2017 Presidential Address, p. 24

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Cosmogenic Nuclides Indicate That Boulder Fields Are Dynamic, Ancient, Multigenerational Features

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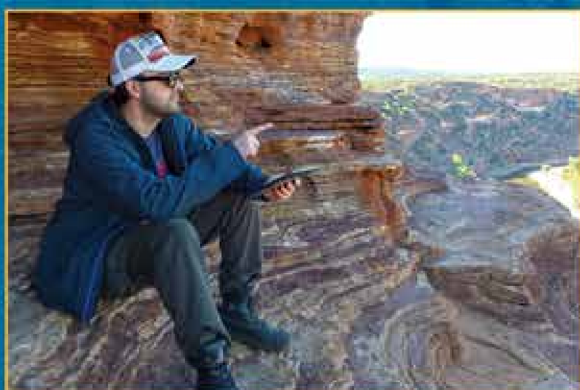

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SCIENCE

Cover: View down the nearly flat, 500-meter-long Hickory Run boulder field, central Pennsylvania, USA, one of the largest boulder fields in North America. The age and history of such boulder fields are poorly constrained, but recent measurements of cosmogenic nuclides such as ^{10}Be, ^{26}Al, and ^{36}Cl demonstrate that some fields are very long-lived. See related article, p. 4–10.

GSA News

Erratum

In the January 2018 science article, "Jurassic Sea-Level Variations: A Reappraisal," by Bilal U. Haq (p. 4–10), figures 1, 2, and 3 in the main text and figure 1 in GSA data repository item 2017387 the upper fourth column from the left should read "Age/Stage" instead of "Stage."

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Cosmogenic nuclides indicate that boulder fields are dynamic, ancient, multigenerational features

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ABSTRACT

Boulder fields are found throughout the world; yet, the history of these features, as well as the processes that form them, remain poorly understood. In high and mid-latitudes, boulder fields are thought to form and be active during glacial periods; however, few quantitative data support this assertion. Here, we use in situ cosmogenic ^{10}Be and ^{26}Al to quantify the near-surface history of 52 samples in and around the largest boulder field in North America, Hickory Run, in central Pennsylvania, USA.

Boulder surface ^{10}Be concentrations ($n = 43$) increase downslope, indicate minimum near-surface histories of 70–600 k.y., and are not correlated with lithology or boulder size. Measurements of samples from the top and bottom of one boulder and three underlying clasts as well as ^{26}Al/^{10}Be ratios ($n = 25$) suggest that at least some boulders have complex exposure histories caused by flipping and/or cover by other rocks, soil, or ice. Cosmogenic nuclide data demonstrate that Hickory Run, and likely other boulder fields, are dynamic features that persist through multiple glacial-interglacial cycles because of boulder resistance to weathering and erosion. Long and complex boulder histories suggest that climatic interpretations based on the presence of these rocky landforms are likely oversimplifications.

INTRODUCTION

Areas outside the maximum extent of Pleistocene glaciation contain landforms thought to have been produced during cold climate periods (Clark and Ciolkosz, 1988) by frost action and mass wasting (periglaciation). These features, particularly unvegetated boulder fields, boulder streams, and talus slopes (areas of broken rock distinguished by differences in morphology and gradient [Wilson et al., 2016]), are believed to be largely inactive today (Braun, 1989; Clark and Ciolkosz, 1988).

Boulder fields have been documented throughout the world, including Australia (Barrows et al., 2004), Norway (Wilson et al., 2016), South Africa (Boelhouwers et al., 2002), the Falkland Islands (Wilson et al., 2008), Italy (Firpo et al., 2006), Sweden (Goodfellow et al., 2014), and South Korea (Seong and Kim, 2003). Hundreds of such fields exist in eastern North America (Nelson et al., 2007; Potter and Moss, 1968; Psilovikos and Van Houten, 1982; Smith, 1953); however, both the time scale and mechanism of boulder field formation remain poorly understood because few quantitative data constrain the age of boulder field formation or evolution.

Boulder field formation is usually explained by one of two process models, both of which invoke periglaciation as a catalyst for boulder generation and transport (Rea, 2013; Wilson, 2013): (1) boulders fall from a bedrock outcrop upslope of the field and are transported downslope by ice-catalyzed heaving and sliding (Smith, 1953); or (2) boulders form as corestones underground, are unearthed by the progressive removal of surrounding saprolite, and are later reworked (André et al., 2008). However they form, boulder fields are likely altered over time by in situ rock weathering, erosion, accumulation of unconsolidated soil/regolith, and perhaps by periglacial action or glaciation during cold periods (André et al., 2008).

Here, we report 52 measurements of ^{10}Be and 25 measurements of ^{26}Al in boulders and outcrops in and near the Hickory Run boulder field. Data show that boulders in the field have moved over time and can have cosmogenic nuclide concentrations equivalent to at least 600 k.y. of near-surface history. We conclude that boulder fields survive multiple glacial-interglacial cycles, calling into question their utility as climatic indicators.

GEOLOGIC AND PHYSIOGRAPHIC SETTING

Hickory Run boulder field is ~2 km south of the Last Glacial Maximum (LGM) Laurentide Ice Sheet boundary (Pazzaglia et al., 2006; Sevon and Braun, 2000) in east-central Pennsylvania, USA (Fig. 1A), a temperate, forested, inland region of the Atlantic passive margin. The field sits on a low-relief upland surface underlain by gently folded, resistant Paleozoic sandstones and conglomerates.

The field is an elongate, 550- by 150-m-wide, nearly flat (1°) expanse of boulders in the axis of a small valley (Fig. 1) with ~30 m of relief (Smith, 1953). Boulders in the field range from <1 to >10 m long and are hard, gray-red, medium-grained sandstone and conglomeratic sandstone from the Catskill formation (Sevon, 1975), as are the adjacent ridgelines. Upslope boulders at the northeast end of the field (Fig. 1D) are generally more angular than those downslope to the southwest (Fig. 1E) (Wedo, 2013), which are

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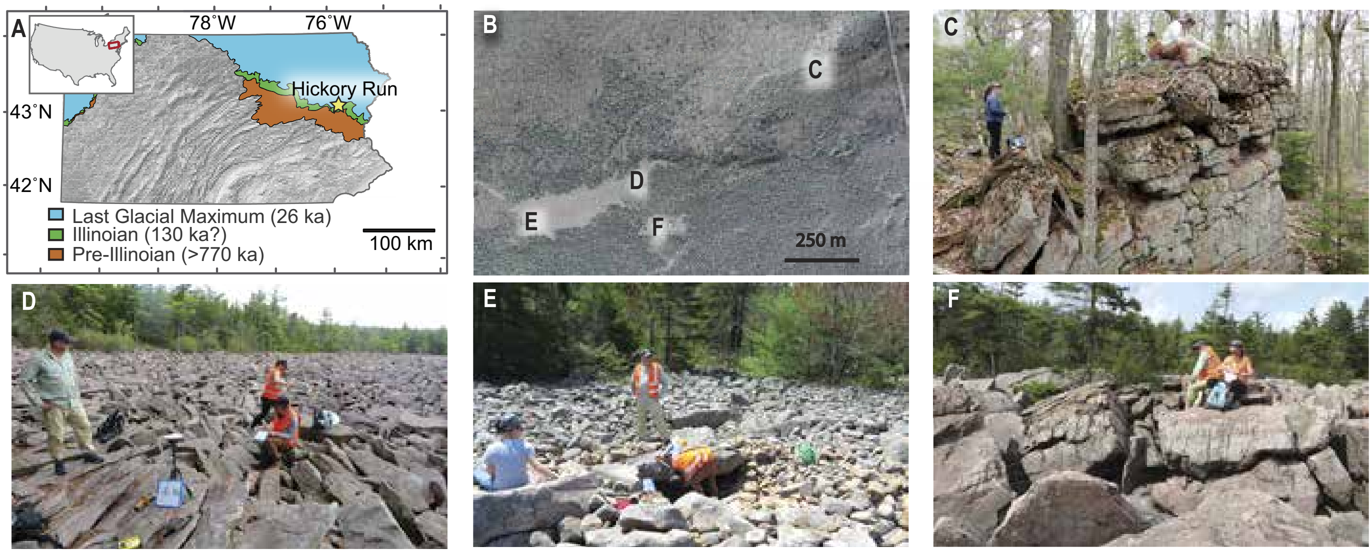

Figure 1. Study site. (A) Hickory Run location in relation to the extent of the Last Glacial Maximum (LGM) (26 ka, Corbett et al., 2017b), Illinoian (130 ka?), and pre-Illinoian glaciations, after Sevon and Braun (2000). Hickory Run is 2 km south of the LGM boundary and is mapped within the Illinoian and pre-Illinoian glaciations. (B) Locations of photographs; (C) tors on a ridgeline 700 m NE of the field; (D) elongate, angular, large boulders upslope; (E) small, rounded boulders downslope; and (F) massive, angular conglomeritic boulders in the SE sub-field.

mostly subrounded and underlain by small, polished clasts with a red weathering rind (Fig. 1E). There is a distinct subsection of the field to the southeast with boulders mostly >5 m long; these appear to be bedrock shattered along bedding planes (Fig. 1F). The field is surrounded by coniferous forest with stony loam soils (NRCS, 2014).

Glacial erratics are found south of Hickory Run (Pazzaglia et al., 2006; Sevon and Braun, 2000), indicating that it was covered by ice at least once, although the timing of ice advances is not well known (Braun, 2004), and we found no obvious erratics in the field. The last glaciation to override Hickory Run is mapped as Illinoian (ca. 150 ka; Fig. 1A), though it is possible that it was 400 ka (Braun, 2004). South of the boulder field, reversed magnetic polarity deposits indicate that the oldest, most extensive glaciation was in the early Pleistocene (likely >900 ka); there is another event mapped between the Illinoian event and the >900 ka event, distinguished by proglacial lake sediments of normal polarity, likely <740 ka (Braun, 2004).

APPLICATION OF COSMOGENIC NUCLIDES TO BOULDER FIELDS

Cosmogenic nuclides are produced predominately in the uppermost meters of Earth's surface by cosmic ray bombardment (Gosse and Phillips, 2001; Lal and Peters, 1967). Nuclides build up over time and can be used to provide age control for surficial deposits; however, such dating requires that at the time of initial surface exposure, rock contained few if any nuclides (Lal, 1991). This is not the case for boulder fields because both models of development (see Introduction) include initial cosmic-ray exposure before incorporation of blocks into the field (on cliffs or below a weathered regolith mantle).

The pertinent question becomes, "Where were the sampled boulders when they received the cosmic ray dosing that accounts for the ^{10}Be and ^{26}Al concentrations they contain today?" This question arises because there is no unique and agreed upon process model for boulder field development. If boulders were sourced from outcrops upslope of the field and moved downfield, they inherited nuclides from exposure on the outcrops. If boulders originated in place, they inherited nuclides from subsurface exposure. In either case, measured nuclide concentrations do not allow direct dating of the time any boulder became exposed as part of the boulder field; rather, they allow for the calculation of minimum total near-surface histories for each sampled boulder. Such histories integrate cosmic-ray exposure and express it as the equivalent of uninterrupted surface exposure. These times are minima because we know boulders eroded and also experienced less than surface production rates before they were exhumed, when they were covered by other boulders, and/or when they flipped during transport.

If rock surfaces experience burial before, during, or after exposure, by flipping or cover with soil, snow, ice, or other boulders, such complex histories can be detected by measuring two isotopes with different half-lives in the same sample (Bierman et al., 1999; Nishiizumi et al., 1991). Such analyses most commonly employ ^{26}Al and ^{10}Be, which are produced in quartz at a ratio of ~7:1 (Argento et al., 2013; Corbett et al., 2017a). Because the ^{26}Al half-life, 0.71 m.y. (Nishiizumi et al., 1991), is about half that of ^{10}Be, 1.38 m.y. (Chmeleff et al., 2009; Korschinek et al., 2010), if an exposed sample is buried, the ^{26}Al/^{10}Be ratio will decrease; if that sample is re-exposed, production of nuclides begins again and the ratio increases. Because of the relatively long half-lives of ^{26}Al and ^{10}Be, the ^{26}Al/^{10}Be ratio is only sensitive to burial by meters of material for >100 k.y. (Lal, 1991).

Published measurements of cosmogenic nuclides, made on samples collected from rock surfaces in high-latitude boulder fields, suggest that some blocks were exposed to cosmic rays relatively recently, while others have concentrations consistent with near-surface histories extending over hundreds of thousands of years. For example, ^{36}Cl concentrations in 18

Australian boulder stream samples reveal a cluster of minimum limiting exposure histories around 21 ± 0.5 ka (LGM), while other samples from the same field have minimum total near-surface histories of 60–480 ka (Barrows et al., 2004). Samples from boulder streams in the Falkland Islands (n = 16) have ^{10}Be histories of 42–730 ka (Wilson et al., 2008). A Korean boulder field has ^{10}Be histories (n = 4) between 38 and 65 ka (Seong and Kim, 2003), while samples from Swedish boulder fields have histories of 33 and 73 ka (n = 2) (Goodfellow et al., 2014). Analysis (n = 15) of paired ^{26}Al and ^{10}Be in block streams suggests some boulders have histories that include either exposure under cover and/or burial after near-surface exposure (Goodfellow et al., 2014; Seong and Kim, 2003; Wilson et al., 2008).

