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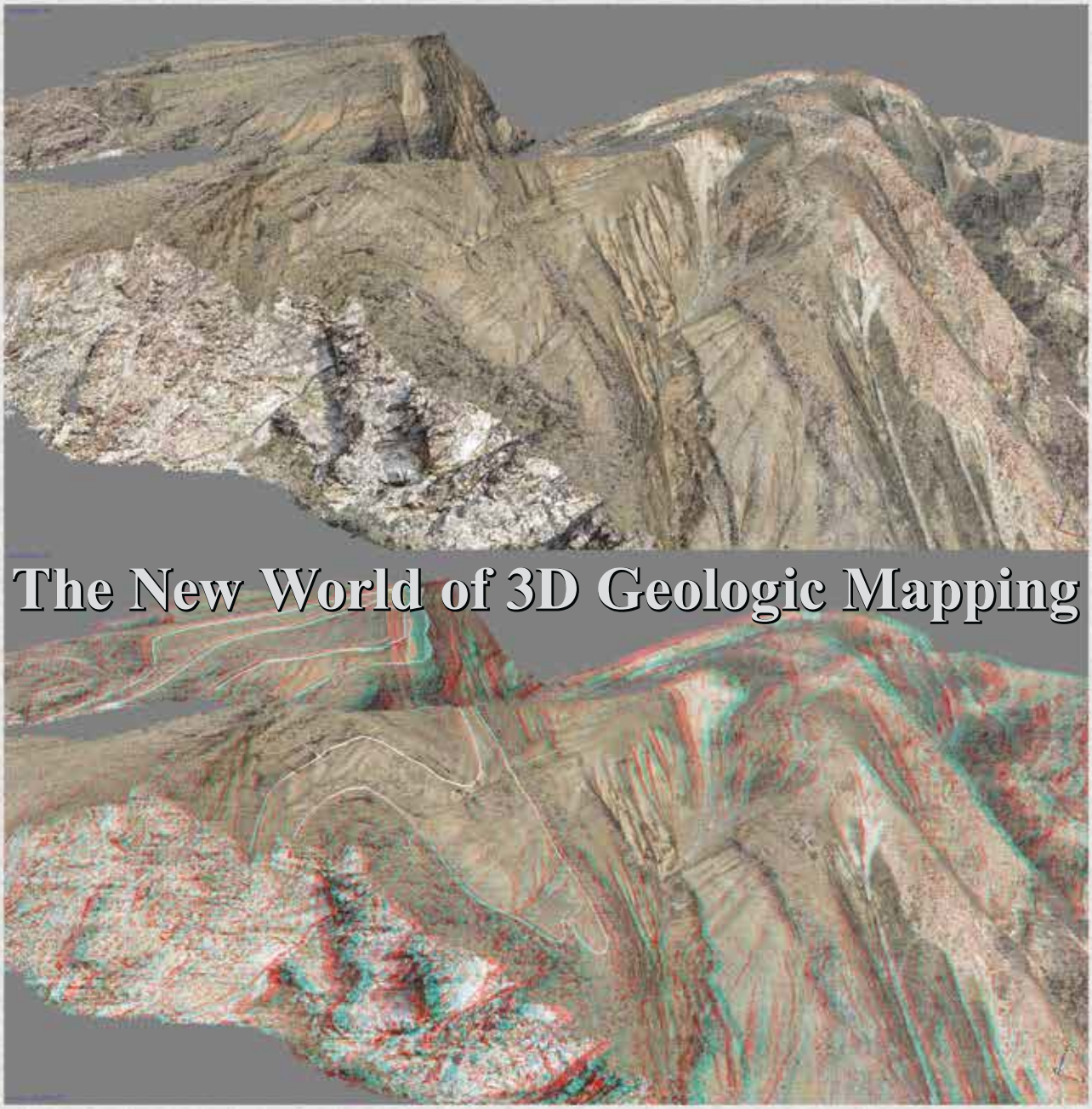

The New World of 3D Geologic Mapping

SEPTEMBER 2017 | VOLUME 27, NUMBER 9

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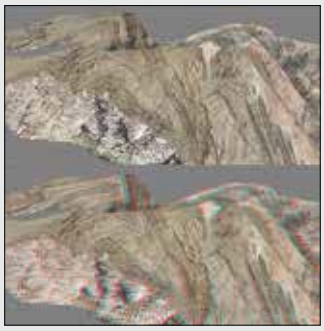

Cover: Perspective view (above) and partially interpreted anaglyph stereo view (below) of 3D terrain model developed from ground-based Structure-from-Motion photogrammetry in Surprise Canyon, western Panamint Mountains, California, USA. View is toward the north. Note how a distinctive schist unit mapped as white lines in the lower image outlines a sub-isoclinal recumbent fold that is refolded by an upright antiform in the foreground but is distinctly different on the ridge in the background. See related article, p. 4–10.

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Cover inset image: The Fremont Troll is a public sculpture in the Fremont neighborhood of Seattle, WA, USA.

THE GEOLOGICAL SOCIETY OF AMERICA®

The New World of 3D Geologic Mapping

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ABSTRACT

Digital geologic mapping is now a fully mature technology that dramatically improves field efficiency and problem solving capabilities. Basic digital mapping is just the tip of the iceberg, however, in regard to new and approaching capabilities with true 3D mapping. The key advance is the ability to easily construct high-resolution, photorealistic terrain models as a base surface for 3D mapping using Structure from Motion (SfM) photogrammetry terrain models, particularly through the aid of unmanned aerial systems (UAS). We show how these technologies can aid field visualization and discuss how developing digital field workflows and 3D visualizations will transform field studies, allowing the resolution of problems that were impossibly complex without this technology.

INTRODUCTION

The past 30 years have witnessed a revolution in digital technology that has led to astonishing changes in our lives, from the use of personal devices to advanced computing. Digital technology is also fundamentally changing field geology in ways that will impact all geosciences. Digital geologic mapping has been practical for more than 10 years (e.g., Pavlis et al., 2010), and, although many cling to paper-based workflows, that approach is now outdated and inefficient in comparison. Digital mapping also transforms a geologic map from a static, fixed-scale object to a dynamic, multiscale database complete with the primary data used to construct it.

Digital mapping, however, is only the beginning of an even bigger revolution that is upon us from three-dimensional (3D) mapping and visualization. The geometry of geologic features analyzed in field studies is inherently 3D, and reliance on 2D maps has handicapped advances in our understanding of the earth system. Three-dimensional geophysical imaging of the subsurface revolutionized hydrocarbon exploration and could do the same for field geology, where rich 3D information is available from surface geology when there is significant topographic relief, yet that 3D information is mostly lost in 2D methods. In addition, we continue to teach students flat-map techniques like visualizing Earth's surface through a topographic map, yet this abstraction of Earth's surface is challenging for most students. Digital globes like Google Earth help with this problem, but we now have far better options.

In this paper, we consider the problem of geologic mapping and how 3D visualization can aid that process. We emphasize here the importance of the distinction between 3D geologic mapping and 3D modeling of geologic features. Whole volumes have been written on the latter, but 3D mapping as a data collection technique is still in its infancy (e.g., MacCormack et al., 2015; Buckley et al., 2016). To date the primary work on 3D mapping has been in Europe and Australia, with most applications in engineering geology and geomorphology (e.g., MacCormack et al., 2015; Buckley et al., 2016). This will soon change. We predict that 3D techniques will soon fundamentally reshape all geologic fieldwork in ways we have not even begun to realize. In particular, we emphasize that new technology, Structure from Motion (SfM) photogrammetry in conjunction with unmanned aerial systems (UAS), aka drones, can allow routine construction of inexpensive, high-resolution, photorealistic 3D terrain models. These 3D surface models can serve as a base for high-resolution surface mapping that will allow construction of a new generation of 3D geologic models at scales ranging from hand specimen to tens of kilometers. To support this claim, we begin with a review of the limitations of widely used 3D visualizations of Earth's surface in comparison to capabilities of SfM models. We then use a case study to illustrate how these high-resolution visualizations of Earth can dramatically improve the ability to resolve geometric problems in the field. We then speculate how this technology will reshape field geology in the next 5–10 years.

THE 2D DIGITAL MAPPING OF TODAY AND THE NEW WORLD OF 3D MAPPING

A few years ago, we (Pavlis et al., 2010) reviewed the history of technology that led to the modern generation of field data collection systems for digital mapping, yet seven years is an eternity in this field of rapidly advancing technology. Two-dimensional digital mapping has now become a fully mature practice with numerous applications for field geology (Mookerjee et al., 2015). Software and hardware issues remain, but there is no longer a doubt that paper mapping is outdated due to the inherent efficiency of digital techniques and ability to share data readily (e.g., Whitmeyer, 2012). Moreover, increased mapping accuracy with GPS, routine access to multiple data layers, and the nearly limitless scaling afforded by digital maps allow for the resolution of field problems that was impossible on paper maps. Nonetheless, these systems are only the vanguard to a true revolution that is upon us, 3D mapping.

The Problem of Early 3D Methods

For many of us, geologic mapping through a 3D interface has been a dream since the first 3D computer visualizations appeared on the scene. Two-dimensional digital mapping is largely a data management/collection variant on paper-based field geology, and therefore remains a flat-map–centric approach to a problem that is fundamentally 3D. Geologists first began to experience 3D mapping from digital elevation models (DEMs) using GIS software and digital globes like Google Earth and NASA's Worldwind (DePaor,

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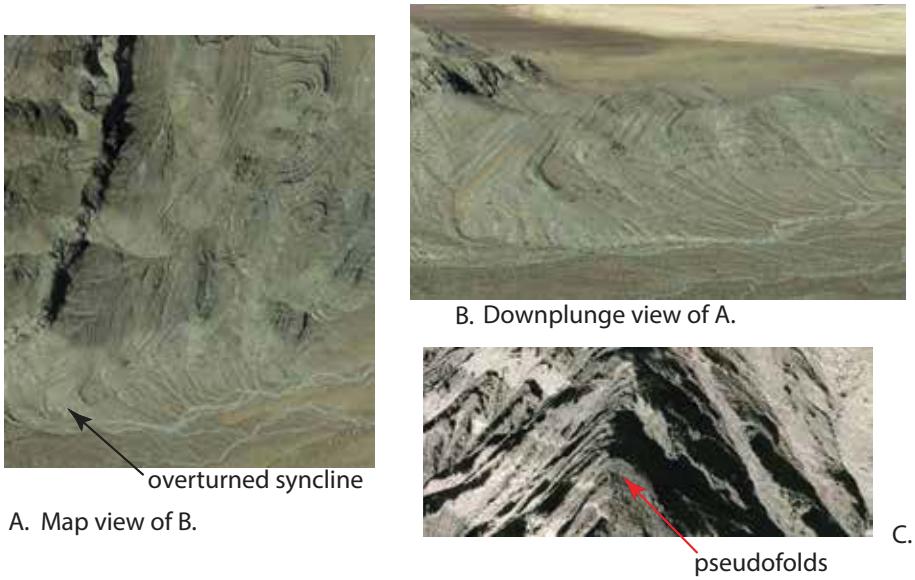

Figure 1. Examples of success and failure of 2.5D techniques for visualization of geologic features. (A) and (B) show a successful visualization of an overturned syncline in the Nopah Range near Pahrump, Nevada, USA, where the visualization is successful due to the large size of the structure (~1 km across) relative to the terrain model. (C) shows a contrasting failure of the method in the same area where pseudofolds are seen in this oblique view due to improper image drape on a narrow ridge line. Oblique view is ~500 m across. All views are from Google Earth.

2016). Digital globes eliminate one problem in flat map approaches by affording an infinite range of views such as down-plunge views of folds (Fig. 1) or down-dip views of dipping beds that eliminates the "law-of-v's" effect. Nonetheless, digital globe visualizations contain errors inherent in the way they are constructed, which is not always appreciated by geoscientists. In particular, any recent GIS textbook describes how surface visualizations like Google Earth are produced by a 2.5D method of draping imagery, typically orthocorrected aircraft imagery or satellite imagery, onto a DEM. When terrain is modest, this approach produces a reasonable rendering of Earth's surface, but in steep terrain this approach produces spatial errors that lead to visualization problems like pixel smear and distortions that introduce spatial errors during 3D mapping (Figs. 1 and 2 and GSA Data Repository supplement 1[1]). This problem has been known for decades in photogrammetry (e.g., Wolf, 1983), but its effects are often misunderstood. For example, consider a vertical or overhanging cliff. In a vertical view, the 3D surface of the cliff is degraded to a line. Alternatively, in an image captured off-nadir, the cliff occupies a 2D area in the photograph, but is distorted due to look angle. In either case, however, orthocorrection, and subsequent draping of the orthophoto onto a terrain model, produces distortions via pixel smear, distorting the image on the terrain model, or both. This effect is particularly significant when the terrain model is low resolution relative to the imagery, which is the case in virtually all visualizations that use a standard 30–90 m DEM (Figs. 1 and 2 and Data Repository supplements 1A–2B [see footnote 1]).

It is easy to show from basic trigonometry that on all steep slopes (>45°) features will be either invisible or hopelessly distorted in conventional map views and 3D visualizations that use a 2.5D image drape approach. Therefore, potentially critical information is mostly lost. Ironically, these same cliff faces are often the most informative rock exposures. Field geologists long have compensated for this limitation by using photographs, field sketches, or both, but these observations contain no quantitative, 3D geographic control. Recognition of this issue was a major driver for the "Virtual Geoscience" initiative in Europe (Buckley et al., 2016), and although the problem can now be resolved, the solution has not yet been widely exploited.

The Solution: A New World of True 3D Terrain Models and 3D Mapping

One solution to this steep-slope/cliff problem has been around for some time through the use of ground-based or airborne LiDAR (light detection and ranging). High-resolution 3D renderings of Earth's surface can be obtained with these methods, including overhanging cliff faces. In addition, photos from any angle can be draped onto the model, or the raw, colored point cloud can be visualized to provide photorealistic scenes.

Although LiDAR is presently the gold standard for terrain modeling, we predict that it will never be used extensively for bedrock field geology except in special cases where very high accuracy is needed. The reason is that a technology has arisen that makes LiDAR overpriced and inefficient. That technology is SfM photogrammetry. SfM has been described elsewhere (e.g., Westoby et al., 2012; Tavani et al., 2104; Furukawa and Hernandez, 2015; DePaor, 2016) and is a fundamental advancement in photogrammetry that eliminates the requirement for near vertical imagery in conventional photogrammetry. Specifically, SfM, or more specifically, multi-view stereo, allows the use of a suite of arbitrary oblique images in the construction of a 3D terrain model (e.g., Westoby et al., 2012; Furukawa and Hernandez, 2015). Most applications of SfM to date have been in geomorphology and engineering geology or in the construction of virtual outcrops (e.g., Buckley et al., 2016; DePaor, 2016). We suggest here, however, that ultimately SfM will have its greatest application at map scales commonly used in bedrock field geology, particularly in areas of extensive rock outcrop. SfM is advantageous at this scale over LiDAR because (a) it only requires equipment already routinely carried by field geologists—a camera, GPS unit, and field computer; and (b) it can be exploited at sites of opportunity via construction of virtual outcrops or at map scales, depending on project needs. Thus, there is no need to carry an expensive extra piece of equipment, and a single individual or small group can produce a photorealistic terrain model at resolutions of centimeters with none of the problems of 2.5D terrain

[1] GSA Data Repository Item 2017128, four supplementary figures and two animations, is online at http://www.geosociety.org/datarepository/2017/.

