for this open forum ." [*Michael Tarullo*]

…In The Community

"I would like to add to this very interesting discussion." [*Georges Pardo*]

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John W. (Jack) Hess, *GSA Foundation President*

Donors Make Real-Life Impact for Recipients

GeoCorps™ America is a popular GSA program offering short-term assignments in beautiful natural areas and across a wide spectrum of geoscience disciplines. In partnership with government agencies and organizations committed to science and stewardship, the hands-on career development opportunities further geoscience research, education, and awareness—a purpose closely aligned with GSA's mission. Dating back to 1997, the program's number of geoscience projects has steadily increased with the need for expertise in public lands.

Long-time GSA members Sally and Bob Newcomb are supporters with a strong commitment to GSA's GeoCorps program and the National Park Service Geoscientists-in-the-Parks Denali National Park and Preserve assignment:

> "When Bob and I decided to support the Geoscientists-in-the-Parks through GeoCorps, it was suggested we might like the position to be near us in Maryland. That seemed a bit tame—I wanted to think about work being done in a more challenging area. Denali National Park has certainly fulfilled that desire. A few of the areas addressed include glaciation, hazard mitigation, river morphology, novel fossils, monitoring fossil access, and visitor education. Keeping up with the interns, reading their reports, going to their papers and posters at GSA meetings, all have been very rewarding as well as just plain fun, giving us a view of the world we could never otherwise have, as well as introducing us to a series of talented and dedicated young people. Sandra is certainly one of them, and she joins a very distinguished group we've been pleased to support over the years."

Sandra Cronauer had the opportunity to meet the Newcombs during the 2015 GSA Annual Meeting after her assignment in Denali the previous summer. It is a rare opportunity and a pleasure for enthusiastic donors to hear firsthand experiences of their support and for the recipient to convey appreciation to the people who made this highly coveted opportunity possible. We bumped into Sandra again at GSA's 2016 Northeastern Section Meeting, where she was presenting research from her work in Denali:

> "I will always remember my GeoCorps/Geoscientists-in-the-Parks internship at Denali National Park and Preserve as a period of intense personal and professional growth. Fording frigid braided streams, facing off against angry caribou, and calling out 'Hey, bear!' to avoid stumbling across a grizzly while bushwhacking were more than worth it to collect the data needed for the glacier monitoring program in Denali. During my time working with the National Park Service, I gained invaluable field experience and developed technical research skills that will elevate my future research endeavors. I am grateful to Mr. and Mrs. Newcomb for supporting the program and making it possible for me to conduct research in the beautiful backcountry of Alaska."

Consider joining the Newcombs in supporting important geoscience projects across public lands, and see the impact of contributions as GeoCorps participants continue on-the-ground research and protection of geologic resources and the development of education and outreach activities. Contact Bill Tortorici at +1-303-357-1007 or btortorici@geosociety.org to learn how you can support an area of interest.

Bob and Sally Newcomb visiting with Denali program participants Andrew Collins and Sandra Cronauer, GeoCorps/GIP 2015, during GSA's 2015 Annual Meeting in Baltimore.

GROUNDWORK
Furthering the Influence of Earth Science

Nepal at Risk: Interdisciplinary Lessons Learned from the April 2015 Nepal (Gorkha) Earthquake and Future Concerns

Elizabeth J. Catlos, *Jackson School of Geosciences, Univ. of Texas at Austin, Austin, Texas 78712, USA, ejcatlos@gmail.com;* ***Anke M. Friedrich,*** *Dept. of Earth & Environmental Sciences, Geology, Univ. Munich, Luisenstr. 37, Munich, 80333, Germany;* ***Thorne Lay,*** *Earth & Planetary Sciences, Univ. of California Santa Cruz, 1156 High Street, Santa Cruz, California 95064, USA;* ***John Elliott,*** *COMET, Earth Sciences, Oxford, UK;* ***Sara Carena,*** *Dept. of Earth & Environmental Sciences, Geology, Univ. Munich, Luisenstr. 37, Munich, 80333, Germany;* ***Bishal N. Upreti,*** *Dept. of Geology, School of Mines, Univ. of Zambia, Lusaka, Zambia;* ***Peter DeCelles,*** *Dept. of Geosciences, Univ. of Arizona, Tucson, Arizona 85721, USA;* ***Brian Tucker,*** *GeoHazards International, 687 Bay Road, Menlo Park, California 94025, USA; and* ***Rebecca Bendick,*** *Dept. of Geosciences, Univ. of Montana, Missoula, Montana 59812, USA*