METHODS

We sampled in and around the Hickory Run boulder field in eight slope-normal transects, collecting a total of 52 samples by removing the surficial few centimeters of rock. Of these samples, 30 were from boulders in the main field, six were from the southeastern sub-field, seven were from boulders in the surrounding forest, five were from bedrock tors cropping out on a ridgeline 700 m NE (Fig. 1C), and one was from the bottom of a boulder accompanied by three underlying clasts (Fig. 2A). We photographed and recorded the dimensions, sub-meter resolution UTM coordinates, sample thickness, and lithology of each boulder. Additionally, we used eCognition software to automatically extract boulder outlines from aerial imagery to test for trends in boulder size and orientation.

We purified quartz (Kohl and Nishiizumi, 1992) and extracted ^{10}Be and ^{26}Al (Corbett et al., 2016) at The University of Vermont. We measured ^{10}Be/^{9}Be ratios at Lawrence Livermore National Laboratory, normalizing them relative to ICN standard 07KNSTD3110 with an assumed value of 2.85×10^{-12} (Nishiizumi et al., 2007). We corrected our data using process blanks (see GSA Data Repository[1] Table DR1) and processed four replicates to test reproducibility; the difference between replicates ranged from <1%–4% (mean 2%). We then selected the boulder bottom and clast samples (n = 4) along with a subset of upslope (n = 10) and downslope (n = 11) boulder samples for ^{26}Al/^{27}Al analysis at PRIME Lab. Minimum near-surface histories were calculated using the CRONUS Earth online calculator (http://hess.ess.washington.edu/), wrapper script 2.2, main calculator 2.1, constants 2.2.1 (see Balco et al. [2008]) based on the constant production rate model (Lal, 1991; Stone, 2000) using the regional northeastern U.S. production rate (Balco et al., 2009).

RESULTS

Boulders at Hickory Run have experienced widely varying and substantial near-surface exposure. Hickory Run samples have ^{10}Be concentrations ranging from 0.44 to 3.26×10^{6} atoms g^{-1} (Fig. 3), the equivalent of between 70 and 600 k.y. of surface exposure.

There is no significant correlation between ^{10}Be concentration and boulder lithology, size, or proximity to the edge of the field. Boulders downslope are more rounded, smaller (Fig. DR1 [see footnote 1]), and have more developed weathering rinds than those upslope, suggesting that boulder weathering increases downslope. We also observe spatial trends in boulder orientation; downslope boulders align with the main axis of the field (NE-SW), whereas upslope boulders align E-W (Fig. DR1 [see footnote 1]).

Our ^{10}Be results support the inference of increased weathering and near-surface exposure time downfield. The strongest correlation we observe is between downfield distance and ^{10}Be concentration (r^2 = 0.45; Fig. 3); additionally, ^{10}Be

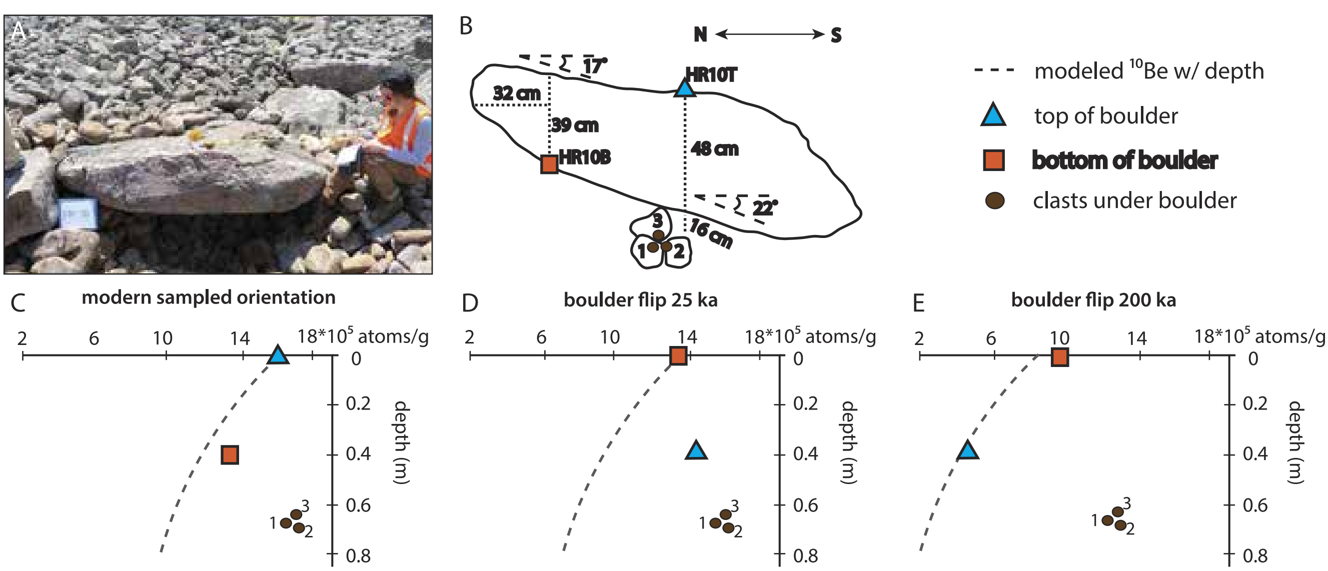

Figure 2. Measurement of boulder HR10 and underlying clasts. (A) Photograph of boulder HR10 on top of clasts; (B) side view of HR10 samples and underlying clasts; (C) ^{10}Be production decreases exponentially with depth. The black dashed line represents the ^{10}Be concentrations expected in HR10B and samples 10C1–C3 if they remained in place at depth for their entire histories. (D) Depth profile assuming the boulder flipped 180° at 25 ka—the concentration in HR10T is too high to have flipped then. (E) Sample HR10T aligns with the depth profile assuming the boulder flipped at 200 ka.

[1] GSA Data Repository Item 2017393, a detailed description of methodology, is online at www.geosociety.org/ft2017.htm.

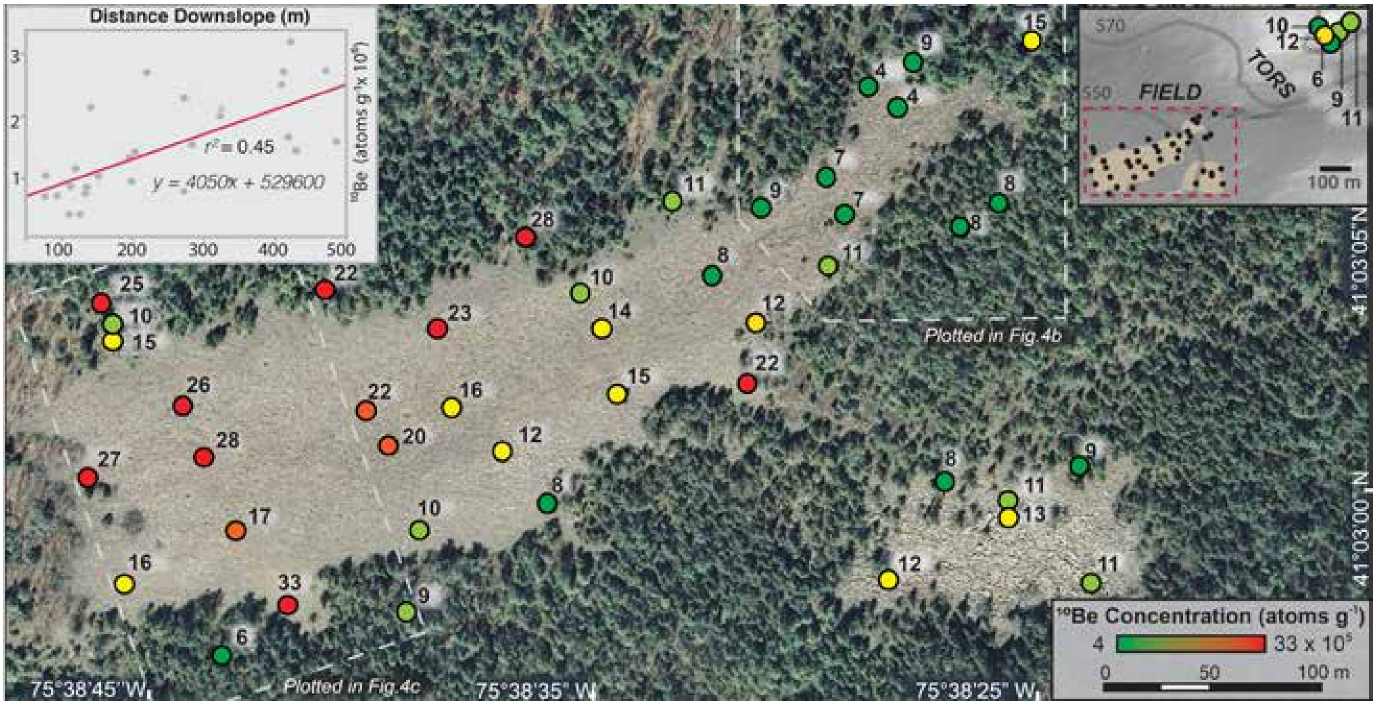

Figure 3. ^{10}Be concentration (10^5 atoms g^{-1}) of Hickory Run boulders and tors; red dots indicate higher ^{10}Be concentration; green dots indicate lower. Insets show location of tors (Fig. 1C) relative to the main boulder field and positive correlation between ^{10}Be concentration and downslope distance.

concentrations within the main body of the field become increasingly different with distance between boulders (Fig. DR2 [see footnote 1]). Boulders upfield (n = 10) include the two lowest measured ^{10}Be concentrations ($0.4 \pm 0.07 \times 10^6$ atoms g^{-1}; Fig. 4) whereas downfield boulders contain much more ^{10}Be, averaging $2.1 \pm 0.6 \times 10^6$ atoms g^{-1}. Concentrations on ridgeline tors and in the southeastern sub-field tend to be lower than the main body of the field (Fig. 4).

Our measurements of boulder HR10 and of the clasts below it are inconsistent with simple exposure in place (Fig. 2) and imply movement and flipping of the boulder. The measured ^{10}Be concentration in sample HR10B (from the underside of the boulder, 0.39 m below the surface) is 170% of what it would be if the boulder had received all of its exposure as currently oriented (Table DR1 [see footnote 1]). Clasts C1, C2, and C3 have more than triple the expected ^{10}Be concentration than if they had been continuously irradiated underneath the boulder; all three have higher concentrations than the sample from the top of the boulder. The boulder and clasts could not have been exposed and irradiated only in their current position.

Concentrations of ^{26}Al range from 3.00 to 19.3×10^6 atoms g^{-1} (n = 25), and correlate well with ^{10}Be measurements (r^2 = 0.99). ^{26}Al/^{10}Be ratios range from 5.4 to 7.3. When plotted on a two-isotope diagram (Fig. 5), all but five samples fall below the upper constant exposure line, consistent either with exposure followed by erosion (between the upper and lower lines), with at least one episode of burial after initial exposure, or with exposure under cover followed by exhumation. Samples from the top of the field (n = 10) have an average ^{26}Al/^{10}Be of 6.61 ± 0.46, whereas those from the bottom of the field (n = 11) have an average ^{26}Al/^{10}Be of 5.96 ± 0.31 (separable at 95% confidence, Student's t-test). In part, this decrease reflects longer near-surface histories of boulders downfield.

DISCUSSION

Cosmogenic nuclide measurements, when considered along with field observations, provide a means to infer how boulder fields change over time. For example, boulders at Hickory Run are more rounded, smaller, and thus more weathered downfield than upfield; the downfield increase in ^{10}Be concentration suggests the importance of near-surface residence time in physical and chemical

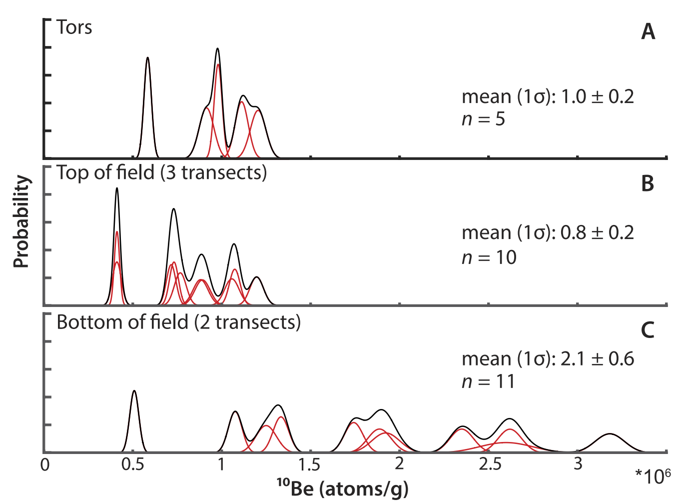

Figure 4. Summed probability plot of ^{10}Be concentrations (A) in tors, (B) of the three furthest upslope boulder transects, and (C) of the two furthest downslope. Red curves represent single ^{10}Be measurements with 2σ internal error; the black line represents the sum of all samples.