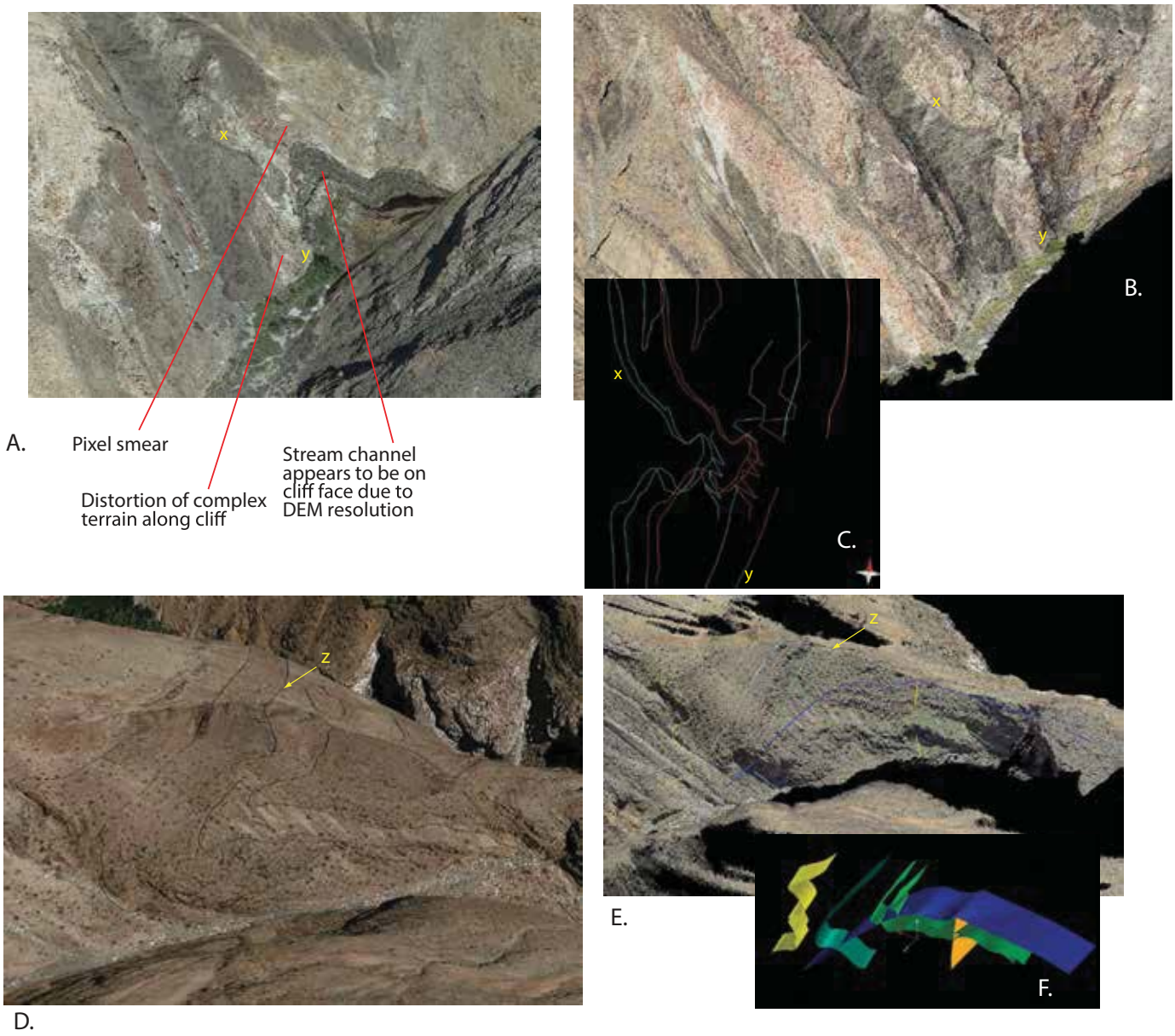

Figure 2. Virtual scenes of the case study area in Surprise Canyon, California, USA (near 36.1133N, 117.1617W), illustrating errors introduced in conventional 2.5D methods (left, perspective views in Google Earth [A] and ArcGIS Pro [D]) versus approximately equivalent perspective views of georeferenced SfM point clouds obtained from oblique, ground-based photography (right). Insets (C) and (F) show local geologic interpretations with (E) and (F) described further in Figure 4. Several errors are apparent in the left scenes. In (A) and (B) (yellow [x] and [y] are equivalent points on the images and [C]) note the distortions and pixel smear in (A) versus true renderings in (B). (C) is a cyan-magenta stereo rendering of the lithologic contact between the dark and light units between (x) and (y) as well as two faults (white lines, rendered blue and red in the view, are from the SfM model and yellow, rendered green and red in the view); note how the 3D model allows 3D rendering of exposed fault faces as a jagged line versus the poor rendering of the faults from map drapes as well as superior 3D resolution of the contact in the SfM model. In scenes (D) and (E) note how errors in the 2.5D method introduce an artifact in D, labeled z, that could produce a major error in a geologic interpretation. In the left scene (D) rock units (outlined in black) clearly appear to dip to the right in this rendering and a three-point analysis of the scene would confirm this, yet the true dip is to the left, which is clear in the right scene (E) and in the field. (F) shows a visualization of structures present in the scene with the dark blue surface, indicating the folded axial surface of early isoclinal folds and the vertical orange plane showing the axial surface of a second generation antiform that warps the older fold system.

visualizations (Figs. 1 and 2 and Data Repository supplement 1 [see footnote 1]). The colored terrain model is still subject to look angle issues such that a model generated entirely by surface observations will be limited by the available views (Fig. 3). Nonetheless, it is straightforward with this technology to combine ground-based photographs and aerial photographs, producing a photorealistic 3D model of Earth's surface (Fig. 3). Best practices still need further research, but we have found that direct mapping on the colored point cloud is straightforward in several software packages (e.g., see workflow suggestions at www.geo.utep.edu/pavlis/digitalmappingwebpages/). In this approach, problems like pixel smear and distortions from image drape are eliminated. In addition, there is no doubt in this method that every point in the point cloud has a proper color for its position in 3D space because the point color is derived directly from the photographs that generated the model. In the following section, we illustrate the power of using these models to solve a field problem, but applications are nearly limitless.

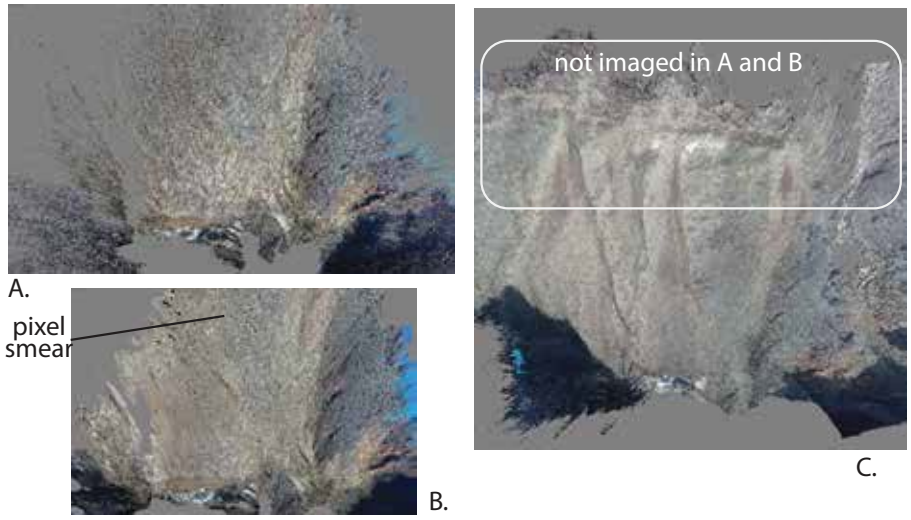

Figure 3. Illustration of the power of using unmanned aerial system (UAS) imagery in Structure from Motion studies. Figure is a comparison of a near-vertical view of the same area developed using the same camera from ground-based images only (A and B) versus ground-level to ~100 m elevation UAS flight images (C). (A) is a visualization of the colored point cloud, whereas (B) is a textured triangulated irregular network model, and (C) is a colored point cloud with all scenes processed at the same resolution using Agisoft PhotoScan. Seventy images were used in (A) and (B) versus 400 in (C), but the increase in resolution is primarily due to greater ranges of look angles in (C).

Case Study: Surprise Canyon, Panamint Mountains, California, USA

Methods

Terrestrial LiDAR survey (TLS) data were acquired in Surprise Canyon in the Panamint Mountains west of Death Valley to conduct an experiment in 3D mapping. Following that survey, we used a handheld, GPS-enabled camera at sites of opportunity and used the photographs to develop SfM models that overlapped with the TLS survey. The SfM data were co-registered with the TLS data using a variety of ground control methods. Data acquisition and error assessment for this study is considered elsewhere (Brush, 2015). The study area was chosen because it contains complex, metamorphic structures, arguably the most challenging 3D visualization problem in field studies, yet the area contains superb bedrock exposures and significant topographic relief. Thus, the site is nearly ideal to test 3D mapping methods. SfM models were generated using Agisoft PhotoScan Professional software; Maptek's I-Site Studio was used to co-register SfM and LiDAR point clouds as well as a 3D

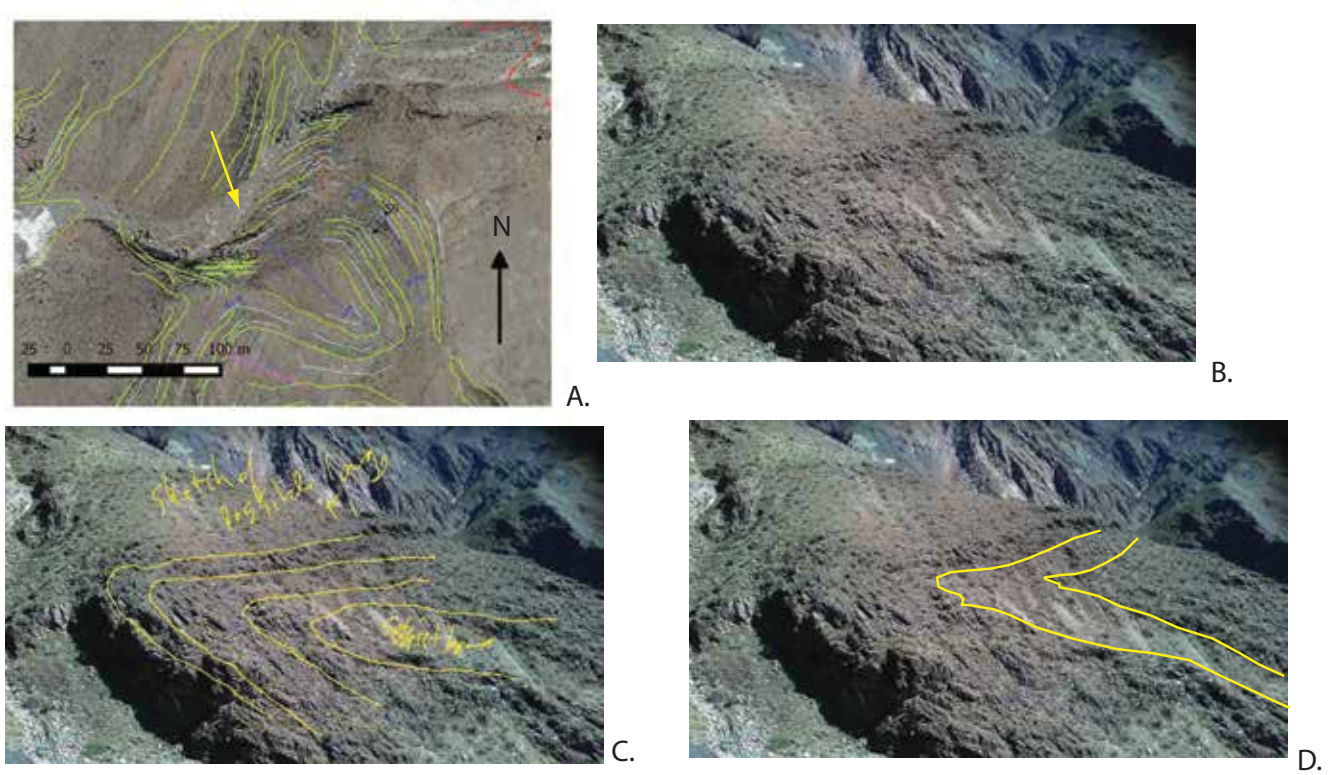

Figure 4. Sequential development of the structural interpretation for the area in Figure 2D–2F. (A) shows field map at the end of the first season (one field day) with contradictory interpretations. Yellow arrow shows view direction in Figure 2 and (B)–(D) in this figure. (B) shows an uninterpreted field image captured on a tablet computer with the same image annotated in (C) showing the field interpretation after the second visit to the site versus the final interpretation (D) developed from model interpretation and a field visit to confirm the interpretation. Linework in (A) shows form lines of layering (green), main foliation (blue), inferred second cleavage (dashed thin red lines), intrusive contacts (magenta), and fault contacts (dashed red line).

mapping interface. We began the study with conventional 2D mapping, albeit aided by 2D digital mapping techniques using the GIS data structure of Pavlis et al. (2010) with QGIS software. Orthocorrected satellite imagery with resolutions of 1–2 m from the USGS and ArcGIS online were used as a base map for our 2D mapping. ArcGIS Pro and Midland Valley's Move software were used for draping 2D map data onto the USGS DEM for the area and for comparison with 3D mapping results (see Brush, 2015, for more details on workflows).

Results

Our 2D geologic map is high resolution by almost any standards due to GPS positioning and the resolution of the orthoimagery (Data Repository supplement 2 [see footnote 1]). Nonetheless, the problems of conventional 2D mapping and 2.5D draping to a terrain model quickly became apparent when we attempted to analyze the data in 3D.

Figure 2 shows a comparison of a 2.5D image and linework drapes (2A) onto a low-resolution elevation model versus mapping directly onto a true 3D view afforded by the SfM models (2D). The principal source of the distortions in Figure 2 include (1) artificial smoothing of the terrain in the low-resolution model leading to errors in elevation positions of image pixels, which transfer to the geologic interpretation; and (2) errors inherited from the orthophoto production process that are transferred to the image drape.

Beyond these issues of spatial errors from the 2.5D method, we suggest that the greatest strength of SfM 3D surface models is the increased geologic insight that can be gained from using these distortion-free, 3D visualizations as a mapping base during and after fieldwork. Probably every field geologist has wanted the ability to "fly like a bird" to view features from different perspectives. Indeed, this is one reason helicopters are used in field studies and is the most obvious reason UAS are beginning to see widespread use in fieldwork (e.g., Jordan, 2015; Hackney and Clayton, 2015). SfM models +/– UAS flight video provide a virtual experience close to this capability at a tiny fraction of the cost of a helicopter and allow limitless virtual views of the scene that is impossible from a live aircraft flight. As an illustration of the power of this capability, Figure 4 shows the evolution of our understanding of the structure shown in Figures 2D and 2E. In the 2D field map from the initial visit to the site (Fig. 4A), the field interpretation was relatively simplistic and contradictory. Field-note sketches considered several alternative fold geometries, but the initial work was inconclusive. In a second visit to the site, more orientation data were obtained and photographs were acquired for the SfM model shown in Figure 2. Like the first visit, however, multiple hypotheses were considered for this structure, and a field sketch (Fig. 4C) at the end of the field day was the working hypothesis. After later analysis manipulating 3D visualizations and mapping onto the SfM model, we realized that the structure was a large, refolded recumbent fold (Fig. 2F). This hypothesis was confirmed by a third field visit to the site.

Clearly this was not a controlled experiment and arguably we would have recognized the structure anyway, either with more field time or through traditional methods like serial section construction. Moreover, the approach was inefficient relative to our present workflow model because we were developing techniques at the time. Nonetheless, the ease of the analysis from the 3D visualization made recognition of the feature easier and led to greater confidence in the interpretation.