INTRODUCTION

In response to the devastation caused by the 25 April 2015 M_W 7.9 Nepal (Gorkha) earthquake and its aftershocks, the Geological Society of America convened an interdisciplinary session at its 2015 Annual Meeting in Baltimore. The forum allowed researchers from diverse disciplines to exchange information and develop meaningful paths toward reducing the societal impacts of future large earthquakes in the Himalayan region. Major seismic hazards exist near Kathmandu and along the Himalayan front due to incomplete rupture of the Main Himalayan Thrust (MHT) (Avouac et al., 2015; Bendick et al., 2015; Elliott et al., 2015; Lay, 2015) and thousands of co-seismic landslides (Andermann et al., 2015; Gallen et al., 2015; Ohja and DeCelles, 2015; Poudel, 2015). Surprisingly, the 2015 event ruptured a limited region. Given shortening rates and interseismic geodetic indications that the MHT is almost uniformly locked along strike, larger earthquakes may occur along the collision zone.

GEOLOGICAL FRAMEWORK

The 2015 Gorkha earthquake occurred within the India-Eurasia convergent plate boundary, defined by the >2500-km-long Himalayan orogenic system. Major Himalayan faults sole into the MHT, a pervasive décollement that separates the downgoing Indian plate from the Himalayan orogenic wedge (Brown et al., 2015). Above the MHT, the Lesser Himalayan Duplex is the locus of an ~50-km-wide seismogenic zone of predominately moderate earthquakes, up-dip of which the MHT has low background activity but intermittent large slip events (Khattri and Tyagi, 1983).

The challenge of the rugged and steep terrain of the Himalayas, coupled with its large size, have resulted in an incomplete understanding of its paleoseismicity and tectonic history. Unknowns include the northward extent of the Indian craton prior to collision (Lippert et al., 2015) and the role of previously unrecognized or underappreciated fault systems that accommodated convergence in historical times (Taylor and Murphy, 2015). Segmentation of the MHT is also unclear. Structural variations along the Himalayas control the extent of rupture of large earthquakes, and the convergence rate is not constant. The paleoseismic record is limited to ground-rupturing events (Wesnousky et al., 2015); the Gorkha earthquake left little surface record that would be identified by trenching. Models of the Himalayan seismic cycle based on only mapped surface ruptures lead to misfits between geodetic rates and estimated recurrence intervals.

Space-geodetic measurements of present-day strain accumulation across active fault systems directly test structural geological models. Earthquakes help to illuminate detailed fault geometry, but event observables must be interpreted in context. In the past, verification of geometric and kinematic relationships depended on rare earthquake occurrences on a fault. Space-geodetic and 3D fault-geometric data will need to be integrated and made available to earth scientists prior to an earthquake. Novel integration techniques may result in quicker and better hazard estimation.

EVENT INFORMATION FROM SEISMOLOGY AND GEODESY

The Gorkha earthquake occurred on Saturday, 25 April 2015, at 11:56 NST, with an epicenter ~75 km WNW of Kathmandu (e.g., Avouac et al., 2015; Lay, 2015). The event started along the eastern side of a millennial-scale seismic gap and ruptured eastward to the 1934 Bihar-Nepal earthquake zone. It did not break to the surface as in 1934, which leads to concern about limited paleoseismic recognition of past events (Bendick et al., 2015; Wesnousky et al., 2015; Upreti, 2015).

Interseismic strain could proceed to the sub-Himalaya via post-seismic creep along the unruptured portions of the MHT, or a large earthquake could occur along the shallower portion of the MHT, feeding slip to the surface (Wesnousky et al., 2015). Another major earthquake is expected near Kathmandu, because the Gorkha event ruptured only a portion of the MHT and its up-dip region remains locked with minor afterslip occurring south of Kathmandu (Avouac et al., 2015; Bendick et al., 2015; Elliott et al., 2015). Rupture of a shallower, highly strained portion of the MHT may involve higher stress drop failure and possibly

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stronger ground shaking as a result. Three-dimensional visualization approaches linking framework- and event-analysis using seismic, geodetic, and structural data indicates that initial seismological data failed to constrain the geometry of the source fault and the reported uncertainties are unrealistic (Carena and Verdecchia, 2015).