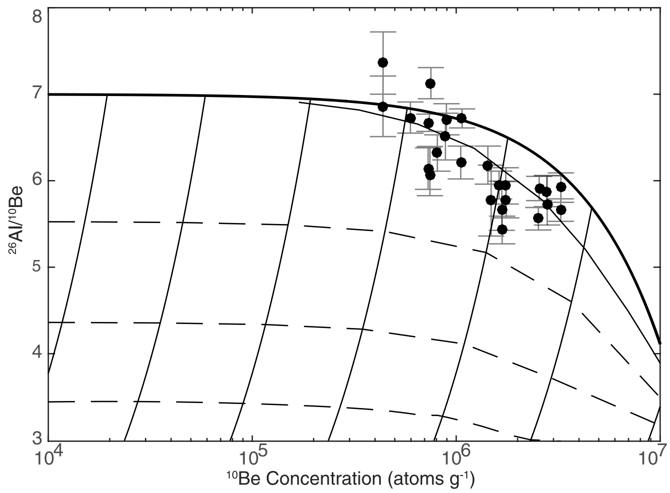

Figure 5. Measured $^{26}Al/^{10}Be$ plotted against measured ^{10}Be concentrations (n = 25). Plot is based on a local production rate of six atoms g^{-1} y^{-1} and surface production ratio of 7.0 (Argento et al., 2013). The thick black line indicates constant surface exposure, and the line beneath it marks the end of the "steady erosion envelope"; points beneath this envelope have had at least one period of burial or shielding during or after exposure. Thin lines represent the trajectory that a sample would follow if buried, and dotted lines indicate burial isochrons of 0.5, 1.0, and 1.5 m.y. assuming surface exposure followed by deep burial (top to bottom).

boulder weathering. The decrease in $^{26}Al/^{10}Be$ ratios downfield indicates that boulders there have experienced more complex exposure histories, including erosion, exhumation, burial, and/or flipping, than upfield boulders. Changes in boulder long-axis alignment downfield likely indicate at least some downfield, and thus downslope, boulder transport.

Multiple cosmogenic measurements on a single boulder (HR10) reveal more about boulder history and boulder field processes. Measurements of samples from the top and bottom of the boulder, as well as the underlying clasts, demonstrate that it has changed position and not simply weathered in place. Although there is no unique solution, this disparity in concentration between the top and bottom of the boulder can be resolved if, ~200,000 years ago, it flipped after initial exposure and was then deposited on top of the clasts now underlying it (Fig. 2 and Tables DR3–DR5 [see footnote 1]). High nuclide concentrations in clasts under the boulder provide further evidence for boulder movement. Nuclide concentrations in clasts HR10 C1, C2, and C3 are comparable to those of nearby surface boulders, and their $^{26}Al/^{10}Be$ ratios are indistinguishable from the production ratio. This is likely because the clasts spent most of their history near the surface and still receive substantial cosmic ray dosing through the overlying 48 cm of rock.

The positive linear relationship between ^{10}Be concentration and distance downfield allows calculations of the rate at which the field changes over time. Assuming boulders were sourced from outcrops upslope of the field, the relationship between ^{10}Be concentration and distance downslope can be interpreted as a rate of transport (Jungers et al., 2009; Nichols et al., 2005; West et al., 2013). Given a local ^{10}Be production rate of 6 atoms g^{-1} y^{-1} and a regression slope of 4050 atoms m^{-1} (Fig. 3), the average rate of boulder movement is ~15 mm y^{-1} presuming the boulders remain exposed at the surface, and slower if the boulders were buried or flipped during transport as suggested by $^{26}Al/^{10}Be$ ratios, discussed above. Alternatively, if the field is the result of progressive

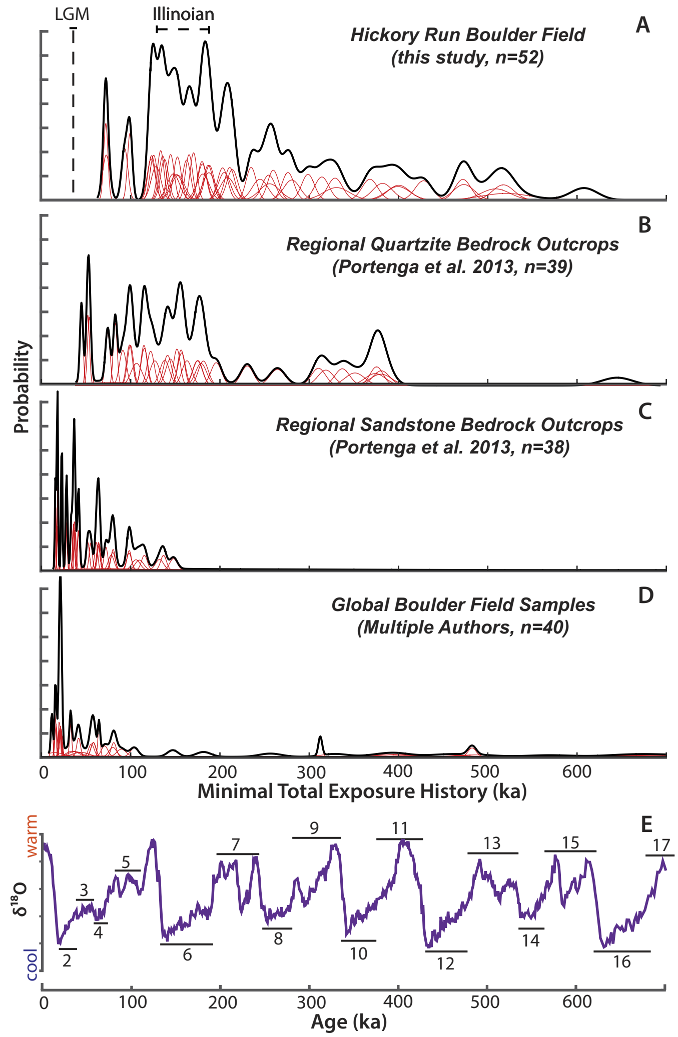

Figure 6. Summed probability plots of minimum total near-surface history derived from ^{10}Be. Red curves represent single ^{10}Be measurements with 2σ internal error; the black line represents the sum of all samples. (A) All Hickory Run samples. (B) Quartzite bedrock outcrops. (C) Sandstone outcrops. (D) Other boulder field samples (Barrows et al., 2004; Goodfellow et al., 2014; Seong and Kim, 2003; Wilson et al., 2008). (E) Stable $\delta^{18}O$ ratios in deep sea foraminifera (Railsback et al., 2015). Even numbers represent cold glacial stages; odd numbers are interglacials. LGM—Last Glacial Maximum.

up-field stripping of regolith and the boulders have remained in place, then the speed represents the rate at which the bedrock/regolith boundary moved upslope.

At Hickory Run, minimum total near-surface histories are varied and long. They range from 70 to 600 k.y. with a mode between 120 and 210 ka. Such histories are similar to those reported in boulder field samples collected elsewhere (Wilson et al., 2008) (Fig. 6) and together suggest that boulder fields are persistent features that can survive multiple glacial cycles. Boulders at Hickory Run have much longer minimum total near-surface histories than sandstone outcrops in the central Appalachian Mountains, but have minimum total near-surface histories only slightly greater than quartzite outcrops in the region (Portenga et al., 2013), consistent with the indurated nature of rock exposed at Hickory Run (Fig. 6). The similarity of near-surface residence time (Fig. 6) between quartzite outcrops and Hickory Run boulders suggests a different approach to interpreting boulder fields—considering them as fractured outcrops, unmantled by soil and regolith. In this framework, boulder field longevity is controlled by the resistance of boulders to erosion over time.

Although most prior research suggests that boulder fields result from periglacial activity (Braun, 1989; Clark and Ciolkosz, 1988), extant cosmogenic data are largely agnostic as to the timing of boulder generation. The absence of LGM histories among the 52 Hickory Run samples we analyzed could indicate a lack of new boulder generation during the most recent cold period. Conversely, the absence of LGM histories may reflect pre-exposure of boulders, at depth if they are unroofed, or upslope if they moved downslope from source outcrops. Comparison of the cumulative probability distribution of all boulder analyses (Fig. 6) to the marine oxygen isotope record of climate shows no obvious correlation of boulder histories with climate except that the mode of boulder histories at Hickory Run is generally consistent with the Illinoian cold period (130–190 ka, MIS 6). Either the complexity of boulder histories (flipping, erosion, exhumation) blur any coherent time signal in the data or perhaps boulder field generation is not strictly a periglacial phenomenon.

Hickory Run is mapped within the Illinoian glacial margin (Sevon and Braun, 2000) and, if mapping and dating of the Illinoian are correct, would have been under glacial ice ca. 150 ka (Fig. 1A). The absence of erratics within the field and the presence of boulders with minimum histories far exceeding 150 k.y. suggest that the "Illinoian" in this part of Pennsylvania is likely older than previously assumed, a possibility given the lack of quantitative age constraints on old glaciations (Sevon and Braun, 2000). Alternately, if the mapping were correct, then any overriding Illinoian ice must have been cold-based and non-erosive, as the boulder field was preserved rather than eroded. The preservation of block streams under cold-based ice is possible (Kleman and Borgström, 1990), and portions of the southern Laurentide ice sheet were likely cold-based (Colgan et al., 2002; Bierman et al., 1999, 2015).

High concentrations of cosmogenic nuclides in samples collected from Hickory Run highlight the stability and persistence of this landform, which has survived at least one, and likely several, glacial/interglacial cycles. Cosmogenic nuclide measurements provide limited information about the timing of boulder field activity (insufficient to confirm it is a periglacial feature), but clearly indicate that Hickory Run and at least some other boulder fields throughout the world are ancient, dynamic, multigenerational features, the longevity of which appears to be controlled by the resistance of their boulders to erosion.

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GSA 2018 Annual Meeting & Exposition

4–7 November
Indianapolis, Indiana, USA

Important Dates

Late March:	Meeting room request system opens (non-technical, social, and business meeting room requests)
Mid-May:	Housing opens (VisitIndy is the official housing bureau for GSA 2018 Indianapolis)
Early June:	Registration and Travel Grant applications open
6 June:	Meeting room request deadline—fees increase after this date
Early August:	Student volunteer program opens
14 August:	Abstracts deadline
1 October:	Early registration deadline
1 October:	GSA Sections travel grants deadline
8 October:	Registration and student volunteer cancellation deadline
10 October:	Housing deadline for discounted hotel rates

GSA 2018

Hotel Information

The official GSA Housing Bureau, VisitIndy, will open for reservations in mid-May. The JW Marriott will serve as GSA headquarters, and it's just half a block from the Indiana Convention Center (ICC). The GSA block includes 14 hotels offering rates from US$141 to US$199 single/double occupancy (per night, plus tax). All hotels are within walking distance of the ICC.

Protect yourself: As the number of online hotel bookings continues to increase, so does the rate of booking scams. According to the American Hotel & Lodging Association, fraudulent websites con 2.5 million North Americans out of US$220 million every year. Only use a trusted source to make your hotel reservation and beware of anyone contacting you directly via email, phone, or fax. If you have any questions, please contact the GSA Meetings Department at meetings@geosociety.org. We will post information on our website (www.geosociety.org/AnnualMeeting) regarding hotel reservations in mid-May.

CALL FOR NOMINATIONS

GSA Division Awards

Give recognition where it is due—nominate a deserving colleague today!
For award descriptions and nomination details, see the January 2018 issue of *GSA Today*, or go to **www.geosociety.org/divisions.**

ARCHAEOLOGICAL GEOLOGY DIVISION

Nomination and application information for these awards is at **http://rock.geosociety.org/arch/.**

Claude C. Albritton, Jr., Award
Nominations due 5 March.
Submit nominations to gsa.agd@gmail.com.

Richard Hay Student Paper/Poster Award
Nominations due 20 Sept.
Submit nominations to gsa.agd@gmail.com.

GEOSCIENCE EDUCATION DIVISION

Nomination information is at **community.geosociety.org/gedivision/awards/biggsaward.**

Biggs Award for Excellence in Earth Science Teaching
Nominations due 15 March.
Submit nominations online; direct questions to GEOEDGSA@gmail.com.

HISTORY AND PHILOSOPHY OF GEOLOGY DIVISION

Nomination information for the following awards is at **community.geosociety.org/histphildiv/awards.**

History and Philosophy of Geology Student Award
Nominations due 15 June.
Submit nominations to Kathleen Lohff, kathylohff@msn.com.

LIMNOGEOLOGY DIVISION

Nomination information is at **http://rock.geosociety.org/limno/**

Israel C. Russell Award
Nominations due 15 March.
Submit nominations to David Finkelstein, finkelstein@hws.edu.

MINERALOGY, GEOCHEMISTRY, PETROLOGY, AND VOLCANOLOGY (MGPV) DIVISION

Nomination information is at **community.geosociety.org/mgpvdivision/awards.**

MGPV Distinguished Geologic Career Award
MGPV Early Career Award
Nominations due 31 March.
Submit nominations to J. Alex Speer, Mineralogical Society of America, 3635 Concorde Pkwy Suite 500, Chantilly, Virginia 20151-1110, USA; jaspeer@minsocam.org.

QUATERNARY GEOLOGY AND GEOMORPHOLOGY

Nomination and application information is at **community.geosociety.org/qggdivision/awards/awardsoverview.**

Farouk El-Baz Award for Desert Research
Nominations due 1 April.

Distinguished Career Award
Nominations due 1 April.

SEDIMENTARY GEOLOGY DIVISION AND STRUCTURAL GEOLOGY AND TECTONICS DIVISION JOINT AWARD

Nomination information is at **community.geosociety.org/sedimentarygeologydiv/awards/laubach.**

Stephen E. Laubach Structural Diagenesis Research Award
Nominations due 1 April.
Nomination instructions are at http://rock.geosociety.org/sgt/Laubach.htm.