Similarly, 3D analysis of the broader area in this study answered several questions (e.g., Data Repository supplement 2 [see footnote 1]) but, perhaps more importantly, led to hypotheses that probably would not have arisen without the 3D mapping. For example, directly along structural trend from Figure 2, outcrop-scale, plunging, type 3 (coaxial) refolded folds (terminology of Ramsay, 1967) like those in Figure 2 are common. However, the orientation of the most prominent isoclinal folds is grossly different along strike—approximately recumbent to the north and upright to the south. In the absence of a 3D model, this observation is difficult to evaluate, but using the 3D model to visualize geometry across the area, our working hypothesis is that there is a large-scale west-vergent recumbent fold that was refolded by upright folds associated with the second cleavage (Pavlis et al., 2016). More work is needed to test that hypothesis and will be the subject of future fieldwork. Nonetheless, the important point is that in the absence of the 3D visualization we probably couldn't have even raised this question without much more fieldwork, the ability to climb across the steep terrain, or both. Thus, how many other unresolved geologic problems or missed issues lie hidden in steep terrain that could be resolved with these methods?

3D Mapping and its Importance to 3D Modeling

This case study gives a partial illustration of the potential of using SfM for solving geologic problems, but it is a limited example in the broad range of potential applications. The key features in this case were (1) the dramatic increase in accuracy of the 3D view, which aided confidence in geometric interpretations as real, not artifacts of mapping imprecision; and (2) the ability to view 3D features from a variety of viewpoints, and revisit these views repeatedly, allowing fast evaluation of geometry, something impossible with conventional mapping. This ability is a cognitive breakthrough for field geology because it allows geologists to break from the traditional paradigm (e.g., Compton, 1985) that key features should always be recognized the first time around due to the economics and logistics of fieldwork—i.e., this paradigm may still hold for the field visit, but a key site can now be captured as a 3D visualization that can be viewed ad infinitum to help resolve problems.

For those inexperienced with field geology in areas of complex structure, particularly in steep terrain, it may not be obvious how important these abilities can be. From our experience, the 2.5D method can be used for construction of 3D geologic models of complex structure (e.g., Pavlis et al., 2012), but the distortions and imprecision in the underlying terrain model make geologic model construction inefficient as well as potentially wrong due to uncertainties in the sources of spatial error. In a true 3D model based on SfM, none of those spatial uncertainties exist in the raw data, and the only uncertainties arise from potential interpretation errors—a problem much more easily evaluated through an iterative mapping approach. Note also that for those who have only used 2D methods (maps and cross sections) for geologic analysis, it is easy to underestimate the difficulty of constructing a true 3D geologic model

from 2D sources. It is largely for this reason, and the spatial error issues in the 2.5D method, that most 3D geologic modeling to date has been limited to the relatively simple visualizations of flat-lying to nearly flat-lying strata or simply deformed rocks (e.g., MacCormack et al., 2015).

At present, workflows for both 3D mapping and 3D model construction are dependent on software that is neither customized for the field environment nor readily amendable to the limitations of field computers. Nonetheless, given the speed of development of software and hardware, this limitation will be trivial within the next two to three years, suggesting that all of these capabilities will be readily available for field geology, if we choose to embrace them.

Near Future Capabilities and the Importance of UAS

Another technology, unmanned aircraft systems (UAS), promises to expand 3D mapping further in ways we undoubtedly do not yet fully grasp. UAS have become a prominent topic across society, and their proliferation offers huge opportunities for field geologists (e.g., Hugenholtz et al., 2013; Bemis et al., 2014; Jordan, 2015; Hackney and Clayton, 2015). They already serve as aerial platforms to enhance construction of SfM models. However, there are many opportunities beyond this application. Some examples include

1. A low-cost, lightweight drone that could become every geologist's "field assistant," with tasks ranging from safety to planning (e.g., applications as simple as route planning to as complex as geologic recon or hazard assessment).
2. A drone with a remote video feed equipped with a suitable magnetometer-accelerometer system and an ability to orient the device remotely could gather remote orientation measurements from cliff faces or inaccessible terrain. To our knowledge no such device yet exists, but is possible with modern technology.
3. A major advance in geomorphology arose with bare-ground models obtained by filtering airborne LiDAR data (e.g., Haugerud et al., 2003). A drone equipped with an object-avoidance system, such as an optical proximity measurement tool, could be developed to fly through a forested area below treetop level carrying a LiDAR system and cameras for SfM work. The resultant data could be used to obtain a true bare-ground model with no questions on potential filtering artifacts that can arise from conventional airborne LiDAR. Alternatively, this application could be used as a simple outcrop finder tool in areas of poor exposure.
4. The expansion of cheaper and lighter-weight multi- and hyperspectral sensors for UAS and the improvement of commercially available UAS to more easily integrate with these sensors (e.g., see Buckley et al., 2016) will potentially lead to a geologist's ability to develop 3D lithological classification maps in the field—essentially giving field geologists live, multispectral eyes. As of yet, studies with multi- or hyperspectral cameras on UAS have been limited, with few applications to bedrock geology (e.g., Buckley et al., 2016). In the United States this is likely due to the previously strict Federal Aviation Administration UAS regulations as well as the high cost of these sensors, but experiments of this type clearly are ongoing in Europe (Buckley et al., 2016). In addition, the current commercially available sensors for UAS only provide visible and near infrared (VNIR) imagery/data designed for agricultural purposes (Link et al., 2013; Herrero-Huerta et al., 2014; Rasmussen et al., 2016) or thermal infrared (TIR) for disaster management, monitoring geothermal environments, etc. (Nishar et al., 2016; Yahyanejad and Rinner, 2014), while lithology is best distinguished with shortwave infrared (SWIR).

Beyond these drone-based applications, perhaps the biggest advances will come from full 3D visualization and mapping capabilities in software in the field environment. Virtual reality (VR) headsets are becoming more readily available and could be used in a field scenario to produce a 3D representation of a scene in front of the geologist, potentially complete with multispectral 3D renderings, providing an augmented reality interface that would allow resolution of features undreamed of, even now. Perhaps most important, however, is the potential of this technology to teach concepts to the next generation of students at all levels. Freed from the confines of flat maps, there is a potential for accelerated learning of 3D concepts using this technology. Nonetheless, research is needed on how these techniques can aid learning rather than hinder it.

Finally, many have lamented the decline of field geology, yet at the same time blame high-tech for this decline (e.g., Callan, 2016). Our experience is the opposite. Specifically, paper-based field geology using nineteenth-century technology is viewed by most modern students as "old school," and many shy away from field studies as a result. Incorporation of digital mapping and these 3D techniques, however, excites modern students and has the potential to attract a whole new generation of tech-savvy field geologists who could solve problems previously considered impossibly complex.

CONCLUSIONS

Three-dimensional terrain models derived from SfM, particularly when augmented with aerial photography from UAS, provide an inexpensive base for the next generation of geologic mapping using a 3D interface. Visualization of these models frees geologists from the confines of flat maps and allows high-precision mapping of steep slopes and cliffs, which are virtually invisible in conventional maps. The ability to easily examine multiple view angles of Earth's 3D surface outside the time limitations and logistical constraints of fieldwork is a cognitive breakthrough that frees field geology from the one-site–one-visit paradigm. Many geologists have lamented the decline of field geology, but the rise of these 3D technologies has a potential to revitalize field geology and launch a new generation of studies. Research is desperately needed, however, on ideal workflows that employ this technology across a range of applications and the range of field sites, and perhaps most importantly, how this technology can aid 3D learning rather than hinder it.

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REFERENCES CITED

Bemis, S.P., Micklethwaite, S., Turner, D., James, M.R., Akciz, S., Thiele, S.T., and Bangash, H.A., 2014, Ground-based and UAV-based photogrammetry: A multi-scale, high-resolution

mapping tool for structural geology and paleoseismology: Journal of Structural Geology, v. 69, p. 163–178, doi:10.1016/j.jsg.2014.10.007.
Brush, J.A., 2015, Evaluating methods of field-based 3D visualizations and their applications to mapping metamorphic terranes: An example from the Panamint Mountains, California [M.S. Thesis]: ETD Collection for The University of Texas, El Paso, paper AAI1592882.
Buckley, B., Naumann, S.J., Kurz, N.K., and Eide, C.H., 2016, 2nd Virtual Geoscience Conference, Proceedings Volume: Bergen, Norway, Uni Research CIPR, http://virtualoutcrop.com/assets/images/conference/download/VGC2016_ProceedingsVolume.pdf (last accessed 16 Feb. 2017), 212 p.
Callan, N.J., 2016, Geological mapping in exploration: A view from the trenches: Society of Economic Geologists Newsletter, v. 105, p. 13–15.
Compton, R., 1985, Geology in the Field: New York, John Wiley & Sons, 416 p.
De Paor, D., 2016, Virtual Rocks: GSA Today, v. 26, no. 8, p. 4–11, doi:10.1130/GSATG257A.1.
Furukawa, Y., and Hernandez, C., 2015, Multi-view stereo: A tutorial: Foundations and Trends in Computer Graphics and Vision, v. 9, no. 1–2, p. 1–148, doi:10.1561/0600000052.
Hackney, C., and Clayton, A.I., 2015, Section 1.7: Unmanned aerial vehicles (UAVs) and their application in geomorphic mapping: Geomorphological techniques, *in* Clarke, L.E., and Nield, J.M., eds., Geomorphological Techniques (online edition): London, British Society for Geomorphology, p. 1–12.
Haugerud, R.A., Harding, D.J., Johnson, S.Y., Harless, J.L., Weaver, C.S., and Sherrod, B.L., 2003, High-resolution LiDAR topography of Puget Lowland, Washington—A bonanza for earth science: GSA Today, v. 13, no. 6, p. 4–10, doi:10.1130/1052-5173(2003)13<0004:HLTOTP>2.0.CO;2.
Herrero-Huerta, M., Hernández-López, D., Rodriguez-Gonzalvez, P., González-Aguilera, D., and González-Piqueras, J., 2014, Vicarious radiometric calibration of a multispectral sensor from an aerial trike applied to precision agriculture: Computers and Electronics in Agriculture, v. 108, p. 28–38, doi:10.1016/j.compag.2014.07.001.
Hugenholtz, C.H., Whitehead, K., Brown, O.W., Barchyn, T.E., Moorman, B.J., LeClair, A., Riddell, K., and Hamilton, T., 2013, Geomorphological mapping with a small unmanned aircraft system (sUAS): Feature detection and accuracy assessment of a photogrammetrically derived digital terrain model: Geomorphology, v. 194, p. 16–24, doi:10.1016/j.geomorph.2013.03.023.
Jordan, B.R., 2015, A bird's-eye view of geology: The use of micro UAS/UAVs in geologic fieldwork and education: GSA Today, v. 25, p. 50–52, doi:10.1130/GSATG232GW.1.
Link, J., Senner, D., and Claupein, W., 2013, Developing and evaluating an aerial sensor platform (ASP) to collect multispectral data for deriving management decisions in precision farming: Computers and Electronics in Agriculture, v. 94, p. 20–28, doi:10.1016/j.compag.2013.03.003.
MacCormack, K., Thorleifson, H., Berg, R., and Russell, H., 2015, Three-dimensional geologic mapping: Workshop Extended Abstracts, Baltimore, Maryland, 2015, AER/AGS Special Report 101, http://isgs.illinois.edu/2015-Baltimore-Maryland (last accessed 16 Feb. 2017).
Mookerjee, M., Vieira, D., Chan, M., Gill, Y., Pavlis, T.L., Spear, F., and Tikoff, B., 2015, Field data management: Integrating cyberscience and geoscience: Eos, v. 96, doi: 10.1029/2015EO036703.
Nishar, A., Richards, S., Breen, D., Robertson, J., and Breen, B., 2016, Thermal infrared imaging of geothermal environments and by an unmanned aerial vehicle (UAV): A case study of the Wairakei–Tauhara geothermal field, Taupo, New Zealand: Renewable Energy, v. 86, p. 1256–1264, doi:10.1016/j.renene.2015.09.042.
Pavlis, T.L., Langford, R., Hurtado, J., and Serpa, L., 2010, Computer-based data acquisition and visualization systems in field geology: Results from 12 years of experimentation and future potential: Geosphere, v. 6, p. 275–294, doi:10.1130/GES00503.1.
Pavlis, T.L., Chapman, J., Bruhn, R.L., Ridgway, K., Worthington, L.L., Gulick, S.P.S., and Spotila, J., 2012, Structure of the actively deforming fold-thrust belt of the St. Elias Orogen with implications for glacial exhumation and 3D tectonic processes: Geosphere, v. 8, p. 991–1019, doi:10.1130/GES00753.1.
Pavlis, T.L., Brush, J.A., and Cobb, J., 2016, Mesozoic ductile deformation in the Panamint Mountains: Sevier contraction overprinted by Laramide age hinterland-vergent folding: Geological Society of America Abstracts with Programs, v. 48, no. 4, 20-6.
Ramsey, J.G., 1967, Folding and Fracturing of Rocks: New York, McGraw Hill, xvi + 568 p., illus.
Rasmussen, J., Ntakos, G., Nielsen, J., Svensgaard, J., Poulsen, R.N., and Christensen, S., 2016, Are vegetation indices derived from consumer-grade cameras mounted on UAVs sufficiently reliable for assessing experimental plots?: European Journal of Agronomy, v. 74, p. 75–92, doi:10.1016/j.eja.2015.11.026.
Tavani, S., Granado, P., Corradetti, A., Girundo, M., Iannace, A., Arbues, P., Munoz, J.A., and Mazzoli, S., 2014, Building a virtual outcrop, extracting geological information from it, and sharing the results in Google Earth via OpenPlot and PhotoScan: An example from the Khaviz Anticline (Iran): Computers & Geosciences, v. 63, p. 44–53, doi:10.1016/j.cageo.2013.10.013.
Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., and Reynolds, J.M., 2012, 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications: Geomorphology, v. 179, p. 300–314, doi:10.1016/j.geomorph.2012.08.021.
Whitmeyer, S.J., 2012, Community mapping in geology education and research: How digital field methods empower student creation of accurate geologic maps, *in* Kastens, K.A., and Manduca, C.A., eds., Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences: Geological Society of America Special Paper 486, p. 171–174, doi:10.1130/2012.2486(27).
Wolf, P.R., 1983, Elements of Photogrammetry, with Air Photo Interpretation and Remote Sensing (2nd edition): Boston, McGraw-Hill, 628 p.
Yahyanajad, S., and Rinner, B., 2014, A fast and mobile system for registration of low-altitude visual and thermal aerial images using multiple small-scale UAVs: ISPRS Journal of Photogrammetry and Remote Sensing, v. 104, p. 189–202, doi:10.1016/j.isprsjprs.2014.07.015.

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RENEW YOUR 2018 MEMBERSHIP

The things I value most . . .

Lewis Land
The things I value most about my GSA membership are the opportunities it provides for professional interaction with other geoscientists and students at the national and regional meetings. I continue to be surprised at how much I learn, and not just from the technical sessions.

New Mexico Bureau of Geology and Mineral Resources; and National Cave and Karst Research Institute
GSA Member since 1992

Tiffany Rivera
GSA is more than just a membership. It is a community of learners and scientists. It is a way to be involved with geoscience beyond my institution, and a way to give back to an organization that has given me so many opportunities.

Westminster College
GSA Member since 2006

Steven Semken
GSA membership has been indispensable to my career, and is important to me because of the Society's long-standing support of effective practice and rigorous research in geoscience education.

Arizona State University
GSA Member since 1988
GSA Fellow since 2014

Chris Gellasch
GSA is my professional home where I can interact with other geologists and give back to the profession in many ways. GSA short courses and field trips allow me to engage in lifelong learning and remain current in my field.