Among the large unknowns are the details of the subsurface structure in Nepal. A systematic program of reflection seismic profiling and targeted 3D reflection imaging that spans past and potential future rupture zones would help assess continuing hazard (Brown et al., 2015). This should include partnerships with Nepal (Upreti, 2015) and build upon both existing resources, including dense portable seismic recording systems that reduce costs. The focus should be on fault-system geometry and structures that may control rupture segmentation and for time-lapse imaging for rupture zone reflectivity.

DAMAGE

The Gorkha earthquake caused ~9,000 deaths and ~25,000 injuries (Gallen et al., 2015). The destruction was extensive for larger structures in Kathmandu (Acharya et al., 2015; Poudel, 2015), but moderate ground motions limited urban impact. Destabilized hillslopes and weakened soil horizons present an ongoing threat (Andermann et al., 2015; Gallen et al., 2015). More than 60% of the villages in central Nepal, which are located on near-threshold or threshold dip slopes, are at high risk (Ojha and DeCelles, 2015). The main industry affected by the earthquake is agriculture, which is the primary occupation of rural communities, even along steep Himalayan slopes (Poudel, 2015). More than 6,000 schools collapsed, but because the earthquake occurred on a Saturday, the vulnerability of most Nepali schools remains underappreciated (Acharya et al., 2015).

Nepali national capacity is building (Upreti, 2015). Acharya et al. (2015) discussed the Kathmandu Valley Earthquake Risk Management Project, initiated in 1995 by the National Society for Earthquake Technology of Nepal and GeoHazards International to train local masons to retrofit 300 schools. Ninety percent of these schools are in areas affected by the Gorkha earthquake, and all survived without significant damage. Nepal plans to repair collapsed schools at a rate of 1,200/year, a massive economic and social challenge because time pressure is at odds with construction training and standards. Overcoming local apprehension of retrofitting and building confidence in Nepali communities regarding geosciences education requires major effort. Stone masonry houses are common throughout the Himalayas, which can collapse instantaneously even during moderate earthquakes. Inexpensive ways to retrofit and design these homes will save lives.

A GIS-based inventory of natural resources and crop production practices in the region affected by the earthquake was proposed as a first step in rebuilding rural Nepal (Poudel, 2015). The convergence zone poses a transnational hazard, and opportunities exist to use this event as an impetus to inform decision making in other countries exposed to the potential of large earthquakes. Investments in earthquake disaster response and recovery compared with preparedness and mitigation are unbalanced and require immediate change.

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Looking back: What do geoscience graduates value most from their academic experience?

Carl E. Renshaw, *Dept. Earth Sciences, Dartmouth College, Hanover, New Hampshire 03755, USA, carl.e.renshaw@dartmouth.edu*

Rising tuition and the advent of online learning alternatives are compelling geoscience departments to define and quantify the value of their degrees (Arum and Roksa, 2011). Because the value of a college education is multidimensional, no single metric can capture it in its entirety. For example, course evaluations have long served as the primary means of assessment in higher education. But course evaluation data provide limited, and sometimes contradictory, insight into the overall value of an academic degree, particularly because most evaluations focused more on teaching rather than learning (Benton and Cashin, 2012; Denson et al., 2010; Renshaw, 2014).

A more direct approach to measuring a key dimension of the value of a college degree is to ask graduates what aspects of their academic experience they found most useful in developing the skills and abilities they use in their careers. Such studies are uncommon, so results from even a relatively small sample provide a rare lens on the value of a college geoscience degree.

With this goal in mind, in 2014 the Department of Earth Sciences at Dartmouth College surveyed all of its alumni (undergraduate and graduate) for whom we had up-to-date contact information ($n = 817$). In addition to the usual questions on post-Dartmouth education and careers, we asked alumni to reflect back on their academic experience. We asked both general and detailed questions on what aspects of their training were most helpful in supporting their careers.

For alumni who graduated after 1995, the survey presented each respondent with an individualized list of earth-science courses they had taken at Dartmouth and asked them to assess the effectiveness of each course in developing the skills and abilities they use on the job.

For all courses offered in the fall of 2009 or later, we were able to compare alumni retrospective assessments of course effectiveness with end-of-course evaluations. Nearly half of the alumni completed the survey ($n = 369$). About one-third of our alumni were pursuing careers outside of the geosciences. Among those in geoscience careers, the distribution of employment sectors was broadly similar to national averages (Gonzales and Keane, 2010). Additional details on the survey design, implementation, and results are given in the GSA Supplemental Data Repository[1].

Conventional wisdom often posits that students only appreciate the long-term value of a course after they graduate and join the working world. However, repeated studies have shown that end-of-course student ratings are strongly correlated with retrospective ratings of the same course provided years later by the same students (e.g., Overall and Marsh, 1980). Only rarely do a course's ratings improve with time.