Penrose CONFERENCES
THE GEOLOGICAL SOCIETY OF AMERICA

250 Million Years of Earth History in Central Italy: Celebrating 25 Years of the Geological Observatory of Coldigioco

25–29 September 2017 • Apiro, Marche Region, Italy

CONVENERS:

Alessandro Montanari, Osservatorio Geologico di Coldigioco, I-62020 Frontale di Apiro (MC), Italy; sandro.coldigioco@gmail.com
Christian Koeberl, Department of Lithospheric Research, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria, and Natural History Museum, Burgring 7, A-1010 Vienna, Austria; christian.koeberl@univie.ac.at

Cosponsored by *GSA Foundation; Barringer Crater Company; Associazione Le Montagne di San Francesco*

Central Italy has been a cradle of geology for centuries. Since the beginning of the last century, the Triassic to Miocene carbonate succession exposed along the valleys of the Umbria and Marche Apennines of Italy has been a fertile playground for generations of earth scientists, particularly paleontologists, sedimentologists, stratigraphers, geophysicists, and structural geologists from all over the world. Here pioneering studies in the most disparate disciplines of the earth sciences have led to the understanding of novel principles and natural phenomena of the past, the development of new methodologies and experimental research approaches, and ultimately to discontinuities in scientific thinking. The Umbria-Marche Apennines are a foreland fold-and-thrust belt, which was formed in the latest phase of the Alpine-Himalayan orogenesis. These mountains are entirely made of marine sedimentary rocks of the so-called Umbria-Marche Succession, which represents a continuous record of the geotectonic evolution of an epeiric sea from the Early Triassic to the Pleistocene. Studies of these rocks have led to important discoveries, particularly about major events that have punctuated the history of Earth, such has the Cretaceous Oceanic Anoxic Events (OAE1 and OAE2), the Cretaceous-Paleogene (K-Pg) Boundary Event (with the global mass extinction caused by a catastrophic extraterrestrial impact), the events across the Eocene-Oligocene transition from a greenhouse to an icehouse world, and the Messinian Salinity Crisis of the Mediterranean, just to name the most famous ones.

The objective of the Penrose Conference that was held in late September 2017 in Apiro in the Marche Region, central Italy, was to present an updated vision of 250 million years of Earth history as recorded in the sedimentary succession of the northern Apennine orogeny in central Italy. The occasion for the timing of the conference was the 25th anniversary of the Geological Observatory of Coldigioco, an independent research and

Group photo (courtesy D. Jalufka) in the historic Teatro Mestica in Apiro, Italy. Participants: Walter Alvarez, Milly Alvarez, Drew Barringer, Massimiliano Barchi, David Bice, Samuele Boschi, David Bowen, Megan Bowen, Lung Chan, Lily Chan, Nate Church, Philippe Claeys, Rodolfo Coccioni, Maurizio Conte, Dave Eby, Ken Farley, Markus Fiebig, Luigi Folco, Marco Franceschi, Fabrizio Frontalini, Anthony Frushour, Diana Galassi, Peter Geiser, Gabriele Giuli, Bill Glass, Christian Koeberl, Paul Kopsick, Tvrtko Korbar, Davide Lenaz, Sarah Lucas, Steve Lundblad, Ellinor Martin, Jenn Macalady, Maurizio Mainiero, Marco Menichetti, Francesco Mirabella, Ross Mitchell, Alessandro Montanari, Frank Pazzaglia, Gaia Pignocchi, Ann Pizzorusso, Michael Rampino, Birger Schmitz, Clare Schneider, David Shimabukuro, Matthias Sinnesael, Jan Smit, Enrico Tavarnelli, Peter Ward, John Weber.

educational center, which was founded in an abandoned medieval hamlet near Apiro in 1992. Fifty attendees from eleven countries (Australia, Austria, Belgium, China, Croatia, Italy, Netherlands, Norway, Sweden, UK, and USA), including seven students, presented original research and reviews in the form of keynote, oral, and poster presentations, covering specific subjects related to topics in tectonics and structural geology, integrated stratigraphy and astronomical tuning, extraterrestrial event stratigraphy, and Quaternary geology and geo-bio speleology.

A variety of studies about the recent tectono-seismic and structural history of the still active Umbria-Marche Apennines (as is exemplified by the recent seismic activity in 2016) were presented. This included investigations by international teams of stratigraphers through long and continuous stretches of the Umbria-Marche sedimentary succession, focusing on the integration of bio-magneto-chemostratigraphy and radioisotopic geochronology with astronomical tuning via multiproxy cyclostratigraphic analysis.

Some of the most significant and widely recognized results of the investigations at the Umbria-Marche sedimentary succession during the past 25 years, with the support of the Geological Observatory of Coldigioco, concerned the importance that extraterrestrial events, such as meteoritic/asteroid impacts, comet showers, and asteroidal breakups, played in the biologic, environmental, and climatic changes of planet Earth. Several papers on this topic were presented at the Penrose Conference.

Another set of presentations at the meeting dealt with the tremendous advancements in the studies on the Pleistocene and Holocene history that focused on the extraordinary speleologic record of the Frasassi hypogenic cave complex (i.e., karstic geomorphology, slack water deposits, extremophile sulfidic ecosystems, speleo-archaeology). Interdisciplinary studies by international teams of speleo-geologists, geochemists, radioisotopic and cosmogenic geochronologists, biologists, and archaeologists were presented at the meeting.

Meeting participants enjoyed not only a vibrant three-day conference at the historic Teatro Mestica in the medieval hilltop town of Apiro, complete with local gourmet lunches, and a big anniversary celebration in Coldigioco, but also two field trips to classic geological sites (to Gubbio, where the K-Pg asteroid impact hypothesis started, and to the Frasassi caves, the largest show caves in Italy); an optional field trip to Massignano near Monte Conero, where the GSSP of the Eocene-Oligocene Boundary is located, was also well attended.

ACKNOWLEDGMENTS

The meeting conveners are grateful to many local helpers for important assistance, to the city of Apiro for making the theater available, to the sponsors, and to all the participants, but we want to specifically thank our spouses Paula and Dona for unfailing support.

The Geological Society of America®

GEOCAREERS

2018 GeoCareers Section Meeting Programs

Geoscience Career Workshops

For more information, contact Jennifer Nocerino at jnocerino@geosociety.org.

Part 1: Career Planning and Informational Interviewing. Your job-hunting process should begin with career planning, not when you apply for jobs. This workshop will help you begin this process and will introduce you to informational interviewing. This section is highly recommended for freshmen, sophomores, and juniors. The earlier you start your career planning the better.

Part 2: Geoscience Career Exploration. What do geologists in various sectors earn? What do they do? What are the pros and cons of working in academia, government, and industry? Workshop presenters and professionals in the field will address these issues.

Part 3: Cover Letters, Résumés, and CVs. How do you prepare a cover letter? Does your résumé need a good edit? Whether you are currently in the market for a job or not, learn how to prepare the best résumé possible. You will review numerous examples to help you learn important résumé dos and don'ts.

Mentor Programs

Enjoy a free lunch while meeting with geoscience mentors working in the applied sector. The popularity of these programs means that space is limited, so plan to arrive early, because lunch is first-come, first-served. For further information, contact Jennifer Nocerino at jnocerino@geosociety.org.

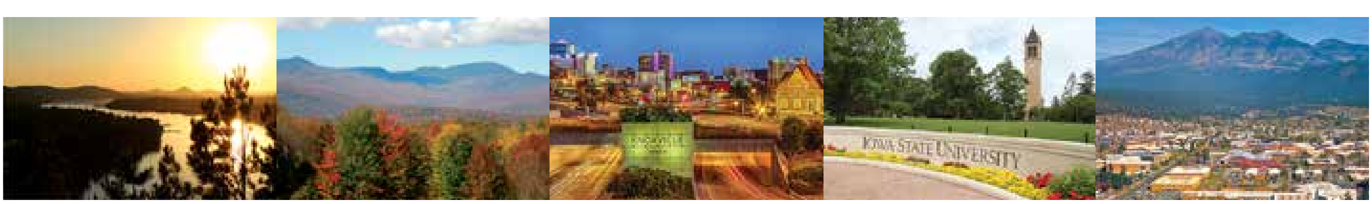
South-Central Section Meeting, Little Rock, Arkansas, USA
Shlemon Mentor Luncheon Program: Monday, 12 March
Mann Mentors in Applied Hydrology Luncheon: Tuesday, 13 March

Northeastern Section Meeting, Burlington, Vermont, USA
Shlemon Mentor Luncheon Program: Monday, 19 March
Mann Mentors in Applied Hydrology Luncheon: Tuesday, 20 March

Southeastern Section Meeting, Knoxville, Tennessee, USA
Shlemon Mentor Luncheon Program: Thursday, 12 April
Mann Mentors in Applied Hydrology Luncheon: Friday, 13 April

North-Central Section Meeting, Ames, Iowa, USA
Shlemon Mentor Luncheon Program: Monday, 16 April
Mann Mentors in Applied Hydrology Luncheon: Tuesday, 17 April

Rocky Mountain & Cordilleran Joint Section Meeting, Flagstaff, Arizona, USA
Shlemon Mentor Luncheon Program: Tuesday, 15 May, and Wednesday, 16 May
Mann Mentors in Applied Hydrology Luncheon: Thursday, 17 May



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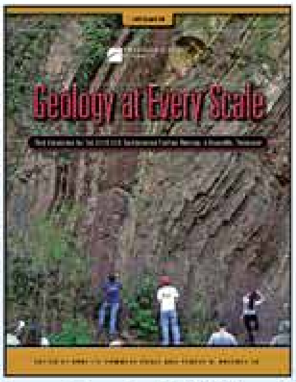

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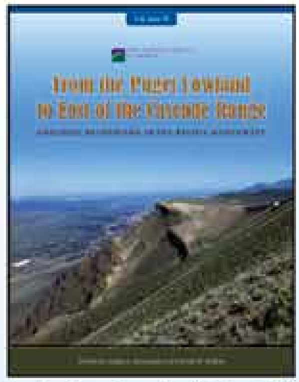

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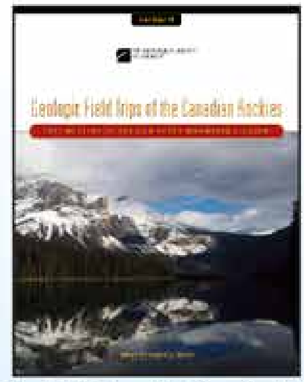

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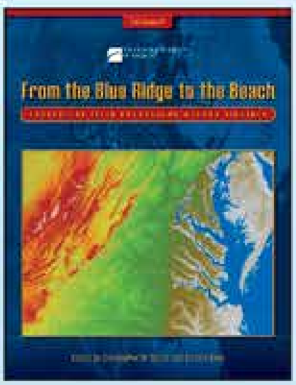

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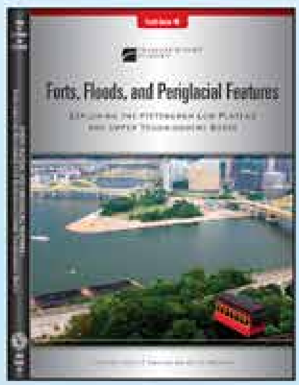

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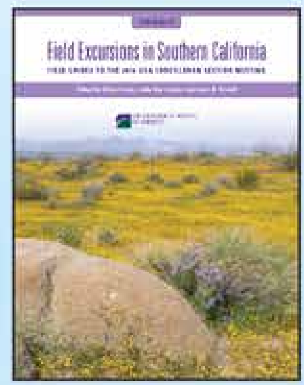

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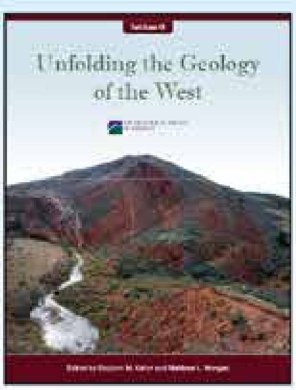

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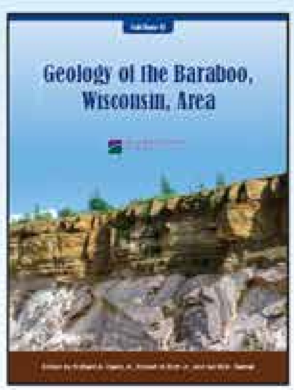

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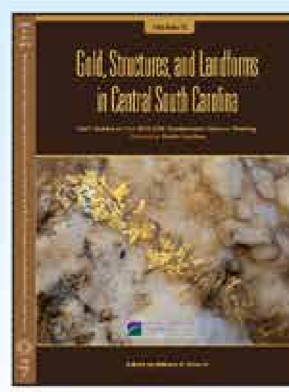

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GSA Committee Vacancies Available for Nominations by 15 June 2018

Terms begin 1 July 2019 unless otherwise noted. View open positions and access the nomination form at **www.geosociety.org/nominate.** GSA Headquarters Contact: Dominique Olvera, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA; fax: +1-303-357-1060; dolvera@geosociety.org.

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.