GSA Member since 1991

Catherine Smith
My advice to all geoscience students is to attend GSA annual and sectional meetings, apply for student and conference travel grants, and to be an active member. You never know when you are going to meet someone who can help you.

GSA Member since 2013

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THE GEOLOGICAL SOCIETY OF AMERICA®

President's Welcome

Join your colleagues and friends in Seattle for GSA's 129th Annual Meeting. Seattle is most befitting as the site of this year's meeting because it is truly a hotbed of geology and geologic activity. The meeting will offer a near record 257 Topical Sessions spanning the geoscience disciplines and addressing issues of diversity, science communication, and education. There will be six Pardee Keynote Symposia, particularly fitting given Joseph Thomas Pardee's contributions to reconstructing Glacial Lake Missoula.

Participate in one or more of the 23 field trips that capitalize on the geologic diversity of the Seattle region, with its proximity to the Cascade Range and Olympic Mountains, some of the best Pleistocene glacial landscapes, and multiple natural hazards, as well as its rich archeological history. Enroll in a short course to hone your skills in topics ranging from nano-scale imaging to simulating magma chambers to 3D visualization of terrestrial landscapes. Visit the exhibit hall to view scientific posters and engage with publishers, vendors, and representatives of geoscience organizations and graduate school programs. And students: There will be multiple venues for you to interact with one another and to network with academic and professional mentors.

A stimulating program awaits you in Seattle. Don't miss the opportunity to share your research, enrich your mind, interact with colleagues and friends, and enjoy the cultural, recreational, and gastronomic offerings of Seattle.

I look forward to seeing you in October.

Isabel P. Montañez, GSA President
Distinguished Professor, Dept. of Earth and Planetary Sciences, University of California, Davis

GSA Presidential Address

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

Isabel P. Montañez, GSA 2017 Presidential Address
Sun., 22 Oct., noon–1:30 p.m., Washington State Convention Center, Ballroom 6A

We are at the cusp of a historic time regarding the interface of science and society. Over two decades ago, GSA President Eldridge Moores addressed the "gulf in perception separating geoscientists from many other people" and presaged the growth of the divide (Moores, 1996). Facets of this issue have been the focus of several subsequent GSA presidential addresses highlighting its importance to the Society's mission. The gap has multiple dimensions, including those between the subdisciplines of geosciences, unfulfilled potential for cross-disciplinary research, and the broader divide between the science literate and others less knowledgeable or appreciative of the relevance of the earth sciences to their lives. Most notable is the apparent growth of the science-society gap in recent years. In this talk, Montañez will address the role of GSA in this evolving global landscape and the opportunities to contribute to mending the gap. As GSA undergoes strategic planning over the next year we will explore innovative ways to build on and enhance the Society's efforts to advance, communicate, and promote our science and its benefit to humanity.

Shi Shi Beach and Point of the Arches, Olympic Peninsula Pacific Coast, Washington, USA.

GSA Awards Ceremony

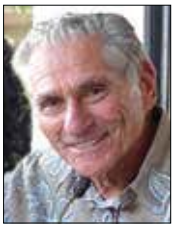
PRESIDENT
Isabel P. Montañez

Sun., 22 Oct., noon–1:30 p.m.,
Washington State Convention Center, Ballroom 6A

Please join GSA President Isabel P. Montañez and GSA President-Elect Robbie Rice Gries to honor and greet the 2017 GSA Medals & Awards recipients at the Presidential Address & Awards Ceremony. You will also have the privilege of hearing Montañez give her Presidential Address, " 'Mind the Gap': GSA's Role in an Evolving Global Society."

PRESIDENT-ELECT
Robbie Rice Gries

2017 GSA Medal & Awards Recipients



George Plafker

Neal R. Iverson

Sterling J. Nesbitt

Thure E. Cerling

Alexander E. Gates

Aradhna Tripati

Jean Bahr

Sonia M. Tikoo

Ray E. Wells

PENROSE MEDAL
George Plafker, U.S. Geological Survey, Menlo Park

ARTHUR L. DAY MEDAL
Neal R. Iverson, Iowa State University

YOUNG SCIENTIST AWARD (DONATH MEDAL)
Sterling J. Nesbitt, Virginia Tech

PRESIDENT'S MEDAL OF THE GEOLOGICAL SOCIETY OF AMERICA
Thure E. Cerling, University of Utah

GSA PUBLIC SERVICE AWARD
Alexander E. Gates, Rutgers University–Newark

RANDOLPH W. "BILL" AND CECILE T. BROMERY AWARD FOR MINORITIES
Aradhna Tripati, University of California at Los Angeles

GSA DISTINGUISHED SERVICE AWARD
Jean Bahr, University of Wisconsin–Madison

DORIS M. CURTIS OUTSTANDING WOMAN IN SCIENCE AWARD
Sonia M. Tikoo, Rutgers University

GEOLOGIC MAPPING AWARD IN HONOR OF FLORENCE BASCOM
Ray E. Wells, U.S. Geological Survey, Portland

Promoting Diversity and Inclusion at GSA

GSA is committed to building a safe, universally accessible, and welcoming environment for all geoscientists. GSA's focus on diversity and inclusion in the geosciences began in the 1970s with the formation of a task force to address the underrepresentation of women and minorities in the geosciences. The task force has evolved into the Diversity in the Geosciences Committee, guiding GSA's Council in its efforts to maintain an organizational climate where diverse scientific ideas are welcome and where the diversity of its membership is a reflection of today's population. Over the past year, these efforts have been affirmed through the revision of the Diversity Position Statement (www.geosociety.org/GSA/Science_Policy/Position_Statements/gsa/positions/position15.aspx) and in the creation of the Events Code of Conduct (www.geosociety.org/ConductCode) in 2016.

While at this year's Annual Meeting, you may notice the impact of these efforts at the events and sessions you attend. For the first time, GSA will offer CART (Communication Access Real-Time Translation) services at the GSA Presidential Address and Awards Ceremony, all Pardee Keynote Symposia, and the Feed Your Brain Lunchtime Lectures. For the third year, a fully inclusive and accessible field trip will be offered for faculty learning how to accommodate students with disabilities and for students with disabilities (by invitation only). In addition, the Diversity Committee in the Geosciences will be coordinating an interactive Pardee Keynote session focused on the role of diverse earth scientists in a changing society. GSA will also host a celebration at the Diversity in the Geosciences and On To the Future Alumni Reception, where everyone is welcome.

This meeting will also feature GSA's RISE (Respectful Inclusive Scientific Events) campaign. It is GSA's belief that an inclusive, safe, and respectful environment is optimal for professional learning and growth and critical to diversity and inclusion efforts. The RISE campaign will feature posters and buttons throughout the meeting that highlight the Events Code of Conduct. This code outlines respectful expectations of all participants at GSA events. As a part of this roll out, GSA will also be offering an anti-harassment and bystander training session.

Consider attending one or all of the following events in support of GSA's diversity and inclusion actions:

Pardee Keynote Symposium (P1): The Changing Face of Geoscience in the 21st Century: Increasing Diversity and Inclusion to Solve Complex Problems. Sun., 22 Oct., 2 p.m. –5:30 p.m., Washington State Convention Center, Ballroom 6A, community.geosociety.org/gsa2017/science-careers/sessions/pardee.

No Means No: How to Step Up and Stop Harassment
Mon., 23 Oct., noon–1:30 p.m., Washington State Convention Center, Ballroom 6B. Presented by Sherry A. Marts, Ph.D., S*Marts Consulting LLC.

The damage done by harassers and bullies begins with those they target. It extends to those who witness or hear about it. And it poisons the atmosphere everywhere it happens—including in the workplace, in fieldwork settings, and at meetings and conferences. What can you do to stop harassment when you're the target? How can you step in to stop it when you see it? Learn how to recognize harassment for what it is, how to decide when to step up and step in, and approaches and methods that work to stop harassing and bullying behavior.

Celebrate Diversity at the Diversity and On To the Future Alumni Reception
Tues., 24 Oct., 5:30–7 p.m., Sheraton Seattle Hotel, Room Willow A

The GSA Diversity in the Geosciences Committee invites everyone to attend a reception to share ideas and celebrate diversity with the geoscience community. The 2017 On To the Future awardees will be recognized with a special keynote from the 2017 Bromery Awardee. Appetizers and a cash bar provided.

Schedule at-a-Glance

Pre-meeting

Field Trips and Short Courses, along with a variety of business meetings, will take place Wed., 18 Oct.–Sat., 21 Oct.

Saturday, 21 Oct.

Seattle Icebreaker: 5–7 p.m.

Sunday, 22 Oct.

1. Oral Technical Sessions: 8 a.m.–noon
2. GeoCareers Day: 8 a.m.–1 p.m.
3. Poster Sessions: 9 a.m.–5:30 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, 23 Oct.

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, 24 Oct.

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, 25 Oct.

1. Oral Technical Sessions: 8 a.m.–noon
2. Poster Sessions: 9 a.m.–6:30 p.m.
3. Exhibits: 10 a.m.–2 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.

Post-meeting

Field Trips run Wed., 25 Oct.–Fri., 27 Oct.

LUNCHTIME ENLIGHTENMENT

Laurance Donnelly

Forensic Geology: The Applications of Geology to Police and Law Enforcement

▶ Wed., 25 Oct., 12:15–1:15 p.m. Washington State Convention Center, Ballroom 6A

Forensic geology (also known as forensic geoscience or geoforensics) is the application of geology to policing and law enforcement, and may be applicable in a court of law. Forensic geologists provide advice and support in relation to serious crimes, such as homicide and sexual assaults, organized crime, counter-terrorism, kidnapping, humanitarian incidents, environmental crimes, wildlife crime, precious minerals, illegal mining, metals and minerals theft, frauds, fakes, and searches.

Generally, forensic geologists may support the police by (a) providing the analysis of geological (trace) evidence, (b) crime scene examinations, and/or (c) conducting ground and water searches.

Geological (trace) evidence involves collection from a crime scene, offender, or item, followed by analysis, interpretation, presentation, and explanation of that evidence. This may help determine what happened and where and when it occurred. Geological evidence can vary considerably and may include rock fragments, soils, and sediments; artificial (anthropogenic) man-made materials derived from geological raw materials, such as bricks, concrete, glass, or plaster board; or micro-fossils. These may be transferred onto the body, person, or clothing of a victim or offender. This evidence may then be used to see if there could be an association between different items or objects.

Forensic geologists also search for objects buried in the ground, otherwise concealed, or discarded in water, including homicide graves, mass graves related to genocide, weapons, firearms, improvised explosive device components, drugs, stolen items, money, coinage, and jewelry.

Over the past decade or so, there have been around 227 recorded international forensic geology events. Nine textbooks have been published, along with numerous technical papers, conference proceedings, and popular press articles. Professional working groups have been established, specially aimed at promoting and developing forensic geology, such as the International Union of Geological Sciences Initiative on Forensic Geology (IUGS-IFG).

This presentation will provide an overview of forensic geology. It draws on operational casework experiences and provides information on the logistical aspects of working with the police. It should be noted that, in the context of the theme of this presentation, images of crime scenes and human remains will be included.

Pardee Keynote Symposia


Joseph T. Pardee

These Pardee Keynote Symposia will take place Sun.–Wed., 22–25 Oct. in the Washington State Convention Center (WSCC). Read symposia descriptions and learn more about the featured speakers and cosponsors at **community.geosociety.org/gsa2017/pardee.** Sessions held in Ballroom 6A will be transcribed on screen in real time.

22 SUNDAY

P1. **The Changing Face of Geoscience in the 21st Century: Increasing Diversity and Inclusion to Solve Complex Problems.** 2–5:30 p.m., WSCC, Ballroom 6A

23 MONDAY

P2. **Landscapes in the Anthropocene.** 8 a.m.–5:30 p.m., WSCC, Ballroom 6A

24 TUESDAY

P3. **IODP-ICDP Expedition 364 to the Chicxulub Impact Crater.** 8 a.m.–noon, WSCC, Ballroom 6A

P4. **Speed Dating!: Advice on Sampling and Applications through the Lens of the Geochronologist (Posters).** 8 a.m.–6:30 p.m., WSCC, Halls 4EF

P5. **Origin, Accretion, and Translation of Mesozoic-Cenozoic Terranes along the Pacific Margin of North America.** 1:30–5:30 p.m., WSCC, Ballroom 6A

25 WEDNESDAY

P6. **Earth Anatomy Revealed: Geologic Mapping for Our Future.** 8 a.m.–noon, WSCC, Ballroom 6A

Events Requiring Tickets/Advance Registration

Several GSA Divisions and Associated Societies will hold breakfast, lunches, receptions, and awards presentations that require a ticket and/or advance registration. 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. WSCC—Washington State Convention Center.

Night at the Burke Museum of Natural History and Culture: A Reception for Students & Early Career Professionals
Sun., 22 Oct., 7:30–10:30 p.m.; US$15
Location: Burke Museum of Natural History and Culture, University of Washington

Paleontological Society (PS) Business Meeting & Reception Buffet
Sun., 22 Oct., 6:30–10:30 p.m.; Professionals: US$45; Students: US$10
Location: WSCC, Ballroom 6E

Association for Women Geoscientists (AWG) Networking Breakfast & Awards Ceremony
Mon., 23 Oct., 6:30–8:30 a.m.; Professionals: US$33; Students: US$15*
Location: WSCC, Ballroom 6E

Geoscience Information Society (GSIS) Luncheon & Awards
Mon., 23 Oct., noon–1:30 p.m.; Professionals: US$50
Location: Sheraton Seattle Hotel, Ravenna A-B

GSA Environmental and Engineering Geology Division Dinner & Awards Reception
Mon., 23 Oct., 5:30–9 p.m.; Professionals: US$63; Students: US$45
Location: Blueacre Seafood

National Association of Geoscience Teachers (NAGT), GSA Geoscience Education Division, and the Council for Undergraduate Research (CUR) Joint Awards Luncheon
Tues., 24 Oct., 11:30 a.m.–1 p.m.; US$55
Location: Sheraton Seattle Hotel, Metropolitan Ballroom A

GSA Hydrogeology Division Luncheon, Awards & Business Meeting
Tues., 24 Oct., 11:30 a.m.–2:30 p.m.; US$55
Location: WSCC, Ballroom 6B

GSA History and Philosophy of Geology Division Luncheon, Business Meeting, & Awards Ceremony
Tues., 24 Oct., noon–2 p.m.; Professionals: US$48; Students: US$24*
Location: Sheraton Seattle Hotel, Ballard

Mineralogical Society of America (MSA) Awards Luncheon
Tues., 24 Oct., 12:15–2:30 p.m.; US$55
Location: Sheraton Seattle Hotel, Ravenna

GSA Planetary Geology Division Annual Banquet & G.K. Gilbert Awardee Celebration
Tues., 24 Oct., 7–10 p.m.; Professionals: US$65; Students: US$40*
Location: Blueacre Seafood

Joint Reception of MGPV–MSA–GS
Tues., 24 Oct., 5:45–7:30 p.m.; Professionals: US$10; Students: US$5
Location: The Conference Center, Skagit Foyer

*Limited number of student tickets available at this price. Once they are gone only professional-price tickets will be available.

Registration

You still have time to register for GSA 2017! Space is also available on some tours, ticketed events, field trips, and short courses. Register at **community.geosociety.org/gsa2017/registration** (even during the meeting), or visit the onsite registration desk in the Washington State Convention Center.

Badges will be available beginning at 7 a.m. on Saturday, 21 Oct. Ribbons will be available at the GSA Information Desk during onsite registration hours; eligible attendees should inquire there.

GSA Section Travel Grants

Recipients of the GSA Student Travel Grants will need to check in at the GSA Annual Meeting Office, Room 401, in the Washington State Convention Center, show identification, verify their address, and sign the check-in sheet to receive their check. The checks will be mailed to the recipient following the Annual Meeting.