Our survey adds another dimension to our understanding of how alumni value different courses. We found that regardless of course content, end-of-course ratings of overall course quality, teaching effectiveness, and amount learned were all significantly ($p < 0.001$) correlated with alumni ratings of how effective those courses were for their career.

To further explore why alumni valued some courses more than others, we took advantage of a unique aspect of our end-of-course evaluations; we asked students to rate the emphasis each course placed on different skills and concepts. The data reveal that alumni were more likely to value courses that focused on general skills, such as communication and the process of science. In contrast, we found no significant correlation between courses that focused on data collection and analysis, quantitative analysis, or use of scientific literature and alumni ratings of how useful these courses were in their careers. The perceived value of courses focused on these more specific skills likely depends on the particulars of an individual's career. Not all careers, for example, require extensive use the scientific literature.

A college education is more than just courses. When asked which academic experiences, not just courses, were most effective in developing the skills they use in their careers, the vast majority of alumni indicated that faculty mentorship (87%), the classroom experience (94%), independent research (79%), field-based learning (85%), and peer learning (79%) were all very or extremely valuable to their careers. But a finer parsing of these data (i.e., differentiating ratings of "very" versus "extremely" valuable) reveals interesting trends. For example, alumni were more likely to rate field-based training (69%), faculty mentorship (63%), and independent research (59%) as "extremely valuable" than they were to similarly rate the classroom experience (51%) or peer learning (40%). And the perceived value of field-based training and independent research has increased over time; recent graduates (classes of 1996 or later) placed greater value on these experiences than did earlier generations. In contrast, the perceived

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[1] GSA Supplemental Data Item 2016061, survey design, implementation, and results, is online at www.geosociety.org/pubs/ft2016.htm. You can also request a copy from *GSA Today*, P.O. Box 9140, Boulder, CO 80301-9140, USA; gsatoday@geosociety.org.

value of classroom instruction has decreased more than any other academic experience and was the lowest rated academic experience by recent graduates. Only 37% of recent graduates reported that classroom instruction was extremely valuable, compared to >70% identifying independent research and field-based training as extremely valuable to their careers. Standardized course evaluation data are only available back to 2009, so it is unknown if the decreasing value of classroom instruction reflects a decrease in course quality. It's more likely that the commoditization of the classroom experience reflects the growing importance of non-classroom experiences in a college education.

The same conclusions are evident even when asked about value in different ways. When we asked alumni which skills and abilities they wish had had more emphasis in their training, writing and independent research topped the list for recent graduates, with writing having the greatest increase in perceived need compared to its importance to earlier generations. Even in the era of 140-character tweets, writing skills remain vital to career success.

Although the value of developing skills and abilities to be used in careers is only one measure of the benefit of a college education, it is an undeniably important one. With respect to optimizing the perceived value of a traditional college academic experience in developing these skills and abilities, our results have both good news and bad news for geoscience departments. The good news is that the components of a college education that alumni most value (independent research, field training, and writing) are often already strengths in many geoscience departments and are challenging to provide in online learning environments. The bad news is that these aspects are the most resource-intensive to provide. Maintaining, or even increasing, emphasis on these experiences will require greater efficiency in providing other aspects of a college experience perceived as providing less value.

The decreasing perceived value of the classroom experience, particularly at the introductory level, which was consistently rated as being of lowest value of any academic experience, presents opportunities for enhancing efficiency with little risk of lowering value. This is not to suggest that introductory courses are unimportant. Indeed, introductory geoscience courses serve not only as important gateways to higher-level concepts and ideas but also as critical recruiting tools. But if we seek to maximize the value of a college experience by placing greater emphasis on resource-intensive activities such as independent research, field training, and writing, we must find ways to deliver other critical aspects of their training more efficiently.

One example of such efficiency is the hybrid approach to introductory courses, where high-quality online lectures and learning exercises are supplemented with in-person discussion sections, laboratory exercises, group problem solving, and formative and summative assessments. This approach is entirely consistent with the goals of "flipped classrooms" and "active learning," which critically require enhancing the quality of out-of-classroom learning. By reducing the demand to provide live lectures, such an approach frees up resources required to provide more emphasis on high-value activities, even in large enrollment classes. At the extreme end of this spectrum are experiments such as Arizona State University's Global Freshman Academy. Although touted as a means to expand access to higher education, it can also be viewed as a way to focus resources where value is greatest.