COMMITTEE NAME	NUMBER OF VACANCIES	POSITION TITLE / SPECIAL REQUIREMENTS	TERM (years)
Annual Program Committee (B/E/M)	3	• Members-at-Large • Member-at-Large Student	4 2
Arthur L. Day Medal Award (E/T)	2	• Members-at-Large	3
Diversity in the Geosciences (E/M)	2	• Members-at-Large	3
Education (B/E/M)	3	• Member-at-Large • Graduate Student Representative • 4-Year College Faculty	4 2 4
Geologic Mapping Award (E)	2	• Member-at-Large • Member-at-Large Student	3 3
Geology and Public Policy (B/E/M)	1	• Member-at-Large	3
GSA International (E/M)	4	• Member-at-Large • Secretary • IIG, Chair • Chair	4 4 4 4
Joint Technical Program (E) Terms begin December 2018	2	• Member-at-Large • Member-at-Large (Marine/Coastal Geology)	2 2
Membership and Fellowship (B/T)	2	• Members-at-Large Academia	3
Nominations (B/E)	2	• Members-at-Large	3
Penrose Conferences and Field Forums (E)	2	• Members-at-Large (Convener of a past Penrose Conference or Field Forum)	3
Penrose Medal Award (E/T)	2	• Members-at-Large	3
Professional Development (E)	2	• Former Councilor • Member-at-Large Student	3
Publications Committee (B/E/M)	1	• Member-at-Large	4
Research Grants (B/T)	9	• Members-at-Large (intensive time commitment in February–March each year)	3
Young Scientist Award (Donath Medal) (E/T)	2	• Member-at-Large • Member-at-Large (Councilor, former Councilor)	3 3

ELECTIONS: GSA OFFICERS and COUNCILORS

GSA ELECTIONS BEGIN 15 MARCH 2018

GSA's success depends on you—its members—and the work of the officers serving on GSA's Executive Committee and Council. Members will receive instructions for accessing a member-only electronic ballot via our secure website, and biographical information on the nominees will be online for you to review at that time. Paper versions of both the ballot and candidate information will also be available upon request. Please help continue to shape GSA's future by voting on these nominees.

2018 OFFICER NOMINEES

PRESIDENT
(July 2018–June 2019)
Robbie R. Gries
Gries Energy Partners LLC
Lakewood, Colorado, USA
We congratulate our incoming president!

PRESIDENT-ELECT/PRESIDENT
(July 2018–June 2019)/
(July 2019–June 2020)
Donald Siegel
Syracuse University
Syracuse, New York, USA

TREASURER
(July 2018–June 2019)
Richard C. Berg
Illinois State Geological Survey
Champaign, Illinois, USA

2018 COUNCIL NOMINEES

COUNCILOR POSITION 1
(July 2018–June 2022)
Jeffrey Rubin
Tualatin Valley Fire & Rescue
Tigard, Oregon, USA

David Spears
Division of Geology and Mineral Resources
Charlottesville, Virginia, USA

COUNCILOR POSITION 2
(July 2018–June 2022)
Rodney Metcalf
University of Nevada–Las Vegas
Las Vegas, Nevada, USA

Nathan Niemi
University of Michigan
Ann Arbor, Michigan, USA

COUNCILOR POSITION 3
Sections Liaison
(July 2018–June 2022)
Wendy Bohrson
Central Washington University
Ellensburg, Washington, USA

Jon Mies
University of Tennessee
Chattanooga, Tennessee, USA

To be counted, ballots must be submitted electronically, faxed to GSA Headquarters, or postmarked before midnight on **14 April 2018.**

USA SCIENCE & ENGINEERING FESTIVAL

GSA is teaming up with AGU to host a booth at the USA Science & Engineering Festival to be held at the Washington, D.C., Walter E. Washington Convention Center from 6–8 April 2018.

This biannual event brings science activities to hundreds of thousands of members of the public with booths from industry, government agencies, and professional societies like ours. Visitors to the GSA-AGU booth in the Earth Science Pavilion will have a chance to identify rocks and explore their genealogy within the rock cycle via several age-appropriate activities. Teachers and home-school parents are particularly encouraged to stop by to check out our activities and programming for educators.

LEARN MORE

Details on the festival are available at **https://usasciencefestival.org.**

CONTACT

GSA and AGU members in the D.C. area interested in helping out with our booth should contact Dean Moosavi at smoosavi@geosociety.org.

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GSA INTERNATIONAL

GSA International **TRAVEL GRANTS**

Application deadline: 5 July 2018

GSA International is offering travel grants to help support the participation of international scientists and students in GSA's Annual Meeting (4–7 Nov. 2018 in Indianapolis, Indiana, USA).

Travel grant funds are limited and grants will not cover the full cost to attend the meeting but are intended to help offset the combined cost of registration, housing, and travel.

Applicants do not need to be members of GSA or of GSA International to apply (although it is preferred). **Applicants must be residing outside of North America and presenting at the GSA meeting.**

To apply for a travel grant, go to **www.geosociety.org/Intl_TravelGrant.** You will be asked to provide a title and author list for the abstract you plan to submit. Applicants who intend to submit an abstract will be considered for travel grants, with the expectation that you will submit your abstract on time and be presenting your abstract at the meeting.

GSA International management board members intend to let applicants know about their status (successful or not) by **26 July 2018,** which allows a 90-day window for processing travel visa documents.

Questions? Please contact Barbara Carrapa at **bcarrapa@email.arizona.edu.**

The Geological Society of America® ON TO THE FUTURE

On To the Future Travel Awards

- 74% of applicants awarded grants
- Average award US$497
- Applications accepted 1 March–25 May

Join more than 500 students who have received travel funding to attend their first GSA Annual Meeting. On To the Future (OTF) provides funding to diverse students to attend the fall Annual Meeting in Indianapolis, Indiana, USA, 4–7 November 2018. Awardees will be paired with mentors and have opportunities to interact with GSA leadership. Check the OTF website (**www.geosociety.org/OTF/**) for eligibility guidelines and application information. GSA encourages low-income, minority, first-generation, non-traditional, women, veterans, LGBTQ, and students with disabilities to apply.

GSA Minority Student Scholarships

Application deadline: 15 June

This scholarship is granted to six undergraduate students who demonstrate a genuine commitment to the geosciences. Qualified applicants must be U.S. citizens studying at an accredited university or college in one of GSA's six regional sections (including Canada and Mexico). Students will also receive complimentary GSA student membership and meeting registration for this year's GSA Annual Meeting & Exposition. Email questions to awards@geosociety.org.

Learn more at **http://bit.ly/2Du9z2S.**

GSA GeoCorps™ America Program

Temporary, short-term geoscience opportunities in America's amazing public lands.

Fall/Winter 2018–2019 GeoCorps Opportunities

To be posted 1 May 2018

GeoCorps provides geoscience opportunities on federal public lands. Project areas include a wide variety of topics, such as paleontology, hydrology, geohazards, caves/karst, GIS/mapping, and more.

www.geosociety.org/geocorps

www.facebook.com/GeoCorps

Bureau of Land Management (BLM)

U.S. Dept. of Agriculture (USDA) Forest Service

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

Fall/Winter 2018–2019 GIP Positions

To be posted 1 May 2018

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 the Stewards Individual Placement Program.

www.geosociety.org/gip

National Park Service

Stewards Individual Placement Program

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FIELD CAMP SCHOLAR AWARDS

Are you an undergraduate student attending a field camp this summer?

If so, don't forget to apply for a GSA Field Camp Scholar Award. These US$2,000 scholarships will be awarded to undergraduate geology students for the summer of 2018. Applications are reviewed based on diversity, economic/financial need, and merit. **Deadline:** Friday, 23 March.

Go to **http://bit.ly/2AL9fKI** for more information and to apply. Questions? Contact Jennifer Nocerino at jnocerino@geosociety.org.

Notice of 2018 Spring **Council & Corporate Meetings**

All GSA members are invited to attend the open portions of Council Meetings and the Annual Corporate Meeting. To attend, contact Susan Lofton in advance for building access information and latest meeting times: slofton@geosociety.org.

- **Day 1:** Saturday, 5 May 2018
  9 a.m.–4:30 p.m.
  4:30–5:30 p.m.* (GSA Annual Corporate Meeting)

- **Day 2:** Sunday, 6 May 2018
  7:30 a.m.–3 p.m.*

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*Actual meeting times may vary. Meetings will be held at the GSA Headquarters in Boulder, Colorado, USA.

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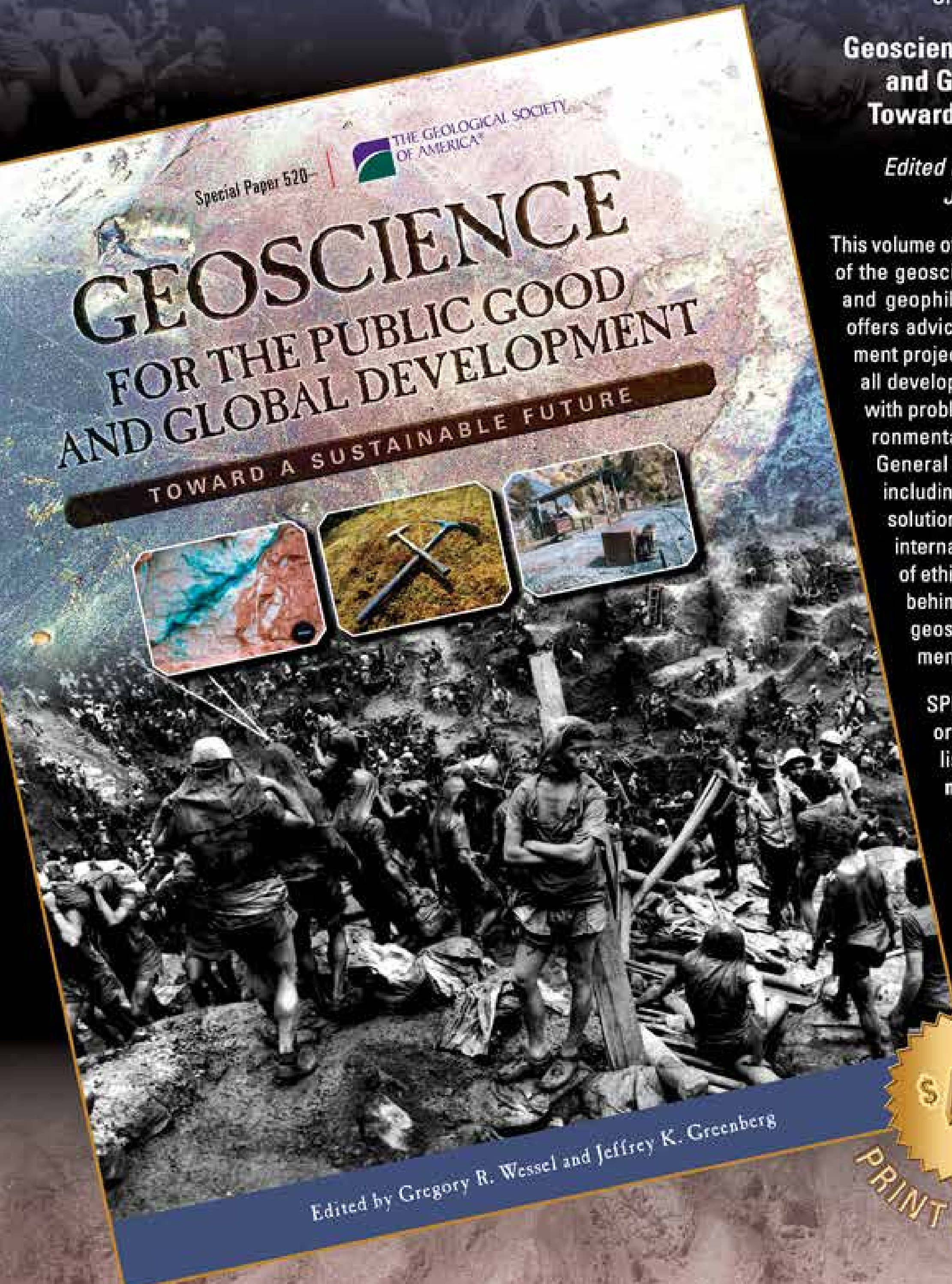

SPECIAL PAPER 520:

Geoscience for the Public Good and Global Development: Toward a Sustainable Future

Edited by Gregory R. Wessel and Jeffrey K. Greenberg

This volume offers an overview of the applications of the geosciences to sustainable development and geophilanthropic efforts worldwide, and offers advice to guide the creation of development projects. The primacy of geologic input to all development activities is highlighted along with problems that are encountered and environmental issues that must be addressed. General principles to follow are discussed, including guidelines for creating sustainable solutions, building foundations for effective international development, the importance of ethical and social values, the motivation behind sustainable development, and how geoscientists can best become development practitioners.

SPE520, 478 p., ISBN 9780813725208
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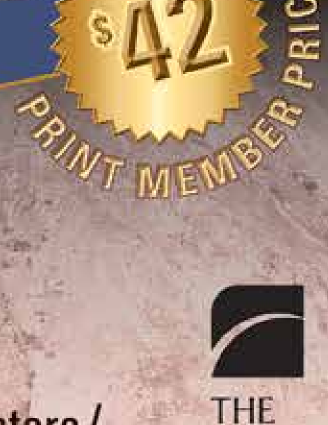

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"Mind the Gap": GSA's Role in an Evolving Global Society

Isabel Patricia Montañez, *Dept. of Earth and Planetary Sciences, University of California, Davis, California 95616, USA, ipmontanez@ucdavis.edu*

GEOSCIENCES: THE SCIENCE INTEGRATOR

Geoscience is the integrator of the natural, physical, and mathematical sciences as our efforts increasingly span across a spectrum of disciplines. As such, we are the stewards of the Earth. Our science, whether basic or applied, has relevance to society. It provides the foundation and path forward for addressing everything from environmental and natural hazard issues to informing discussions on public health, climate change, and global security. And it provides the fundamental context for understanding humanity's existence in the universe. Should it not follow then that the geosciences are a fundamental science—taught as part of a foundational curriculum in all schools in order to create an earth-literate public? The answer to this rhetorical question is clear.