GSA 2017 on Social Media

Annual Meeting attendees are listed in the Annual Meeting Community Directory, which is accessible only to other meeting participants at **community.geosociety.org/gsa2017/directory.** Use this networking tool to search for and connect with colleagues. Keep the connections alive after the meeting through Member Community discussion forums. New to the Member Community? If you are logging in for the first time, please follow the links at community.geosociety.org to get started. We encourage you to activate your profile and upload a photo now so that others can connect with you.

Facebook—Join more than 260,000 GSA fans worldwide at www.facebook.com/GSA.1888.

Twitter—Join more than 32,000 tweeps who follow @geosociety, and tweet the meeting using hashtag #GSA2017.

YouTube—Learn more about GSA and careers in the geosciences at www.youtube.com/user/geosociety.

LinkedIn—Network and stay connected to your professional peers at http://linkd.in/1HsYwni.

Note: GSA meeting policy prohibits the use of cameras or sound-recording equipment in technical sessions.

GEO.SCI Technology Demo Theater

Be sure to visit this centrally located space in the exhibit hall to see live demonstrations and interactive displays of the latest products, software, and innovations!

Keep your eye out for the demo schedule on-site, on the meeting app, and in daily meeting editions of the GSA Connection.

And—there's still time! If you, your company, or your organization is working with exciting new products or software, contact dmarcinkowski@geosociety.org or +1-303-357-1047 to reserve a time slot for a demonstration during the GSA 2017 Annual Meeting.

Meeting App
Build Your Own Schedule

1. Install it as a native app on iOS or Android phones and tablets to browse and search the entire meeting without an Internet connection. This app is available in the Apple Store and Play Store —search for GSA 2017.
2. Use the Web app, which can run in your favorite web browser, works well on screens of any size.
3. App will be in the store in late September.

Everything you need to know about the meeting, always at your fingertips!

- Search the full technical program;
- Locate the sessions and individual talks you want to hear;
- See who is exhibiting and add them as favorites;
- Find speakers and add them as contacts;
- Select events to attend and add them to your calendar; and
- View uploaded presentations.

Visit **community.geosociety.org/gsa2017/mobileapp** for download links.

Add These to Your Checklist ☑

☑ Space Request

18 September is the LAST day to submit a request for the event space and event listing. GSA will not assign any additional meeting space after this date and cannot guarantee to list your event on the website or the mobile app. Don't miss out. Go to **community.geosociety.org/gsa2017/spacerequest** to register your space request today.

☑ Critical Housing Dates

18 Sept.: Last day to cancel rooms without a penalty.

27 Sept.: Room rates are guaranteed as long as there are rooms available in the GSA room block.

After 28 Sept., hotel room rates and/or availability cannot be guaranteed.

13 Oct.: All changes, cancellations, and name substitutions must be finalized through Orchid Events by this date.

14 Oct.: Beginning on this date, you must contact the hotel directly for all changes, cancellations, and new reservations.

Once you receive your hotel acknowledgment and have booked your travel, please review your hotel arrival/departure dates for accuracy. If you do not show up on the date of your scheduled arrival, the hotel will release your room and you will be charged for one night's room and tax**.** If you have travel delays and cannot arrive on your scheduled arrival date, contact the hotel directly to make them aware of your new arrival date.

☑ Child Care

Kiddie Corp is providing child care services for GSA attendees on Sat.–Wed., 7 a.m.–6 p.m. NEW: ONLY A ONE-HOUR minimum! The program is open to children six months to 12 years and the cost is US$9 per hour per child. The advance registration deadline is 22 September. Register now at **community.geosociety.org/gsa2017/attendeeinfo/needs/family** because availability is limited and handled on a first-come, first-served basis.

☑ Accommodations & Services

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. Learn more at **community.geosociety.org/gsa2017/attendeeinfo/needs.**

☑ Visit the Meeting Bulletin Board

Here you'll have a chance to meet other meeting attendees and talk about whatever you want, whenever you want. Meet new people, coordinate your schedules, and plan activities while in Seattle. You can even save money by sharing travel and lodging expenses. It's easy and it's free! To access the secure Bulletin Board, go to **community.geosociety.org/gsa2017/roommates.** Make sure that you put GSA2017 in the subject line. Confirm your plans for Seattle now.

☑ Saturday Seattle Icebreaker

Washington State Convention Center, Ballroom 6E, 5–7 p.m.

The most popular event at the Annual Meeting is the Icebreaker. Join thousands of industry professionals, students, academics, Divisions, and Associated Societies to kick off the Annual Meeting in Seattle with beer and great company.

☑ Coffee

Sun.–Wed., 10–10:30 a.m.

Your caffeine fix is complimentary in the mornings (while it lasts!) in the Washington State Convention Center Exhibit Hall. Coffee will also be available for purchase on the sixth floor.

☑ Libations and Collaborations

Mon.–Wed., 4:30 p.m.–6:30 p.m.

Be a part of the conversations! Posters, beer, and your choice of non-alcoholic beverages will be available at each afternoon reception in the Exhibit Hall (this is a great time to meet with poster presenters).

MENTORS NEEDED

GSA is looking for mentors to help students understand the breadth of careers available to them and to provide advice as they navigate their next steps, academically and professionally. Mentoring opportunities range from one-on-one pairings to 30-minute consultations. Learn more about becoming a mentor and the range of mentoring opportunities available at the GSA Annual Meeting by going to **bit.ly/2r3mW7Z.**

Travel & Transportation

Getting to **Seattle**

Seattle-Tacoma International Airport (SEA, KSEA, or SeaTac) is the largest airport in the U.S. Pacific Northwest, and is located 12 miles south of downtown Seattle. Multiple transportation options connect SeaTac to the metro area from rail, Prince Island Sound transit, metro bus, and taxi. Check Alaska Airlines, GSA's official conference airline, for discounted airfares.
www.seattle-airport.com

Amtrak has three lines that serve Seattle. The Cascades Line travels to and from Vancouver (Canada)–Seattle–Tacoma–Portland–Salem–Eugene. The Empire Builder travels to and from Chicago–Milwaukee–Minneapolis–Portland–Seattle. The Coast Starlight travels to and from Seattle–Portland–Los Angeles. Trains stop at the King Street Station, 303 Jackson Street.
www.amtrak.com/train-schedules-timetables

Getting Around

Link Light Rail runs from the airport to the University of Washington through downtown Seattle Mon.–Sat., 5 a.m.–1 a.m. (last train departs the airport at 12:10 a.m.), and Sunday 5 a.m.–midnight (last train departs the airport at 11:05 p.m.). Trains arrive every 6–15 min., depending on the time of day, and it takes ~40 min. to travel between Sea-Tac and the downtown Westlake Station. One-way fares range from US$2.25 to US$3.
www.soundtransit.org/Schedules/Link-light-rail

King County Metro Transit provides bus service in downtown Seattle and outlying neighborhoods. Time-tables and route maps are available at the Transit Information Center in the tunnel under Westlake Center at 4th Ave. & Pine Street as well as online. King County Metro also has a mobile app.
http://tripplanner.kingcounty.gov

All Day Transit Pass: These US$8 all-day passes are loaded onto regional transit cards (US$5 each) at all **ORCA** vending machines to be used for unlimited one-day riding on all local public transit (excluding the Seattle Monorail and Washington State Ferries). Regular fares are US$3.50 per ride.
https://orcacard.com/ERG-Seattle/p3_001.do

Taxis, Limos, Town Cars, and Ride Sharing: Taxis and ride-sharing companies are available on the third floor of the parking garage at Sea-Tac. One-way rides between the airport and downtown range from US$40–US$55. To arrange for a limo, town car, or taxi in advance, use any of the travelers' information boards in the baggage claim area or visit the ground transportation information booth on the third floor of the parking garage. Contact the concierge team at the Seattle Visitor's Center for referrals to specific transportation companies based on your personal travel needs.
www.visitseattle.org/visitor-information/contact-us/

GSA 2017
22–25 October
Seattle, Washington, USA

Convention Hotels & Rates

1. Sheraton Seattle Hotel- **$219**
2. Crowne Plaza Hotel Seattle - **$169**
3. Hilton Garden Inn Downtown Seattle - **$174**
4. Hilton Seattle - **$189**
5. Homewood Suites by Hilton Seattle - Convention Center - **$179**
6. Paramount Seattle Hotel - **$185**
7. Renaissance Seattle Hotel - **$182**
8. The Roosevelt Hotel - **$185**
9. Springhill Suites Seattle Downtown - **$184**
10. The Westin Seattle - **$185**


GSA 2017
22-25 October
Seattle, Washington, USA
Annual Meeting & Exposition
VISIT seattle
Pike Place Market to CenturyLink Event Center: 1 mi / 1.6 km
Pike Place Market to Space Needle: 1 mi / 1.6 km
Pike Place Market to Convention Center: ½ mi / 800 m
CONVENTION HOTELS
S. LAKE UNION STREETCAR
BUS/LIGHT RAIL TUNNEL STATION
BUS/LIGHT RAIL TUNNEL
INFORMATION CENTER
SEATTLE CENTER MONORAIL
WASHINGTON STATE CONVENTION CENTER
WESTLAKE PARK
PIKE PLACE MARKET
PIONEER SQUARE
CHINATOWN INT'L DISTRICT
CENTURYLINK FIELD
SAFECO FIELD
DENNY PARK
CAL ANDERSON PARK
DR. JOSE RIZAL PARK
PIER 69 VICTORIA CLIPPER
PIER 67 BELL HARBOR CONFERENCE CENTER
PIER 66 BELL ST. CRUISE TERMINAL
PIERS 62 & 63
PIER 59 SEATTLE AQUARIUM
WATERFRONT PARK
PIER 57 SEATTLE GREAT WHEEL
PIER 55 ARGOSY CRUISES/TILLICUM VILLAGE
PIER 52 WA STATE FERRIES
Ferry to Victoria B.C.
Ferry to Tillicum Village
Ferry to Bainbridge Island
Ferry to Bremerton
Ferry to Vashon Island
N
W
E
S

Neighborhood Spotlight: Capitol Hill

Mamnoon, photo by Olivia Brent.

Rainbow Crosswalk, photo by Michael Hinsch.

Volunteer Park, photo by Paul Gordon/Alamy Stock Photo.

▶ Eat

Global flavors rule this eclectic neighborhood, where can't-miss dishes include grilled octopus at Mediterranean oasis **Omega Ouzeri,** the chili cumin pork ribs at Vietnamese-French **Stateside,** and the tajarin al ragu (finely cut egg pasta) at Northern Italian gem **Cascina Spinasse.** You also won't want to shy away from **Mamnoon's** exquisite décor and modern Middle Eastern cuisine, and you certainly won't want to overlook its muhammara dip (walnuts, pepper paste, cumin, garlic, pomegranate). **Bar Vacilando** fuels wanderlust with adventurous eats; begin with the prosciutto and béchamel crusts, followed by the salt cod croquettes.

▶ Shop

Station 7 flaunts its art, jewelry, and vintage furniture inside an old firehouse. Nearby, **Casita International** stocks items designed by local craftspeople as well as by global fair-trade partners—think earrings, incense, bilingual kids' books, onesies, and Haitian and Mexican wall art. And no trip to Capitol Hill is complete without thumbing through the jam-packed cedar shelves at **Elliott Bay Book Company,** a beloved staple since 1973.

▶ Play

Escape from the city clamor in 48-acre **Volunteer Park,** home to a water tower that you can climb for views of downtown. Capitol Hill pulses after the sun goes down, too. Karaoke aficionados rent private rooms to sing their hearts out at **Rock Box,** while some prefer watching professional music acts take the spotlight at **Neumos.** Feel the beat at **Century Ballroom's** classes or dance socials, or keep things more mellow at the two Capitol Hill locations of **Sun Liquor,** a frontrunner on the cocktail scene since 2006.

*Text copy credit Visit Seattle, www.visitseattle.org/neighborhoods/capitol-hill/.

Student Information and Activities

Check out the student information page at **community.geosociety.org/gsa2017/students** for the most up-to-date information on events for students.

Student Volunteers

GSA student members: Get complimentary meeting registration when you volunteer for ten hours—plus get an insider's view of the meeting! Sign up on the meeting website; and then register for the meeting as a student volunteer.

Best Student Geologic Map Competition

Please join us for poster session T208, the Best Student Geologic Mapping Competition (check the meeting program for the date and time). This session provides a venue for students to present their geologic maps that have a significant field component with awards for the top three maps.

GSA Night at the Burke Museum of Natural History and Culture

A Reception for Students (Graduate and Undergraduate) & Early Career Professionals
Sun., 22 Oct., 7–10:30 p.m., US$15

Meet and network with other young professionals while enjoying food and drinks. You must preregister for this event. Tickets will be taken at the doors.

Campus Connection

Bringing Students and Schools Together

Washington State Convention Center, Exhibit Halls 4AB.

GSA's Campus Connection (formerly Graduate School Information Forum) provides an excellent opportunity for students to meet face to face with representatives from top geoscience schools. This four-day event saves students time and travel expenses, giving the schools a chance to meet with some of the best student geoscientists in the world in a relaxed, informal setting. For a preliminary list of schools, see **http://s15.a2zinc.net/clients/corcoran/GSA2017/public/Exhibitors.aspx.**

The Geological Society of America®

GEOCAREERS

Career Development Events for Students and Early Career Professionals

GEOCAREERS DAY

Sun., 22 Oct., 8 a.m.–1 p.m. All GeoCareers Day events will be held in Washington State Convention Center (WSCC) Ballroom 6B. All-inclusive Fee: US$25; registration required, and space is limited.

8–9 a.m.: Career Workshop

Successfully prepare for a career in the industry and government sectors. Workshop will be divided into 20-minute power sessions: reviewing résumés for industry and USA Jobs and Q&A.

9–11 a.m.: Career Information Session

This is your opportunity to ask questions and talk one-on-one with corporate and government representatives and learn about their unique work cultures and types of careers available.

10–11:30 a.m.: Career Mentor Roundtables

Mentors from a variety of sectors will answer your career questions at table stations.

Noon–1 p.m.: Career Pathways Panel

Representatives from government and industry sectors will answer questions and offer advice in preparation for a career in these fields. Lunch provided.

The following GeoCareers Day events may be attended separately:

Career Pathways Panel: Lunch is included but is first-come, first-served. All-day participants will receive priority.

Career Workshop: US$10 fee if attending separately. Registration required. Sign-up on the registration form or contact GSA Sales & Service at gsaservice@geosociety.org or +1-800-443-4472.

NETWORKING AND PANEL EVENTS

Women in Geology Career Pathways Reception

Sun., 22 Oct., 5:30–7 p.m., WSCC, Ballroom 6B

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.

GSA Environmental and Engineering Geology Division's Student Mentoring Session

Sun., 22 Oct., 5:30–6:30 p.m., WSCC, Tech Room TBD

A panel of experts will address a series of commonly asked questions from those emailed in advance of the meeting, and the panelists will also address questions from the students in attendance. Time will be left at the end for one-on-one interactions with individual panelists. Mentors will be available at the Division's Booth (#118) in the Exhibit Hall to further interact with students and address any outstanding questions.

Early Career Professionals Coffee

Mon., 23 Oct., 9–10 a.m., Sheraton Seattle, Cirrus Room

This informal gathering will include remarks from representatives of several non-profits who have activities of interest to early career professionals. There will be time for networking and sharing ideas on how these organizations can best serve you.

Networking Reception

Mon., 23 Oct., 11:30 a.m.–1 p.m., Sheraton Seattle, Metropolitan Ballroom B

This reception provides students and early career professionals with an exciting opportunity to network with more than 40 geoscience professionals. The mentors will answer questions, offer advice about career plans, and comment on job opportunities within their fields.