It is naïve to believe that higher education will be exempt from the technology-driven enhancement in productivity seen in virtually all other industries. The idea that hybrid approaches to course delivery offer enormous potential for providing greater learning opportunities while reducing resource costs is not novel, and many informal and formal experiments of this type are ongoing. What is new here is putting these experiments within a broader strategic design that is not based on altruism, branding, or outreach to potential donors, but instead on a strategic plan rooted in an understanding of the perceived value of different college academic experiences. Ultimately, what the alumni are telling us is that we should let college faculty do what they do best, which generally is not lecturing in large enrollment classes, but rather providing more individualized learning experiences.

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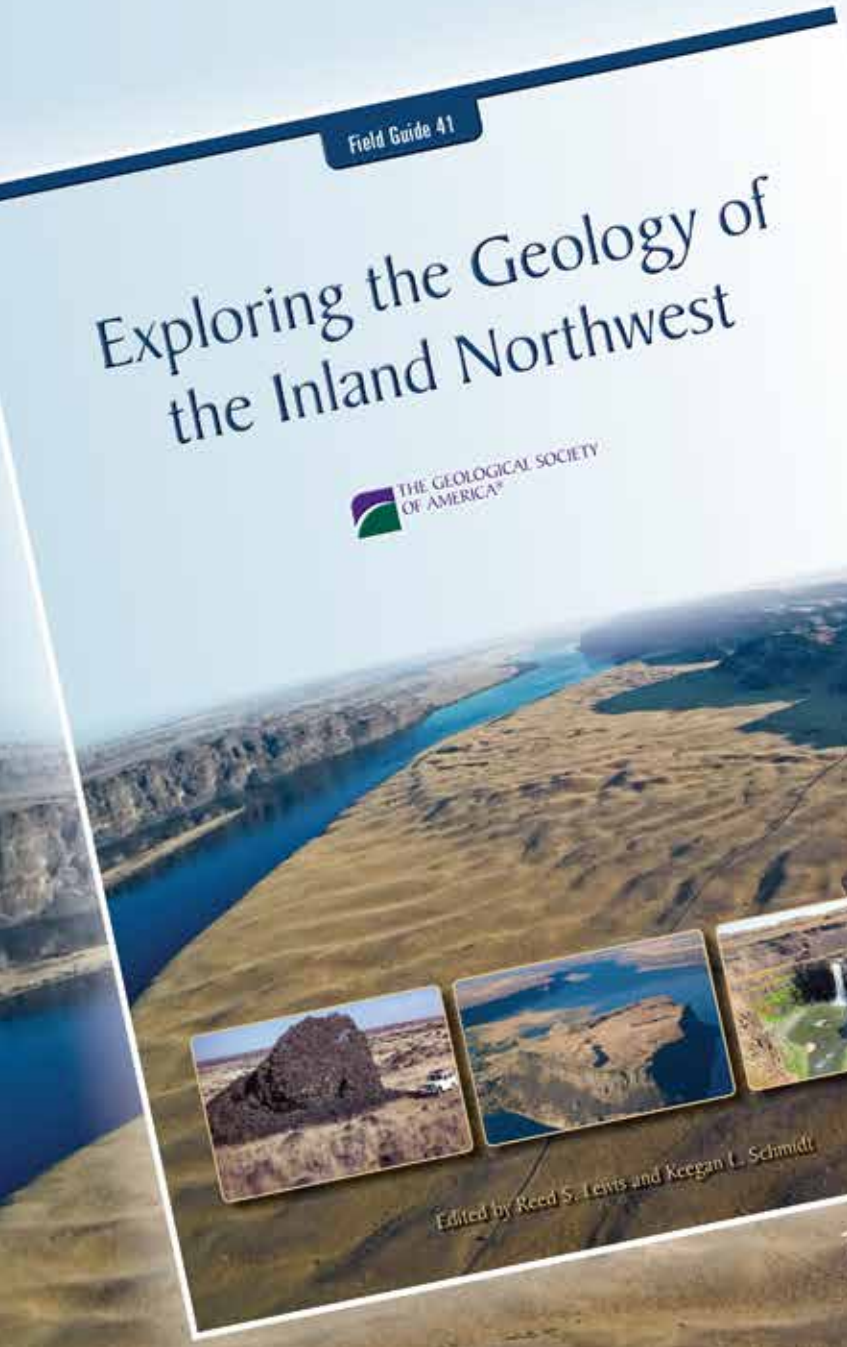

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