There continues to be broad public support for the nation's scientific achievements, a trend that has been stable for the past few decades. Approximately 76% of Americans have at least a fair amount of confidence in scientists to act in the public interest (Pew Research Center, Oct. 2016), including an appreciation for the positive impact that science research has on the environment. And about the same number (~70%) think that government investment in basic science research pays off (Pew Research Center, 29 Jan. 2015). There is, however, substantial disparity between how the public and scientists perceive science-related issues and the contribution of scientific efforts to society. For example, the same study (Pew Research Center, 29 Jan. 2015) reveals the divide among the public regarding perceived consensus by scientists on fundamental topics such as the big bang theory, climate change, and evolution (Fig. 1A). The public is also largely pessimistic regarding the role geoscience research plays in guiding clean air, water, and land-use regulations. And despite the fact that nearly 60% of the public appreciates the impending resource limitation due to population growth, 4 in 10 remain confident that "the world will find a way to stretch its existing natural resources" (Fig. 1B). In this context, it is not hard to appreciate why we struggle to generate government and public support for the geoscience enterprise.

"MIND THE GAP": A PERSISTENT MULTI-DIMENSIONAL PROBLEM

This introduces the "Mind the Gap" in my title. Eldridge Moores, my long-term friend and colleague at the University of California Davis, introduced "the gap" in his GSA Presidential Address, 21 years ago (presented in Oct. 1996, published as Moores, 1997). He spoke of the divide that separates the science literate from those in society who have far less knowledge of and/or regard for the sciences. And he articulated how this divide fuels misunderstandings regarding the scientific process and the relevance of its findings. Since that time, aspects of the "gap" have been a recurrent theme in presidential addresses. This has been articulated by past GSA presidents as the need for increased

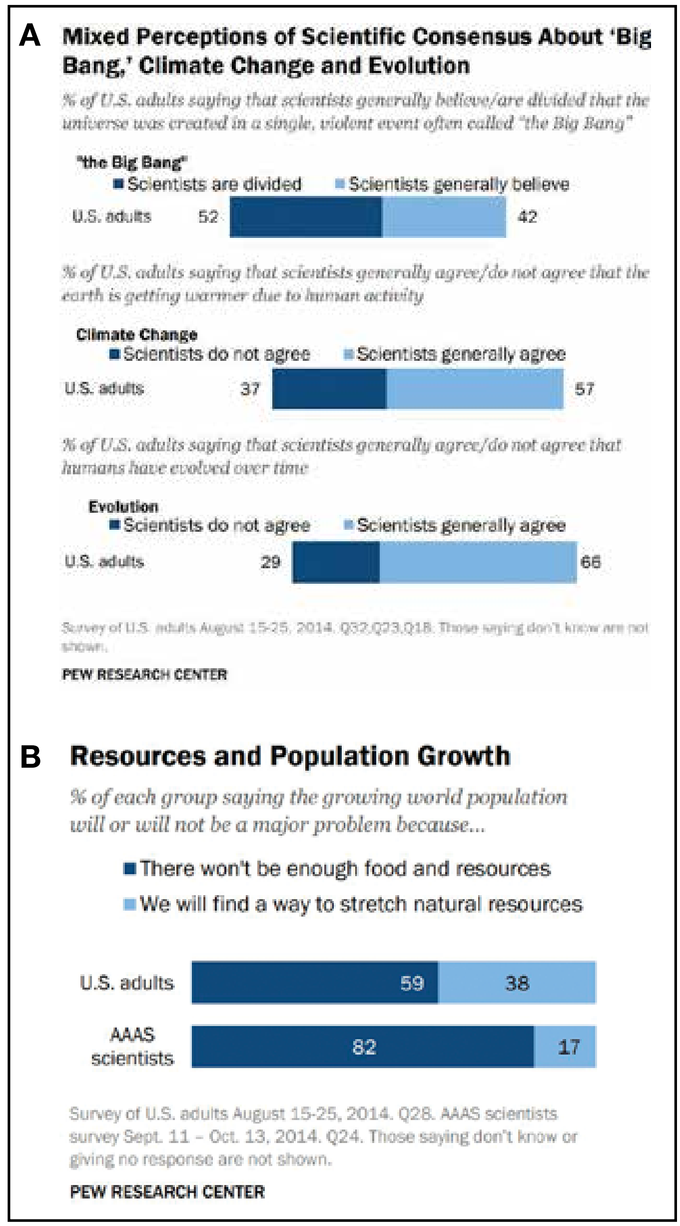

Figure 1. Pew Research Center study (29 Jan. 2015) of the public's view on science and society. (A) Results illustrating the divide among the public regarding perceived consensus by scientists on the big bang theory, climate change, and evolution. (B) The public and scientists' response to whether the growing world population will negatively impact food and resources.

GSA Today, v. 28, no. 3–4, doi: 10.1130/GSAT17PrsAdrs.1.

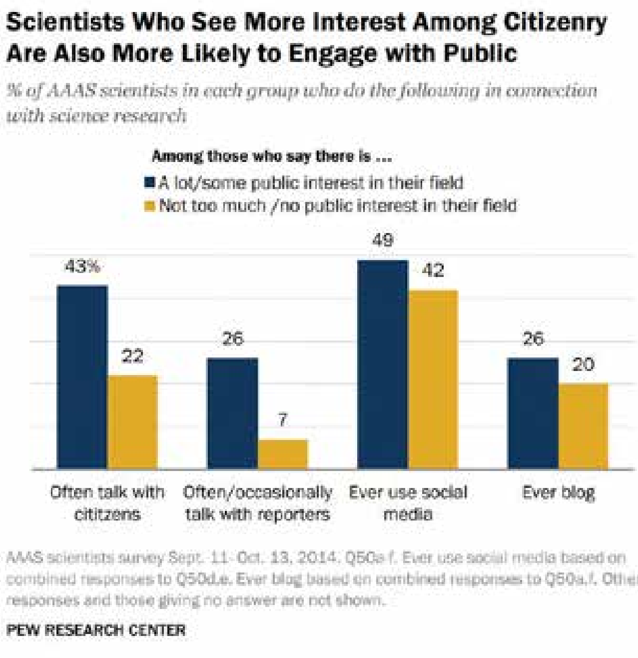

Figure 2. Pew Research Center study (15 Feb. 2015) of the percent of AAAS scientists who engage with the public. Those scientists who perceive some to a lot of interest by the public in their field (dark blue boxes) also engage more with the public than those who see less interest in their scientific field (gold boxes).

engagement with our elected representatives and decision makers, broadening of inter- and cross-disciplinary efforts, investing in the next generation of geoscientists through more effective mentoring and better alignment between student training and future industry trends, and greater infusion of geoscience into K–12 education (Zoback, 2001; Mosher, 2002; Bahr, 2010; Geissman, 2012; Davis, 2013). So why revisit this message now? Because the "gap" is a persistent and detrimental problem. The "Mind the Gap" in my title is a play on words. In Ireland, where I was on sabbatical in April through July 2017, there are signs in rail stations and trains cautioning travelers to "mind the gap" between the railway and the platform. Irish transportation authorities persistently warn people to be mindful of this gap as it is often larger than one appreciates.

We live in a historically significant time—one with new norms. We are moving away from a culture that values evidence-based decision-making to one that is more accepting of actions that are informed by "alternative-truths." This is reflected in the confusion that fake news has created regarding Americans' understanding of issues, including those that are science-based (Pew Research Center, Dec. 2016). And so the gap expands as the inherent uncertainty that we accept as part of the scientific process is translated into cut-and-dried discussions. Or when overly simplistic, unsubstantiated claims are imposed on complex science-based issues. I argue that a fundamental contributor to this problem is the lack of sufficient *effective* public engagement, including science communication. There is much potential to resolve this problem. We see this potential manifest in Americans' overall level of curiosity about science (81%)—a curiosity that is not matched by the amount of desired information they receive (Pew Research Center, Sept. 2017).

We, as part of the scientific community, are contributing to the gap. It turns out that geoscientists stand out well in this community for recognizing the importance of reaching out to the public. I define the public here as including the media and key decision makers. But still, studies show that relatively few among us regularly engage with the public (Fig. 2; Pew Research Center, 15 Feb. 2015). We tend to shy away from such activities for fear of being misrepresented or politically branded. Some argue a lack of time or skills to do so effectively or consider more than "dissemination of information" a futile distraction from research (The Royal Society, 2006; Besley and Nisbet, 2011). Consequently, only 31% of Americans believe scientists communicate effectively (Heagerty, 2015). This is despite their interest in and respect for the importance of scientific contributions to current environmental, political, and social issues. Change, however, is on the horizon—the enthusiasm for public engagement is increasing, in particular among younger scientists (Scientific American's Board of Editors, 2018).

The March for Science earlier this year was one of the first outpourings of support, but it was a sedate affair. I participated in the March in Dublin, Ireland (Fig. 3A), whereas many others participated in marches in the USA and around the globe. What we all recall are the folks on the sidelines encouraging us to shout more. Maybe we should. Not in a partisan manner but figuratively in well-strategized ways that capture the attention and persuade those outside of the scientific community of the importance and relevance of what we do. Notably, a recent study shows that the public's support for such engagement efforts scales by age group (Fig. 3B; Pew Research Center, May 2017), a trend that anecdotally is mirrored in the new generation of geoscientists (Scientific American's Board of Editors, 2018).

Adding to the size of the gap is the fact that the scientific community has long assumed that public apathy and disagreement with science is based on ignorance—this is, the well-studied "information-deficit model" (Besley and Nisbet, 2011; National Academies of Sciences, Engineering, and Medicine, 2017). And scientists further believe that the solution to the problem is a flood of more data, at times with an unconscious bias to "dumb it down." But studies repeatedly show that this assumption is unsubstantiated and

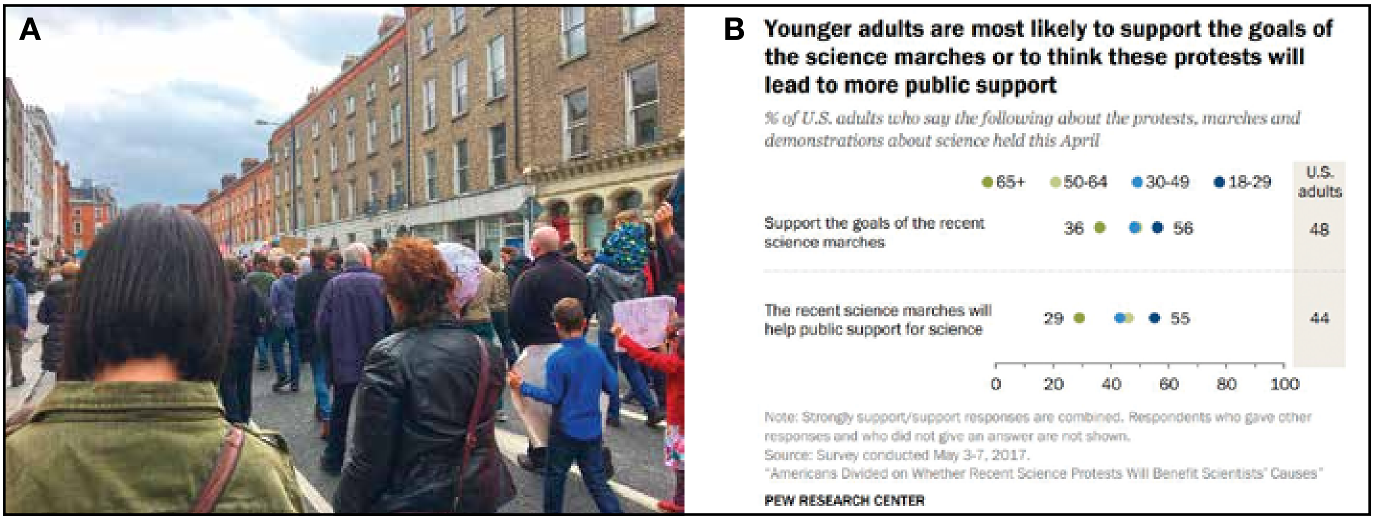

Figure 3. The March for Science, 22 April 2017. (A) The March in Dublin, Ireland. Author's photo from Merrion Street Upper on the way to the Government Buildings, Dublin. (B) Pew Research Center study (Pew Research Center, May 2017) indicating that support for the goals of the science marches and their perceived impact generally scales by age group.

only serves to expand the ideological divides developed around evidence-based issues (Kahan, 2010; Braman et al., 2012; Pew Research Center, Oct. 2016). Complicating this issue is the rapidly evolving shift from legacy media to online platforms. It is clear, however, that dissemination does not equal public engagement (Heagerty, 2015). The scientific community needs to move beyond the traditional focus on one-way transmission of knowledge to one of community discourse (e.g., National Academies of Sciences, Engineering, and Medicine, 2017).