The Paleontological Society Mentors in Paleontology Careers Luncheon

Mon., 23 Oct., noon–1:30 p.m., Tap House Grill

This student and early career professional luncheon features a panel of mentors representing a variety of colleges, universities, museums, and government agencies.

GSA Hydrogeology Division Careers and Networking Event

Tues., 24 Oct., 2:30–4:30 p.m., WSCC, Ballroom 6B

In a relaxed and welcoming atmosphere, this gathering will begin with remarks from hydrogeologists in a variety of career fields, including government, industry, and academia. A roundtable mentoring session will follow, providing time for individuals to network, share ideas, ask questions, and discuss careers in hydrogeology.

MORE WORKSHOPS

Career Short Courses

Sat., 21 Oct. (see page 35)

- Preparing for a Career in the Geosciences
- Review and Preparation for the ASBOG Fundamentals of Geology Examination

Publishing: "What's Your Problem; What's Your Point?"

Sun., 22 Oct., 11:30 a.m.–2 p.m., Sheratan Seattle, Issaquah

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/GSA/Publications/GSA/Pubs/WritersResource.aspx.

EMPLOYMENT ASSISTANCE

Résumé Clinic

Sun., 22 Oct., 9 a.m.–5 p.m., WSCC, Ballroom 6B
Fee: US$10 (cash only)

Stop by the Résumé Clinic for a 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. First come, first served; space is limited.

Geoscience Job Board

Check the online Geoscience Job Board at **www.geosociety.org/jobs** for employment, fellowship, and student opportunities.

GSA 2017
22–25 October
Seattle, Washington, USA

On To the Future

Congratulations to the 2017 On To the Future (OTF) travel awardees. GSA recently awarded more than 75 travel grants to a select group of students from diverse backgrounds to attend their first GSA Annual Meeting. OTF students were chosen based on their commitment to pursuing a career in the geosciences, merit, and financial need.

Mentor an OTF student at the meeting and help one of these students navigate their first professional meeting. To apply to mentor a student, check the OTF Mentor Application Form (bit.ly/2tJB8Qs).

On To the Future Events

GSA welcomes the new cohort of On To the Future (OTF) award recipients. Attendance is required for the following events (WSCC—Washington State Convention Center):

OTF Welcome: Sat., 21 Oct., 4:30 p.m., WSCC, 4th floor Atrium

OTF Group Photo: Sun., 22 Oct., 6:15 p.m., WSCC, Exhibits Hall, GSA Headquarters Booth

OTF Gatherings: Mon.–Wed., 23–25 Oct., 7:30 a.m., WSCC, 4th floor Atrium

Diversity and OTF Alumni Reception: Tues., 24 Oct., 5:30 p.m., Sheraton Seattle, Willow A Room

Celebrate Diversity at the Diversity and On To the Future Alumni Reception

Tues., 24 Oct., 5:30–7 p.m., Sheraton Seattle, Willow A Room

The GSA Diversity in the Geosciences Committee invites everyone to attend a reception to share ideas and celebrate diversity with the geoscience community. The 2017 On To the Future awardees will be recognized with a special keynote from the 2017 Bromery Awardee. Appetizers and a cash bar provided.

OTF Broadening Participation in the Geosciences through Effective Mentoring and Social Capital Development

Wed., 25 Oct., 3–8 p.m., Thurs., 26 Oct., 8 a.m.–noon, Sheraton Seattle, Ravenna Room. Invitation only.

Experts in the field of Geoscience and Higher Education are hosting a workshop focusing on Mentoring and Diversity in Earth System Science. This NSF-funded workshop will explore effective mentoring strategies for mentors as well as identify ways mentees can successfully engage in mentoring relationships. This workshop is open to all On to the Future students and alumni and all On to the Future mentors. By invitation only.

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 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.

101. **Emerald City Highlights Tour**
Sun., 22 Oct., 9 a.m.–2 p.m. US$90; min. 15 participants.

Known as a world-class city, Seattle is the best of both worlds: offering the best of urban lifestyle while embracing the rugged outdoors. A local expert will take you through the city's must-see attractions, famous landmarks, and beautiful sights. You will learn about Seattle's history and culture, and get insider tips on special shopping and sightseeing areas. This tour includes historic Pioneer Square and the Seattle waterfront, Hiram Locks, Chihuly Garden & Glass, and Pike Place Market.

102. **Walking Tour & Tasting Tour of Pike Place Market**
Mon., 23 Oct., 10 a.m.–noon. US$80; min. 10 participants.

Join us for Seattle's original food and cultural tour of Pike Place Market. Become a market insider on this behind-the-scenes adventure to experience the sights, sounds, and flavors of this historic 100+-year-old landmark. This is a special "Behind the Scenes" tour where you will learn the history of the Pike Place Market, meet the purveyors and food producers, as well as the Market's lively characters, and hear their memorable stories. See fish fly, cheese being made, and the original Starbucks store. Our tour guides are past and present members of the Pike Place Market community.

103. **Boeing Everett Plant Tour/Aviation Tour**
Tues., 24 Oct., noon–4 p.m. US$78; min. 15 participants.

William Edward Boeing founded one of the greatest dynasties in commercial aviation. The Boeing Company has transformed the Pacific Northwest into a major aeronautical hub. This fascinating tour offers an in-depth view into the many facets of the airplane industry. You will actually get to view airplanes being assembled right before your eyes, including the new 777 and 787 Dreamliner. The Boeing Factory Tour also begins here, which offers the *only* publicly available opportunity to tour a commercial jet assembly plant in North America.

104. **Washington Wine Tasting Tour**
Tues., 24 Oct., 12:30–4:30 p.m. US$105; min. 15 participants.

Washington State is the nation's second largest wine producer and is ranked among the world's top wine regions. Nestled in the Sammamish River Valley, Woodinville is a small community that has become a haven for fine winemakers. With the perfect climate for wine, ideal growing conditions, quality wines, business innovation, and social responsibility, Washington State is a premium wine producing region. Located just 30 minutes from Seattle, Chateau Ste. Michelle, Columbia Winery, and Novelty Hill Januik are three of the area's top attractions. These vineyards run grape-producing areas throughout Washington State and bring the fruits of the labors to Woodinville for the creation of excellent wines under the guidance of expert winemakers. Guests will enjoy private tours and tastings at these amazing locations. Locations include Chateau Ste. Michelle and Novelty Hill Januik.

105. **Waterfalls, Chocolate, and Wine Tour**
Wed., 25 Oct., noon–5 p.m. US$88; min. 15 participants.

This Pacific Northwest outing takes you to scenic waterfalls, a quaint Swiss chocolate factory, and wine tasting at Chateau Ste. Michelle Winery. The day begins with a visit to one of Washington's most popular scenic attractions, Snoqualmie Falls. Here, the Snoqualmie River cascades 270 feet through a spectacular rock gorge into a 65-foot-deep pool. The tour will continue to Boehm's Candy Kitchen, known throughout the Northwest for their fabulous Swiss chocolates. The guided tour of Boehm's will take you through the candy factory, where you will receive samples of their amazing confections and see how their candies are made. The tour will continue to nearby Chateau Ste. Michelle Winery. Located on 87 acres of arboretum-like grounds, Chateau Ste. Michelle is Washington's oldest winery, taking its place among the classic wineries of the world. Enjoy a tour that allows a romantic yet technologically accurate view of the art and science of wine-making.

Site of Boeing widebody assembly, 747, 777, 787. Photo by Maurice King.

The grounds of Chateau Ste. Michelle in Woodinville wine country. Photo by Ron Zimmerman.

Guest Program

Penrose Guest Hospitality Suite
Washington State Convention Center
Hours: Sun.–Wed., 22–25 Oct., 8 a.m.–5:30 p.m.

We warmly welcome all members of the GSA community to Seattle! 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 also have admittance to the Exhibit Hall. Activities in the suite include complimentary refreshments, entertaining and educational seminars, and local experts ready to answer your questions about Seattle. 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

Understanding Social Media
Sun., 22 Oct., 10 a.m., Penrose Guest Hospitality Suite

Learn the ins and outs of social media, from Facebook, Twitter, and Instagram to hashtags. Guests will gain an understanding of what these sites are about and how to best utilize them. For parents, this seminar will provide insight to the connected world of kids and teens, which can be challenging because many adults don't communicate online in the same way and are not necessarily using the same social media. The goal is to help parents better understand how their kids are using social networking and to provide them with tips and tools they can use to help them minimize negative experiences and maximize the positive opportunities that social media has to offer.

Washington's Wine Industry
Mon., 23 Oct., 10 a.m., Penrose Guest Hospitality Suite

Washington State is the nation's second largest wine producer and is ranked among the world's top wine regions. Nestled in the Sammamish River Valley, Woodinville is a small community that has become a haven for fine winemakers, with the perfect climate for wine, ideal growing conditions, quality wines. In recent years, Washington's wine industry has become the fastest-growing agricultural sector in the state. The number of Washington wineries has increased 400% in the last decade, attracting millions of visitors to Washington wine country every year and creating a multi-million-dollar wine-tourism industry. In the meantime, California is pulling out vineyards. A decade from now, there could be an interesting shift in West Coast wine powers. Currently, one out of every four bottles of wine sold in Washington is made in Washington. The other three come from California, Europe, and the Southern Hemisphere. Will Washington become the next Napa Valley?

Seattle Glassblowing
Tues., 24 Oct., 10 a.m., Penrose Guest Hospitality Suite

Seattle is known as the epicenter of American glass art. The first thing most Seattleites think about upon hearing the words "glass art" is Dale Chihuly. And with good reason; the history of Northwest glass has Chihuly's name woven throughout, from its earliest beginnings. Glassblowing is built on mentorship, teamwork, and a wildly experimental spirit. Students come from around the world to train here and have a life-changing experience, so they stick around. As a result, it has built an incredible community. Studios and artist have flourished. By the early 1990s, the Pacific Northwest had become so well known as a glass haven that talk of a glass museum began. In 2002, the Tacoma Museum of Glass opened its doors and in 2012 the Chihuly Garden and Glass museum opened. This one-of-a-kind space houses the most comprehensive presentation of Chihuly's artwork on public view. Learn about the history of glassblowing in Seattle, this amazing community.

Glass art by Dale Chihuly at an extensive exhibition at Kew Gardens, London, in 2005. Public domain Wikipedia Commons.

Scientific Field Trips

Descriptions & details are online at **community.geosociety.org/GSA2017/fieldtrips.**

Photo taken ca. 1970 by Link Washburn. Aerial view of mima prairie and mounds.

Photo taken by Ron Sletten on 3 Aug. 2014 of Mount St. Helens from the Johnston Ridge Observatory.

401. **Generation of the Palouse Loess: Exploring the Linkages between Glaciation, Outburst Megafloods and Aeolian Deposition in Washington State.**
Wed.–Fri., 18–20 Oct. US$399. Cosponsor: *GSA Quaternary Geology and Geomorphology Division.* Leaders: Mark R. Sweeney, Univ. of South Dakota; Eric V. McDonald, David R. Gaylord.

402. **Late Pleistocene Glaciation and Megafloods: The Cordilleran Ice Sheet and Columbia River Valley, Drainage Diversions, and Megafloods from Glacial Lake Missoula and Glacial Lake Columbia.**
Wed.–Sat., 18–21 Oct. US$395. Cosponsor: *GSA Quaternary Geology and Geomorphology Division.* Leaders: Jim E. O'Connor, U.S. Geological Survey; Victor R. Baker, Richard B. Waitt, Andrea Balbas.

$ 403. **Incorporation of Sedimentary Rocks into the Deep Levels of Continental Magmatic Arcs: Links between the North Cascades Arc and Surrounding Sedimentary Terranes.**
Thurs.–Sat., 19–21 Oct. US$485. Cosponsors: *GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Structural Geology and Tectonics Division.* Leaders: Stacia M. Gordon, Univ. of Nevada–Reno; Robert B. Miller, Kirsten B. Sauer.

$ 404. **Exploring the Western Idaho Shear Zone Using the Strabo Data System.**
Thurs.–Sat., 19–21 Oct. US$599. Leaders: Basil Tikoff, Univ. of Wisconsin; Z.D. Michels, Maureen Kahn, Richard M. Gaschnig, Kathy K. Davenport, Christian Stanciu. Trip departs from Boise, Idaho, USA and returns to Seattle.

$ 405. **Mesozoic Terranes of the Central Cascades: Geology of the Hicks Butte Complex, Easton Metamorphic Suite, Peshastin Formation, and Ingalls Serpentinite.**
Thurs.–Sat., 19–21 Oct. US$350. Leaders: James H. MacDonald, Florida Gulf Coast Univ.; Joe D. Dragovich.

406. **Tsunamis in the Salish Sea: Recurrence, Sources, Hazards.**
Fri., 20 Oct. US$199. Leaders: Carrie Garrison-Laney, Univ. of Washington; Ian Miller, Brian Atwater.

407. **Geoarchaeology of the Central Puget Lowland.**
Fri.–Sat., 20–21 Oct. US$399. Cosponsors: *SWCA Environmental Consultants; Burke Museum.* Leaders: Brandy A. Rinck, SWCA Environmental Consultants; Jack Johnson.

INDUSTRY TRACKS—Look for these icons, which identify sessions in the following areas:

$ **Economic Geology**

Engineering

Hydrogeology and Environmental Geology

408. **Geologic Challenges and Engineering Solutions for Major Transportation Construction Projects in Seattle.**
Fri.–Sat., 20–21 Oct. US$285. Leaders: William Laprade, Elizabeth Barnett, Shannon & Wilson, Inc.; Red Robinson, Jenn Parker, Andrew Caneday, Jeremy Butkovich.

409. **Geology of Seattle.**
Fri., 20 Oct. US$125. Leaders: Ralph Haugerud, U.S. Geological Survey; Kathy Goetz Troost.

410. **Rivers Gone Wild: Extreme Landscape Response to Climate-Induced Flooding and Debris Flows, and Implications for Long-Term Management at Mount Rainier National Park.**
Sat., 21 Oct. US$99. Cosponsors: *National Park Service; GSA Quaternary Geology and Geomorphology Division*. Leaders: Scott R. Beason, Mount Rainier National Park; Paul M. Kennard.

411. **Exploring the Mechanics, Frequency, and Impacts of Deep-Seated Landslides in Washington State.**
Sat., 21 Oct. US$130. Cosponsor: *GSA Quaternary Geology and Geomorphology Division*. Leaders: Alison R. Duvall, Univ. of Washington; Sean Richard LaHusen.

412. **Glacial-Interglacial History of Whidbey Island: New Insights.**
Sat., 21 Oct. US$99. Leader: Terry Swanson, Univ. of Washington.

413. **Mount St. Helens—Its 1980 Eruption and Subsequent Hydrogeomorphic and Ecologic Responses.**
Sat., 21 Oct. US$150. Cosponsor: *GSA Quaternary Geology and Geomorphology Division*. Leaders: Jon J. Major, Volcano Science Center; Charles M. Crisafulli.

414. **Accessible Field Geology of Western Washington.**
Sat., 21 Oct. By invitation only; all expenses paid. Cosponsors: *GSA Geoscience Education Division; International Association for Geoscience Diversity*. Leaders: Christopher L. Atchison, Univ. of Cincinnati; Steven J. Whitmeyer.

415. **Geology Underfoot: Helping Students Visualize the Geology of an Urban Landscape by Exploring the Glacial Geomorphology of the Greater Seattle Area.**
Sat., 21 Oct. US$145. Leaders: Alecia Spooner, North Seattle College; Caroline R. Pew.

416. **The Seattle Fault and the Newcastle Anticline: The Structure and Dynamics of an Active Fold-and-Thrust Belt.**
Sat., 21 Oct. US$125. Leader: John T. Figge, North Seattle College.

417. **Groundwater Remedial Activities at Department of Energy's Hanford Site, Southeastern Washington.**
Wed.–Thurs., 25–26 Oct. US$499. Cosponsor: *GSA Hydrogeology Division*. Leaders: Sunil Mehta; Bruce Williams.

419. **Glaciers, Isostasy, and Eustasy in the Fraser Lowland: Resolving Late Pleistocene Glaciation across the International Border.**
Thurs., 26 Oct. US$140. Cosponsor: *GSA Quaternary Geology and Geomorphology Division*. Leaders: Douglas H. Clark, Western Washington Univ; John Clague. Trip departs from Bellingham, Washington, USA.

$ 420. **The Ultimate Washington State Terroir Tour.**
Thurs.–Sat., 26–28 Oct. US$595. Leaders: Alan Busacca, Vinitas Vineyard Consultants, LLC; Kevin Pogue.

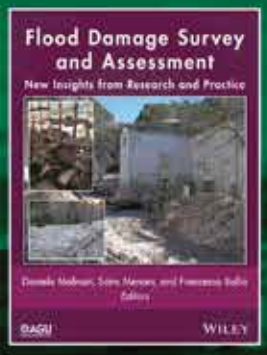
421. **Grounding Line Processes of the Southern Cordilleran Ice Sheet: Whidbey Island, Puget Lowlands.**
Thurs., 26 Oct. US$170. Cosponsor: *GSA Quaternary Geology and Geomorphology Division*. Leaders: John B. Anderson, Rice Univ.; Lauren M. Simkins, Brian P. Demet.

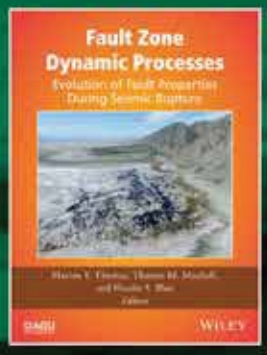
422. **Structure, Neotectonics, Geophysics, and Geomorphology of the Yakima Folds: New Field Research on Fold Structure and Miocene-Present Deformation within the Backarc of the Cascadia Subduction Zone.**
Thurs.–Sat., 26–28 Oct. US$399. Leaders: Harvey M. Kelsey, Humboldt State Univ.; Scott Bennett, Lydia Staisch, Brian L. Sherrod.

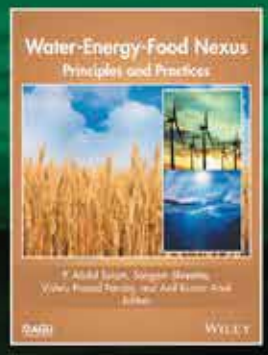
423. **Sedimentary, Volcanic, and Structural Processes during Triple-Junction Migration: Insights from the Paleogene Record in Central Washington.**
Thurs.–Sat., 26–28 Oct. US$350. Leaders: Michael P. Eddy, Princeton Univ.; Robert B. Miller, Paul J. Umhoefer.

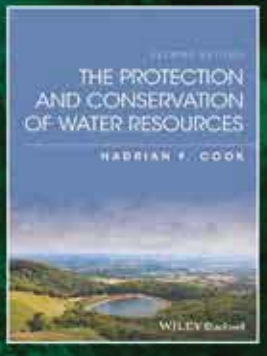
424. **Mima Mounds Tour and Review of Formative Hypotheses.**
Thurs., 26 Oct. US$115. Leader: Ronald S. Sletten, Univ. of Washington.

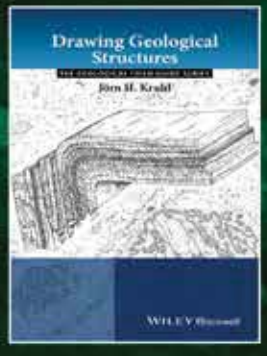
NEW BOOKS

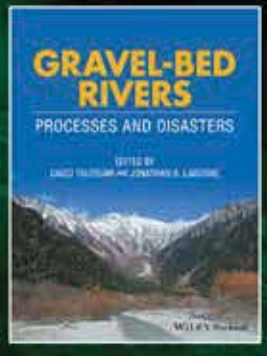


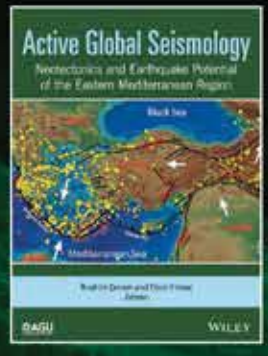












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- **Registration after 18 September** will cost an additional US$30.
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The following short courses are open to everyone. Early registration is highly recommended to ensure that courses will run.

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 18 Sept.) 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/gsa2017/courses** or contact Jennifer Nocerino, jnocerino@geosociety.org, for course abstracts and additional information.

501. **3D Hydrogeological Modeling from Data to Model to Actual Use**
When: Fri., 20 Oct., 9 a.m.–4 p.m.
Where: Sheraton, Jefferson Room
Cost: US$128

502. **High-Resolution Topography and 3D Imaging I: Introduction to Terrestrial Laser Scanning**
When: Fri., 20 Oct., 8 a.m.–5 p.m.
Where: Sheraton, Greenwood Room
Cost: US$52

503. **Modeling Magmatic Processes Using MELTS**
When: Fri., 20 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 204
Cost: US$185

504. **Sequence Stratigraphy for Graduate Students**
When: Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 400
Cost: US$25

505. **Structural and Stratigraphic Concepts Applied to Basin Exploration**
When: Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 203
Cost: US$25

506. **The Magma Chamber Simulator, a Phase Equilibria Modeling Tool for Magma Recharge, Crustal Assimilation, and Crystallization (RAFC)**
When: Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m.
Where: Sheraton, Boren Room
Cost: US$120

507. **Field Safety Leadership**
When: Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 211
Cost: US$25

508. **Petrochronology 2017**
When: Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m. and 8 a.m.–noon
Where: Washington State Convention Center, Room 201
Cost: Professionals US$135, Students US$25

509. **Landlab Earth Surface Modeling Toolkit: Building and Applying Models of Coupled Earth Surface Processes**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 205
Cost: US$130

510. **Collecting Structural Geology Data Using the StraboSpot Data System**
When: Sat., 21 Oct., 8:30 a.m.–5 p.m.
Where: Washington State Convention Center, Room 209
Cost: US$30

511. **Ground-Penetrating Radar: Principles, Practice, and Processing**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Sheraton, Kirkland Room
Cost: US$80

512. **Helping Students Thrive in Geoscience at Two-Year Colleges: Selected Strategies**
When: Sat., 21 Oct., 8:30 a.m.–4:30 p.m.
Where: Sheraton, Greenwood Room
Cost: US$40

INDUSTRY TRACKS—Look for these icons, which identify sessions in the following areas:

Economic Geology | **Energy** | **Engineering** | **Hydrogeology and Environmental Geology**

513. **High-Resolution Topography and 3D Imaging II: Introduction to Structure from Motion (SfM) Photogrammetry**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 214
Cost: US$52

514. **High Resolution and Correlative Microscopy and Spectroscopy for the Geosciences**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 212
Cost: US$100

515. **Review and Preparation for the ASBOG Fundamentals of Geology Examination**
When: Sat., 21 Oct., 8:30 a.m.–4:30 p.m.
Where: Sheraton, Seneca Room
Cost: US$144

516. **Subaqueous Paleoseismology Methods**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Sheraton, University Room
Cost: US$25

517. **U-Pb Geochronology, O and Hf Isotopes, and Trace Element Geochemistry Applied to Detrital Minerals**
When: Sat., 21 Oct., 9 a.m.–5 p.m.
Where: Sheraton, Virginia Room
Cost: US$30

518. **What's in My Lake: The Changing Face of Limnogeology**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Sheraton, Jefferson A Room
Cost: Professionals US$150, Students US$50

519. **Fundamentals to Well Log Interpretation and Reservoir Characterization of Petroleum Systems**
When: Sat., 21 Oct., 8 a.m.–noon.
Where: Sheraton, Jefferson B Room
Cost: US$125

520. **Preparing for a Career in the Geosciences**
When: Sat., 21 Oct., 8 a.m.–noon.
Where: Sheraton, Columbia Room
Cost: US$50

521. **Tools for Water Data Discovery, Publication, and Collaboration**
When: Sat., 21 Oct., 8 a.m.–noon.
Where: Washington State Convention Center, Room 213
Cost: US$25; a GSA bookstore voucher for US$25 will be provided upon completion of the course

522. **Global Geoheritage: Examples and Applications**
When: Sat., 21 Oct., 1–5 p.m.
Where: Sheraton, Columbia Room
Cost: US$107

523. **Taking Students into the Field on Their Own Time: Using the Free, NSF-Funded Flyover Country Mobile App to Design Student Self-Guided Field Experiences**
When: Sat., 21 Oct., 1–5 p.m.
Where: Washington State Convention Center, Room 211
Cost: US$129

524. **Using the Geochron.org Database to Archive, Compile, and Retrieve Geochronology and Thermochronology Data**
When: Sat., 21 Oct., 8 a.m.–5 p.m.
Where: Washington State Convention Center, Room 208
Cost: US$30

Associated Society Course

Paleontological Society

Biogeochemical Approaches in Paleobiology and Paleoecology. Sat., 21 Oct., 9 a.m.–6 p.m. FREE, with no registration needed and no course attendance limit. Washington State Convention Center, Ballroom 6C
Instructors: Kena Fox-Dobbs, Univ. of Puget Sound; Erik Gulbranson, Univ. of Wisconsin–Milwaukee; Sora Kim, Univ. of Kentucky.

Notice of GSA **Council Meetings**

GSA Annual Meeting & Exposition
Seattle, Washington, USA

- **Day 1:** Saturday, 21 Oct. 2017 (Willow Room*)
- **Day 2:** Wednesday, 25 Oct. 2017 (Ravenna Room*)

Council Meetings will be held from 8 a.m.–noon in the GSA Headquarters Hotel—Sheraton Seattle, 1400 6th Ave., Seattle, Washington 98101, USA.

All GSA members are invited to attend the open portions of these meetings.

**Meeting room is subject to change. Updates will be posted.*

Organizing Committee

Thanks to the GSA 2017 Organizing Committee

Co-General Chairs:
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Darrel Cowan, University of Washington

Field Trip Co-Chairs:
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Student Committee Chair:
Linnea McCann, University of Washington

Student Committee Members:
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Michael Zackery McIntire, University of Washington;
Virginia Littel, University of Washington;
Keith Hodson, University of Washington


Virginia Littel


Keith Hodson

Host University: University of Washington

Exhibitors by Category

This list is as of press time. Exhibitors may be listed in multiple categories.
See **community.geosociety.org/gsa2017/ehibitors** for a current list and live floorplan.

Computer Software

CrystalMaker Software Ltd., Booth 216
Dino-Lite Scopes, Booth 206
The Paleobiology Database, Booth 735

Environmental

American Geophysical Union (AGU), Booth 335
Center for Applied Isotope Studies, University of Georgia, Booth 511
DOSECC Exploration Services, Booth 518
EarthScope, Booth 411
Environmental and Engineering Geophysical Society (EEGS), Booth 510
Environmental Isotope Laboratory, Booth 531
Geosciences, University of Massachusetts–Amherst, Booth 923
HORIBA Scientific, Booth 313
Science is Never Settled, Booth 640

Gems/Mineral Dealers/Jewelry/Gifts

Crystals Unlimited, Booth 630
Dino-Lite Scopes, Booth 206
Gems & Crystals Unlimited, Booth 422
Pitkin Stearns International, Booth 317

General Educational Products

American Geophysical Union (AGU), Booth 335
CrystalMaker Software Ltd, Booth 216
EarthScope, Booth 411
Geosciences, University of Massachusetts–Amherst, Booth 923
GSA Geoinformatics Division, Booth 407
IRIS Consortium, Booth 413
Pitkin Stearns International, Booth 317
Science is Never Settled, Booth 640
UNAVCO Inc., Booth 409
University of Chicago Press, Booth 435

Geological and Geophysical Instrumentation

Advanced Geosciences Inc., Booth 416
ASC Scientific, Booth 330
Beckman Coulter Life Sciences, Booth 741
Bruker Corporation, Booth 625
Dino-Lite Scopes, Booth 206
Geophysical Survey Systems Inc. (GSSI), Booth 441
HORIBA Scientific, Booth 313
MALA Geoscience USA, Booth 533
SEC Co. Ltd., Booth 207
UNAVCO Inc., Booth 409

Geological Society of America

GSA Energy Division, Booth 114
GSA Environmental and Engineering Geology Division, Booth 118
GSA Geoinformatics Division, Booth 407
GSA Geology and Health Division, Booth 110
GSA Hydrogeology Division, Booth 408
GSA International, Booth 108
GSA Karst Division, Booth 623
GSA Limnogeology Division, Booth 116
GSA Planetary Division, Booth 120
GSA Sedimentary Division, Booth 112

Government Agencies (Federal, State, Local, International)

DOSECC Exploration Services, Booth 518
EarthScope, Booth 411
National Park Service, Booth 223
National Science Foundation, Booth 410

Other

Geological Society of London, Booth 334
Geoscience Information Society (GSIS), Booth 311
IRIS Consortium, Booth 413
Québec City 2018—20th International Sedimentological Congress, Booth 542
Science is Never Settled, Booth 640
University of Chicago Press, Booth 435

Professional Societies and Associations

American Geophysical Union (AGU), Booth 335
Association for Women Geoscientists (AWG), Booth 234
EEGS, Booth 510
European Geosciences Union (EGU), Booth 516
Geochemical Society, Booth 211
Geological Association of Canada, Booth 213
Geological Society, London, Booth 334
Geoscience Information Society (GSIS), Booth 311
GSA Geoinformatics Division, Booth 407
Mineralogical Association of Canada, Booth 212
Mineralogical Society of America, Booth 208
National Cave and Karst Research Institute, Booth 617
SEPM Society for Sedimentary Geology, Booth 231
Sigma Gamma Epsilon, Booth 722
The Paleontological Society, Booth 730

Publications, Maps, Films

American Geophysical Union (AGU), Booth 335
Elsevier, Booth 637
Geological Society, London, Booth 334
GSA Bookstore, Booth 31
IRIS Consortium, Booth 413
Mineralogical Society of America, Booth 208
Treatise on Invertebrate Paleontology, Booth 731
University of Chicago Press, Booth 435
Wiley, Booth 443

Services (Exploration, Laboratories, Consulting, and Others)

Beta Analytic Inc., Booth 431
Center for Applied Isotope Studies, University of Georgia, Booth 511
DOSECC Exploration Services, Booth 518
Environmental Isotope Laboratory, Booth 531
GeoSep Services, Booth 513
GNS Science, Booth 541
UNAVCO Inc., Booth 409

Universities/Schools

Center for Applied Isotope Studies, University of Georgia, Booth 511
Central Washington University, Booth 912
DOSECC Exploration Services, Booth 518
EarthScope, Booth 411
Environmental Isotope Laboratory, Booth 531
Geosciences, University of Massachusetts–Amherst, Booth 923
Indiana University, Booth 910
Indiana University–Purdue University Indianapolis, Booth 924
LSU Department of Geology & Geophysics, Booth 811
UC Riverside Earth Sciences Department, Booth 810
University of Texas at Dallas, Booth 723
University of Washington Earth & Space Sciences, Booth 826
University of Wyoming, Booth 805
Virginia Tech Department of Geosciences, Booth 636

Exhibit Hall Hours & Opening Reception

Washington State Convention Center

Sun., 2–7 p.m.; Opening Reception: 5:30–7:30 p.m.

Mon.–Tues.: 10 a.m.–6:30 p.m.

Wed.: 10 a.m.–2 p.m.