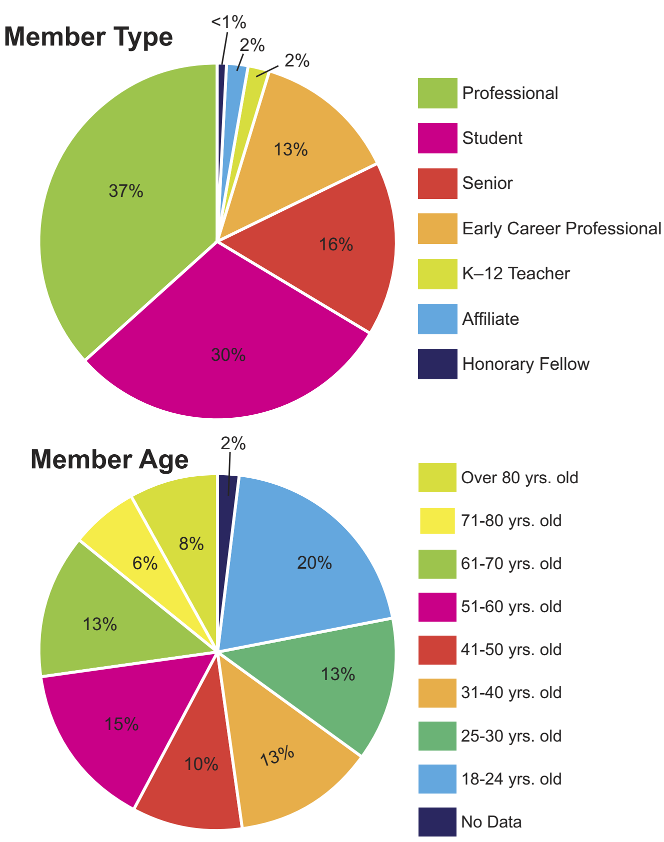

Figure 4. Demographics of GSA members by membership category and age (2017).

OPPORTUNITIES TO BRIDGE THE GAP

In every crisis, there is opportunity. High-quality public engagement has been shown to increase the public's positive perception of science (Liang et al., 2014), to elicit policy change, and to increase federal research funding (Bergan, 2009). The scientific community appreciates that decisions informed by scientific understanding will always trump those based on unsubstantiated or confused arguments.

Here, I build on the "call to bridge the gap" articulated so well by previous GSA presidents. Why? Because the "gap" remains, has grown larger, and now represents a true threat to how geoscience research will be funded, accepted, and utilized by those outside our scientific community. And GSA is critical to bridging the "gap." A core component of GSA's mission is to promote and communicate geoscience findings. The Society has several programs available that do this well and I'll highlight a few in the following discussion. I see three emerging opportunities for enhanced public engagement by the Society.

1. Empowering a New Generation of Receptive Geoscientists

This opportunity is presented by the current demographics of our membership. Students and early career professionals make up 43% of GSA (Fig. 4). This age group of geoscientists has spoken clearly regarding their interest in being part of the solution. They want to develop professional skills that provide them access to high-profile and interactive science discourse. In 2013, the National Science Foundation "challenged" graduate students across the USA to identify ways to improve their education. More than 500 students articulated a common desire for improved training in transferable and marketable professional skills, which are not traditionally taught in the geosciences or other STEM fields. The single most common skill identified was science communication—they want to excel at making science more accessible to the public (e.g., Shorr et al., 2013; Scientific American's Board of Editors, 2018). The students appreciate that engaging the public increases science literacy, leads to more informed policy decisions, and improves K–12 education. More effective public engagement will inspire the next generation of scientists and create advocates for the geosciences.

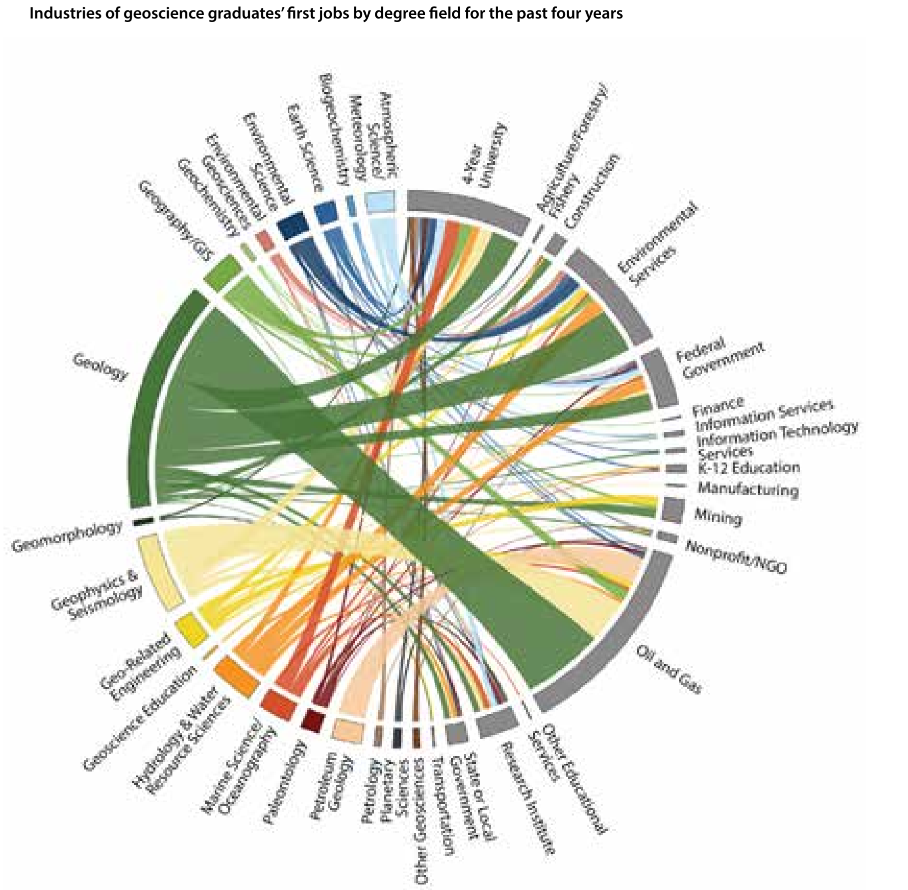

Figure 5. Visualization of the industries in which geoscience graduates obtain their first jobs by degree field for the period 2012–2016. Reprinted from AGI report on the "Status of Recent Geoscience Graduates" (Wilson, 2017). Courtesy of Carolyn Wilson (2018).

At the same time, the new generation of geoscientists is also casting a wider net regarding career options. A recent American Geosciences Institute report (Wilson, 2017) demonstrates the complexity of the workforce and diversity of jobs in which geoscience graduates are placed—at all degree levels (Fig. 5). In this environment of expanding geoscience career paths (e.g., science policy, media outreach, public affairs strategy firms, not-for-profit organizations), incorporating effective science communication into their training expands students' career options.

2. GSA's Decadal Strategic Planning for Future Vitality

The second opportunity is provided by the Society's decadal strategic planning effort. Through 2018, we will be working to develop a bold and empowering plan to guide the Society and to enhance its vitality. This effort will engage the membership broadly. We are asking members to envision future needs within the framework of this changing societal landscape. A key component of assuring our future vitality is evaluating how we can best engage with the public and guide geoscience policy. We have a lot to build on at GSA given our existing activities in this arena. For example, the Society offers professional development in science communication through a short course at our annual meeting, designed on the basis of the American Association for the Advancement of Science (AAAS) workshop *Communicating Science: Tools for Scientists and Engineers*. We are active in "pushing out"—that is, distributing press releases and facilitating press interactions with our members at our meetings as well as throughout the year. Christa Stratton, the Director for Education, Communication, and Outreach at GSA has proactively developed a member-experts directory for media inquiries. Our efforts in these venues are successful, but it's a case of small numbers. This year, we appointed our first Science Communications Fellow, Beth Geiger, chosen from an impressive pool of more than 125 science journalism applicants. This is made possible through the largess of the Bruce R. and Karen H. Clark Fund, which is directed at improving the level of understanding between GSA members and the non-scientific community. As part of a longer-term effort, to which I am strongly committed, Geiger mentored four communication interns in Seattle. These are students who want to be part of the "solution" by creating a more scientifically informed public.

On the science policy side, GSA engages through the Geology and Public Policy Committee and the Geology and Society Division. And it maintains a geoscience policy office in Washington, D.C. Kasey White, who directs that office, and our new Science Policy Fellow, Lindsay Davis, along with the on-the-Hill Congressional Science Fellow, Melanie Thornton, represent GSA within the Beltway and work to bring science and scientists into the policy process. But, if my experience is any indication, I suspect that many of our members underappreciate the opportunities that GSA's policy office provides. For example, Geoscience Day on the Hill and Climate Science Day provide opportunities for our members to obtain hands-on professional policy and communication training and to interface one-on-one with members of Congress and their staff. The Earth and Space Science Caucus sponsored by the U.S. House of Representatives is testament to the success of these visits and the power of individual GSA members to build champions for the geosciences. This event is a direct response from Congress to the scientific community's "ask" delivered at a previous Geoscience Day.

During the strategic planning process, we will be looking for additional ways to better engage the public. As we look inward within our Society, we will be asking "How can we better communicate our professional development opportunities to the members?" Looking outward, our public engagement initiatives can be guided by the new science of "science communication" (National Academies of Sciences, Engineering, and Medicine, 2017). A whole discipline is addressing the need for public discourse in the context of the ideological values that underlie science issues. Opportunities to leverage existing resources are plentiful. For example, the success of the National Association of Science Writers (https://www.nasw.org), composed of 2,200 plus freelancers, relies on good working relationships with individual scientists. We can help to connect them. We might consider how we can become involved as a Society in activities that broaden the public audience to include the sector that is not typically reached by traditional outreach approaches (e.g., museum exhibits, websites, science documentaries; Nisbet and Scheufele, 2009). Or we can find ways to better engage the public by addressing issues through the perspective of shared ideology. Three GSA members recently initiated a dialogue for this type of paradigm shift in science advocacy (Davidson et al., 2017). And I'll admit, I still hope to see one of our colleagues as the guest on one of my favorite late-night comedy shows.

3. Taking a Leadership Role in a Geoscience Culture Change

I referred previously to three opportunities. The third is to assume a leadership position in changing the culture in our workplace. This culture change requires overcoming the negative stigma that we hold regarding public engagement (Mellor, 2010; Liang et al., 2014). In academia, we can add science communication training to our curriculum. Recall the bygone days when graduate programs had a language requirement? Well, consider science communication training as making the next generation "bilingual" (as coined by Jane Lubchenco [2015])—that is, having the skills to captivate the public by effectively translating complex scientific knowledge.

There are well-regarded professional training and engagement workshops, such as those offered by AAAS or COMPASS, which can seed future in-house training efforts in the workplace, whether it be academia, industry, government, or NGOs, thus reaching out to many. I want to share one of my favorite out-of-the box examples. It took just three Ph.D. students, who self-proclaim to have been "frustrated with the public perception of science," to instigate a university-wide initiative in cutting-edge science communication at Carnegie Mellon University (Shorr et al., 2013). The program offers a curriculum of workshops and seminars utilizing empirical knowledge on how modern societies interpret science-based debates in order to train the next generation of scientists to be effective communicators. But here's the cool thing: this initiative, which involves students, faculty, administrators, science communicators, and journalists, was an outgrowth of these students' submission to the NSF Graduate Education Challenge that I mentioned earlier. Now that is what I call being empowered!

Even when we acknowledge the value of public communication and the efforts needed to do so, there is little protocol for legitimizing them (e.g., Lubchenco, 2017). GSA, through its platforms for public engagement, serves as a beacon of support for such activities. But it also requires that individual members be advocates at their institutions. As individuals we need to look for ways to formally recognize investments in public engagement and to educate administrators as to the importance of such endeavors, clearly articulating that such efforts do not come at the expense of scholarly activities, which are perceived as more important. Doctoral candidate Daniel Pham provides a poignant perspective on this issue and the overall importance of public engagement to young scientists and future science research (Pham, 2016).

I offer one final point. That is, each of us needs to constantly reevaluate the relevance of the science in which we are engaged and find ways to effectively communicate that message. My point is not to advocate for the need for "the relevancy of our work" but rather to stress that every one of us invests in work-related or training efforts that benefit humanity in one way or another. This relevance, however, is not always intuitive. As a sedimentary geologist and geochemist interested in deep-time paleoclimatology, establishing the relevance has been all too often hard earned. But I never miss the opportunity to view my large classes of undergraduates as keen future voters receptive to new ideas. And I've pitched the relevance of the deep-time geologic record to climate change discussions to the public and to federal funding agencies (National Research Council, 2011), as well as on the Hill through opportunities provided by GSA's policy office in Washington, D.C.

CONCLUDING THOUGHTS

I reiterate GSA's commitment to promoting the geosciences through effective public engagement. As individuals you may choose to "engage" in various ways or to differing degrees, but it is our collective responsibility to bridge the "gap" through championing the efforts put forth by our colleagues and students. And we can all actively promote informed conversations within and beyond our Society. As my graduate students and family know all too well, I'm a big fan of President Abraham Lincoln. There is wisdom in his words "Public sentiment is everything. With public sentiment, nothing can fail, without it, nothing can succeed" (A. Lincoln as recorded in Angle, 1991).

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Kirstin L. Neff

What We Talk About When We Talk About Congressional Gridlock

Continuing resolutions. Sequestration. Suspended requests for proposals. Delayed grant-making decisions. These have become common refrains in the federal science enterprise. Federal support for science boasts a long history, yet the appropriations process in Congress has ground nearly to a halt, resulting in perennial brinksmanship that leaves agencies, contractors, and academics unsure of near- and long-term funding. Beyond uncertainty in appropriations, many programs proceed without regular reauthorization as congressional gridlock touches all aspects of legislative work.

I have experienced these effects firsthand. As a graduate student, my training and research was funded in large part by federal appropriations, first on my advisor's NSF award, and later on my own EPA Science to Achieve Results (STAR) Fellowship. I was awarded the three-year EPA STAR in 2012, not long before the 2013 sequestration. I was relieved that EPA chose to fully fund the 2012 awards, but that came at the cost of applicants for 2013, who were left waiting a full year, after which a smaller cohort was chosen.

The uncertainty I experienced is likely common among GSA members who have applied for federal research funding in the past five years. Continuing resolutions (CRs) have become standard, and regular order for appropriations now seems a remote ideal. Sen. John McCain (R-AZ) has decried the debilitating impact CRs have on the ability of the military to plan and prepare—a similar argument can be made for the impact on the U.S. science enterprise. Grant-making and contracting take long-term planning, which is made nearly impossible by the current appropriations impasse.

The Government Accountability Office (2013) found that using CRs to delay appropriations decisions resulted in agencies delaying hiring or contracts during the CR period, rushing to spend funds in a compressed timeframe, performing additional work to manage within CR constraints, including issuing shorter term grants and contracts multiple times, and taking action to manage inefficiencies resulting from CRs, including shifting contract and grant cycles to later in the fiscal year to avoid repetitive work.

Congressional gridlock has been identified as a primary factor in Congress' abysmal public approval rating. But how do we measure legislative gridlock, and what are its causes?

Political scientist Sarah Binder of the Brookings Institution defines gridlock as an inability to compromise (Binder, 2014). She argues that congressional gridlock should not be measured as an absolute—how many laws Congress passes—but as a relative measure: how many major legislative agenda items are answered with new laws? She determined this relative measure by looking at the unsigned editorials of *The New York Times* to identify the salient legislative agenda items in a given Congress, and then counted how many of these items were answered with legislation signed into law. She found that the proportion of salient items in gridlock has trended upward, doubling from 30% in 1948 to 60% in 2012.

Congressional observers have identified several causes contributing to this gridlock. One of these is increasing political polarization, which has been exacerbated by several recent political developments. First, the power of lobbies has increased due to several recent Supreme Court decisions that expand the ability of corporations, unions, associations, and individuals to fund campaigns through Super PACs. Second, gerrymandering has redrawn many electoral districts to make them safe for either of the two major parties, allowing more extreme partisans to win election. Finally, polarization has been advanced by what is called the Nuclear Option—in which Senate rules requiring a 60-vote super majority for passage have been swept aside to allow for simple majority approval.

Binder (2014) points to one other possible cause of gridlock: Congress is faced with an increasing number of salient issues. She found that in addition to an increase in proportional gridlock, the absolute number of salient issues per Congress has increased in recent years. It's possible that the complexity of the modern world and the federal government's reach creates more issues than Congress can reasonably address in a single session under current rules.

In my experience, I have found that the Senate only has the bandwidth to work on one or two issues at a time. While in the House majority rule leads to passage of many bills, often by suspension of the rules, Senate rules favor lengthy debate. Early this Congress, topics related to my own portfolio, including an energy bill and an infrastructure package, were floated, but were set aside in favor of health care and, later, tax reform. Bills received legislative hearings with some regularity, but Senate debate rules and the need to vote on presidential nominees left little time on the Senate calendar for floor votes on individual bills. Instead, individual bills must pass through unanimous consent (though any senator can put an anonymous hold on such a request), or by appending them to a larger package of bills that receives a floor vote. Gridlock in the Senate this year can be partly attributed to the crowded legislative calendar, and even more so to the lack of compromise on the salient items that did come to the floor.

The upward trend in congressional gridlock portends danger for the future of federal science support. To bring stability, we must find ways to decrease political polarization and encourage compromise.

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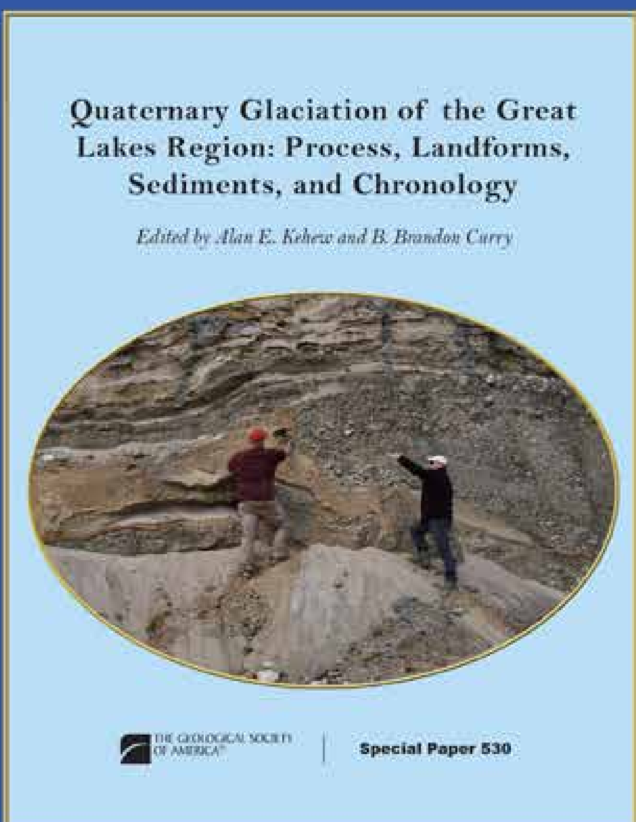

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Update

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

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The GSA Foundation is present at every GSA Section Meeting with a booth full of information on the Society programs that we support. Students find their way to our booth with questions about research grants, GeoCorps, and mentoring programs, and other members inquire about funds and their contributions made in support of GSA's programs.

You will see various Foundation team members at this year's section meetings. At the first meeting of the year, the South-Central Section Meeting in Little Rock, you'll find Director of Development Debbie Marcinkowski joined by the newest member of the GSAF staff, Assistant Director of Individual Giving Clifton Cullen.

Be sure to come meet Cliff and welcome him to the larger GSA family! Cliff will be focused on individual donors to our annual giving program, as well as the Pardee Legacy Circle, GSAF's legacy giving program. Cliff relocated from Pasadena, California, USA, where he was the director of annual giving at Fuller Theological Seminary. With a passion for the sciences since a young age, Cliff carved out time during pursuit of his bachelor's and master's degrees for reading current scientific scholarship, visits to science museums, and listening to science-themed podcasts. With his experience in building funding among varied groups and working with donors to support programs, Cliff is an excellent fit for both our team and for GSA members.

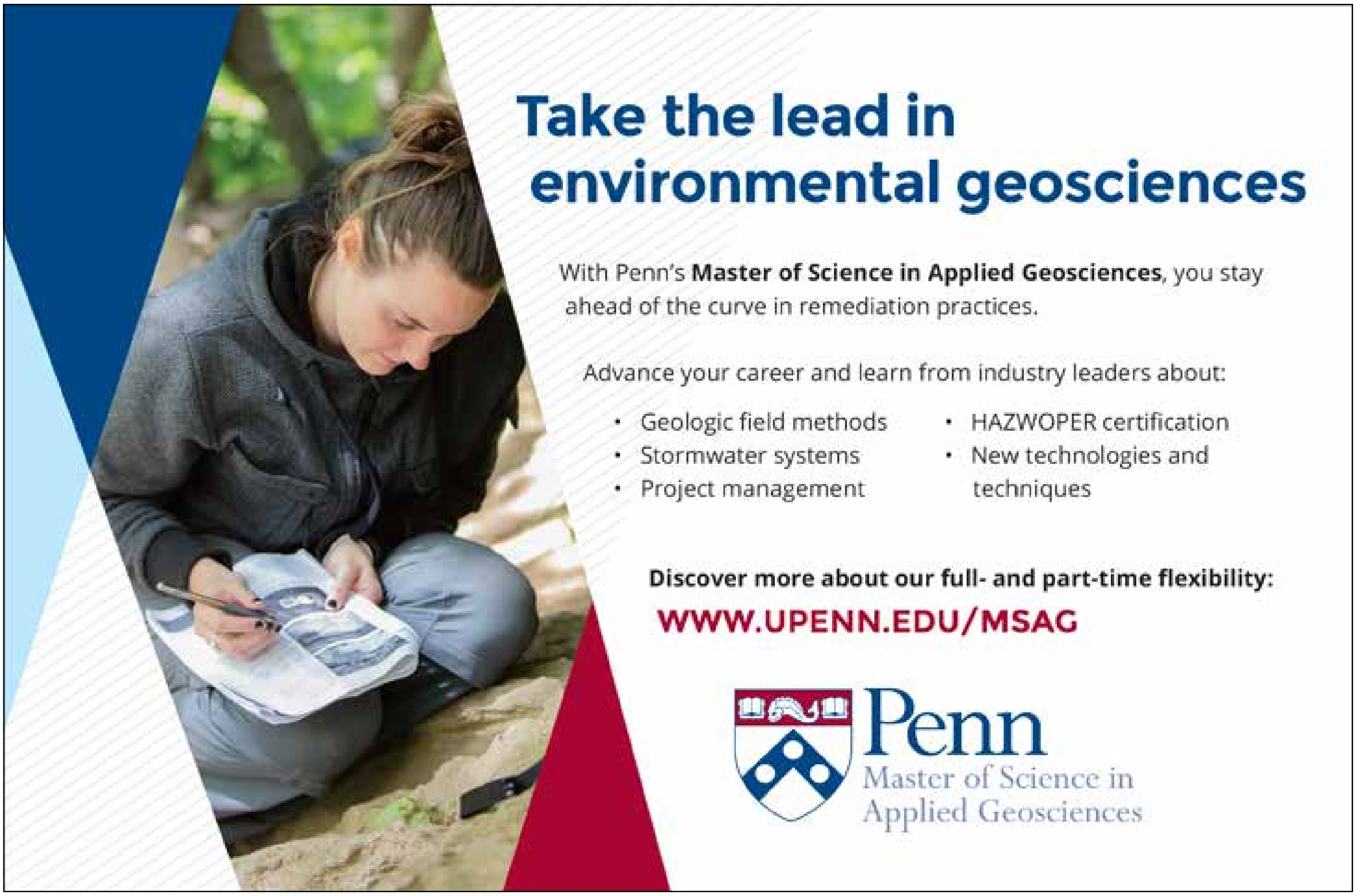
So that he may meet even more of you in person, Cliff will join me in Burlington for the Northeastern Section Meeting. Debbie and I both will be pleased to see our members attending the Southeastern meeting in Knoxville, the North-Central meeting in Ames, and the combined Cordilleran/Rocky Mountain meeting in Flagstaff.

Student members should be sure to stop by for some fun in addition to information on relevant programs. In 2017 alone, we had 1,122 student donors! This group gave back to various student programs, in large part due to their gratitude for support received from GSA. Every gift, no matter the size, makes a difference and helps others along their path in the geosciences. Come learn more at the GSA Foundation booth at your Section Meeting.

Cliff Cullen, GSAF's new Assistant Director, Individual Giving.

Answering students' questions at the GSAF booth during a 2016 Section Meeting.

www.gsafweb.org



Geosphere's Themed Issues

Geosphere, GSA's ambitious online-only journal, periodically runs themed issues devoted to a topic or region. The journal's flexible electronic format allows for rapid publication times even for papers in a themed issue. These papers are published in regular *Geosphere* issues as they are accepted and then collectively published on a webpage devoted to each theme.

In addition to timely publication, *Geosphere* offers authors the opportunity to present information in dynamic ways using animations, movies, oversize figures, and more. The journal is also now fully **open access**!

To see the current call for submissions to themed issues, visit **https://pubs.geoscienceworld.org/geosphere/pages/callforpapers.**

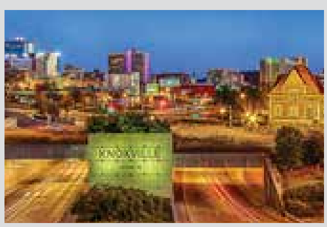
THE GEOLOGICAL SOCIETY OF AMERICA®

GSA Section Meetings

2018

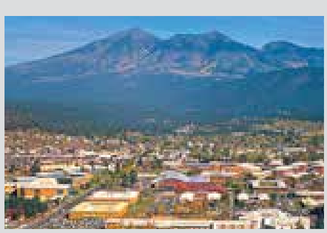
South-Central Section
12–13 March
Little Rock, Arkansas, USA
Meeting Chair: Michael DeAngelis, mtdeangelis@ualr.edu
www.geosociety.org/sc-mtg
Photo by Oliver Beland.

Northeastern Section
18–20 March
Burlington, Vermont, USA
Meeting Chairs: Charlotte Mehrtens, cmehrten@uvm.edu; Andrea Lini, alini@uvm.edu
www.geosociety.org/ne-mtg
Photo by Stephen Wright.



Southeastern Section
12–13 April
Knoxville, Tennessee, USA
Meeting Chair: Colin D. Sumrall, csumrall@utk.edu
www.geosociety.org/se-mtg
Photo by Bruce McCamish.

North-Central Section
16–17 April
Ames, Iowa, USA
Meeting Chair: William Simpkins, bsimp@iastate.edu
www.geosociety.org/nc-mtg
Photo by Bri Gerke.



Rocky Mountain/Cordilleran Joint Section Meeting
15–17 May
Flagstaff, Arizona, USA
Meeting Chair: Paul Umhoefer, paul.umhoefer@nau.edu
Meeting Co-Chair: Dennis Newell, dennis.newell@usu.edu
www.geosociety.org/rm-mtg
Photo credit: findyourspot.com.