Thank You Sponsors!

Your support of the Geological Society of America's Annual Meeting & Exposition continues a longstanding tradition of serving science and the profession. The Society appreciates your investment in the growth of current and future leaders in the geoscience community. The following list is **as of 30 June 2017.**

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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
Location: 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
Location: 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
www.geosociety.org/rm-mtg
Photo credit: findyourspot.com.

Thank You

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GSA thanks all of its partners that it works with to place geoscientists in exciting projects in America's public lands.

Thank you to the U.S. Forest Service, the U.S. Bureau of Land Management (BLM), and Aerotek, Inc., for providing GeoCorps America opportunities in National Forests and BLM lands throughout the nation.

And thank you to the National Park Service and the Stewards Individual Placement Program for providing Geoscientists-in-the-Parks (GIP) opportunities in National Parks across the United States.

Because of the efforts of these organizations, geoscientists have wonderful opportunities to hone their skills while giving back to their nation's public lands.

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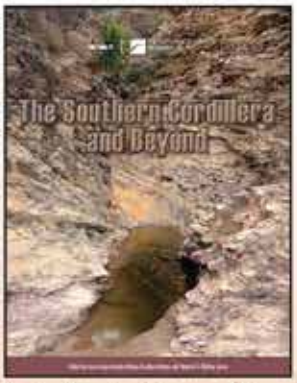
www.geosociety.org/geocorps

GSA is seeking members to lead geoscience field trips for teachers and other educators. The goal of these trips is to give teachers authentic experiences learning about the earth in the field. If you are interested in leading or supporting a trip, please e-mail GSA's education staff at

education@geosociety.org.

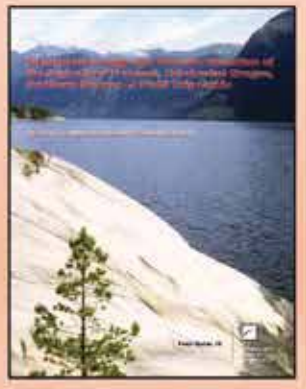
$10 Books at the GSA Store



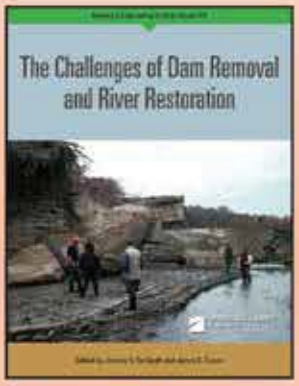
The Southern Cordillera and Beyond
edited by José Jorge Aranda-Gómez, Gustavo Tolson, and Roberto S. Molina-Garza
FLD025, 193 p., ISBN 9780813700250

Impossible Journey: The Story of the Victoria Land Traverse 1959–1960, Antarctica
by John G. Weihaupt, Alfred W. Stuart, Frans G. Van der Hoeven, Claude Lorius, and William M. Smith
SPE488, 136 p. plus index, ISBN 9780813724881

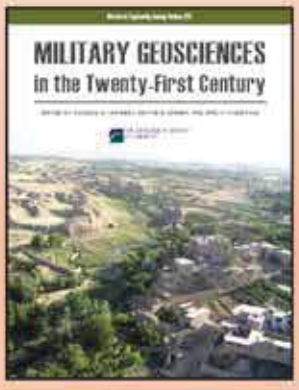
Societal Challenges and Geoinformatics
edited by A. Krishna Sinha, David Arctur, Ian Jackson, and Linda Gundersen
SPE482, 191 p., ISBN 9780813724829



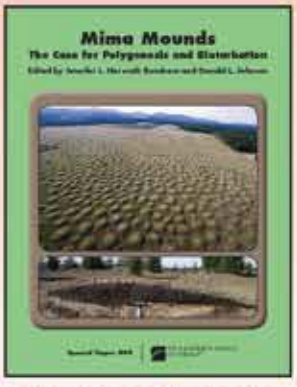
Structural Geology and Tectonic Evolution of the Sognefjord Transect, Caledonian Orogen, Southern Norway—A Field Trip Guide
by Alan Geoffrey Milnes and Fernando Corfu
FLD019, 75 p., ISBN 9780813700199



The Challenges of Dam Removal and River Restoration
edited by Jerome V. De Graff and James E. Evans
REG021, 203 p., ISBN 9780813741215

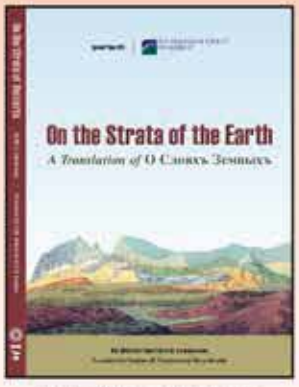


Military Geosciences in the Twenty-First Century
edited by Russell S. Harmon, Sophie E. Baker, and Eric V. McDonald
REG022, 215 p., ISBN 9780813741222



Mima Mounds: The Case for Polygenesis and Bioturbation
edited by Jennifer L. Horwath Burnham and Donald L. Johnson
SPE490, 205 p., ISBN 9780813724904

Mélanges: Processes of Formation and Societal Significance
edited by John Wakabayashi and Yildirim Dilek
SPE480, 277 p., ISBN 9780813724805



On the Strata of the Earth
A Translation of О Слоях Земныхъ
by Mikhail Vasil'evich Lomonosov; translated by Stephen M. Rowland and Slava Korolev
SPE485, 41 p., ISBN 9780813724850

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THE GEOLOGICAL SOCIETY OF AMERICA®

Preliminary Announcement and Call for Papers

SOUTH-CENTRAL SECTION

52nd Annual Meeting of the South-Central Section, GSA
Little Rock, Arkansas, USA
12–13 March 2018

www.geosociety.org/sc-mtg

Photo by Oliver Beland.

Geology in the Natural State

LOCATION

Situated on the Arkansas River, Little Rock is home to a vibrant nightlife, big-time entertainment, world-class attractions, and a booming dining scene. Learn about important events in the civil rights movement at the Central High School National Historic Site, explore the Clinton Presidential Center, and imagine a world free of hunger and poverty at the Heifer Village. Lace up your running shoes or hop on a bicycle and cruise the Arkansas River Trail, which features more than 15 miles of scenic riverfront and one of the longest pedestrian and bicycle bridges in America. From digging for quartz or diamonds to soaking in a natural hot springs bath at Hot Springs National Park, Little Rock is the perfect starting point for a wide range of geology-related adventures. We have put together an exciting program of field trips, workshops, and technical sessions covering a wide range of geology topics that we believe will be very appealing. We look forward to seeing you in Little Rock in 2018!

CALL FOR PAPERS

Abstract deadline: 5 Dec.
Submit online at **www.geosociety.org/sc-mtg**
Abstract submission fee: US$18 for students and US$30 for all others. If you cannot submit an abstract online, please contact Heather Clark, +1-303-357-1018, hclark@geosociety.org. For additional information, please contact the Technical Program Chair, Laura Ruhl, lsruhl@ualr.edu.

THEME SESSIONS

T1. **Late Paleozoic Tectonic Framework of the South-Central USA and the Evolution of the Ouachita Orogen.** Robert Stern, Univ. of Texas at Dallas, rjstern@utdallas.edu; Daniel Rains, Arkansas Geological Survey, daniel.rains@arkansas.gov; Majie Fan, Univ. of Texas at Arlington, mfan@uta.edu.

T2. **Groundwater Resources of the Mississippi Embayment.** Katherine Knierim, U.S. Geological Survey, kknierim@usgs.gov; Samantha Wacaster, U.S. Geological Survey.

T3. **Paleontology of the South-Central Region.** Joseph Daniel, PaleoAERIE, paleoaerie@gmail.com; René Shroat-Lewis, Univ. of Arkansas at Little Rock, rashroatlew@ualr.edu.

T4. **Petroleum Produced Water: Safe Disposal and Beneficial Use.** Javier Vilcaez, Boone Pickens School of Geology, Oklahoma State Univ., vilcaez@okstate.edu; Antonio Cardona, San Luis Potosi Univ., acardona@uaslp.mx.

T5. **Structure and Stratigraphy of the Mid-Continent Region: Mountain Building and Related Sedimentation.** Keith Gray, Wichita State Univ., k.gray@wichita.edu; Xiangyang Xie, Texas Christian Univ., x.xie@tcu.edu; William Parcell, Wichita State Univ., william.parcell@wichita.edu; Matthew McKay, Missouri State Univ., matthewmckay@missouristate.edu.

T6. **Karst Development and Karst Hydrogeology in the Mid-Continent Region of the United States.** Phillip Hays, U.S. Geological Survey and Univ. of Arkansas, pdhays@usgs.gov; Matthew Covington, Univ. of Arkansas, mcoving@uark.edu.

T7. **Insight from Planetary Remote Sensing.** Suniti Karunatillake, Louisiana State Univ., sunitiw@lsu.edu.

T8. **Carbon in the Geosphere.** Omar Harvey, Texas Christian Univ., omar.harvey@tcu.edu.

T9. **Geologic Mapping in the South-Central Region of the United States (Posters).** Richard Hutto, Arkansas Geological Survey, richard.hutto@arkansas.gov; Garrett Hatzell, Arkansas Geological Survey, garrett.hatzell@arkansas.gov.

T10. **Holistic Approaches to Coping with Induced Seismicity in the Mid-Continent.** Casee Lemons, Texas Bureau of Economic Geology, casee.lemons@beg.utexas.edu; Tandis Bidgoli, Kansas Geological Survey, tbidgoli@kgs.ku.edu; Jake Walter, Oklahoma Geological Survey, jwalter@ou.edu; Scott Ausbrooks, Arkansas Geological Survey, scott.ausbrooks@arkansas.gov.

T11. **Demography and Geosciences: Addressing the Growing Diversity Gap.** Stephen K. Boss, Univ. of Arkansas, sboss@uark.edu.

T12. **Drivers and Impacts to Water Quality throughout the Mid-Continent Region of the United States.** Ralph Davis,

Univ. of Arkansas, ralphd@uark.edu; Brian Haggard, Arkansas Water Resources Center, Univ. of Arkansas, haggard@uark.edu; Phillip Hays, Department of Geosciences, Univ. of Arkansas, pdhays@uark.edu.

T13. **Cretaceous Igneous Activity in the South-Central United States.** Robert Stern, Univ. of Texas at Dallas, rjstern@utdallas.edu; Adriana Potra, Univ. of Arkansas, potra@uark.edu; Michael G. Davis, Arkansas Tech. Univ., mdavis@atu.edu.

T14. **Geological Survey Support to Emergency Management.** Brian Blake, Central United States Earthquake Consortium (CUSEC), bblake@cusec.org; Martha Kopper, martha.kopper@arkansas.gov.

T15. **Effects of Carbon-Cycle Perturbations on Marine Ecosystems.** Hannah-Maria Brame, Univ. of Texas at Austin, hmrbrame@utexas.edu; Anna Weiss, Univ. of Texas at Austin, anna.weiss@utexas.edu.

T16. **Geology and Health Research on Trace Elements in Drinking Waters, and Outreach and Education Activities.** Saugata Datta, Kansas State Univ., sdatta@ksu.edu; Robert Finkelman, Univ. of Texas Dallas, bobf@utdallas.edu; Darcia Routh, Arkansas Dept. of Health, Darcia.Routh@arkansas.gov.

T17. **Continuous Improvement, Assessment, and Accreditation of Geology Programs.** Margaret (Beth) McMillan, Univ. of Arkansas at Little Rock, memcmillan@ualr.edu; Jeffery Connelly, Univ. of Arkansas at Little Rock, jbconnelly@ualr.edu; Nickolas Jovanovic, Univ. of Arkansas at Little Rock, nsjovanovic@ualr.edu.

T18. **Earth and Space Science K–Higher Education.** Margaret (Beth) McMillan, Univ. of Arkansas at Little Rock, memcmillan@ualr.edu; Wendi Williams, Univ. of Arkansas at Little Rock and Northwest Arkansas Community College, wjwilliams@ualr.edu; Michele Snyder, Arkansas Department of Education, michele.synder@arkansas.gov.

T19. **Undergraduate Student Research (Posters).** Joshua Spinler, Univ. of Arkansas at Little Rock, jxspinler@ualr.edu.

FIELD TRIPS

For additional information, please contact the Field Trip Chair, Angela Chandler, angela.chandler@arkansas.gov.

1. **Healing Springs of Arkansas.** John Svendsen, Univ. of Arkansas–Little Rock, docnlr@sbcglobal.net; Van Brahana, Univ. of Arkansas, brahana@uark.edu.
2. **Crater of Diamonds State Park.** Doug Hanson, Arkansas Geological Survey, doug.hanson@arkansas.gov; Danny Rains, Arkansas Geological Survey, danny.rains@arkansas.gov.
3. **Hot Springs National Park and Finding Quartz Crystals.** Doug Hanson, Arkansas Geological Survey, doug.hanson@arkansas.gov; Ty Johnson, Arkansas Geological Survey, ty.johnson@arkansas.gov.
4. **Minerals and Geologic History of Magnet Cove.** Corbin Cannon, Arkansas Geological Survey, corbin.cannon@arkansas.gov; Lea Nondorf, Terracon, lea.m.tipton@gmail.com; Christopher DeGarmo, Arkansas Natural Resources Commission, christopher.degarmo@arkansas.gov.
5. **Lithostratigraphy and Sequence Stratigraphy of the Mississippian across Northern Arkansas.** Walter Manger, Univ. of Arkansas, wmanger@uark.edu; Angela Chandler, Arkansas Geological Survey, angela.chandler@arkansas.gov; Richard Hutto, Arkansas Geological Survey, richard.hutto@arkansas.gov.
6. **Lake Ouachita Geofloat.** Ty Johnson, Arkansas Geological Survey, ty.johnson@arkansas.gov; Garrett Hatzell, Arkansas Geological Survey, garrett.hatzell@arkansas.gov; Doug Hanson, Arkansas Geological Survey, doug.hanson@arkansas.gov.
7. **Educators in the Field: Bringing Earth and Space Science into Context.** Wendi Williams, Univ. of Arkansas–Little Rock and Northwest Arkansas Community College, wwilliams@nwacc.edu, wjwilliams@ualr.edu; Keith Harris, Arkansas Partnership for STEM Education at Univ. of Arkansas–Little Rock, krharris@ualr.edu.

WORKSHOPS

1. **Basic Seismic Attributes.** Robert Schneider, Texas A&M–Kingsville, robert.schneider@tamuk.edu; Gary Jones, Yosh Geophysical, gljones@sbcglobal.net.
2. **High-Resolution Geophysical Imaging: An Aid for Geological Mapping.** Ahmed Ismail, Boone Pickens School of Geology, Oklahoma State Univ., ahmed.ismail@okstate.edu.
3. **Earth and Space Sciences in the High School Integrated Approach.** Keith Harris, Arkansas Partnership for STEM Education at Univ. of Arkansas–Little Rock, krharris@ualr.edu; Michele Snyder, Arkansas Department of Education, michele.synder@arkansas.gov; Wendi Williams, Univ. of Arkansas–Little Rock and Northwest Arkansas Community College, wwilliams@nwacc.edu, wjwilliams@ualr.edu.

OPPORTUNITIES FOR STUDENTS AND EARLY CAREER PROFESSIONALS

Roy J. Shlemon Mentor Program in Applied Geoscience. Students and early career professionals will have the opportunity to discuss career prospects and challenges with applied geoscientists from various sectors over a FREE lunch.

John Mann Mentors in Applied Hydrogeology Program. Students and early career professionals interested in applied hydrogeology or hydrology as a career will have the opportunity to network with professionals in these fields over a FREE lunch.

GEOSCIENCE CAREER WORKSHOPS

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 to 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 résumés to help you to learn important dos and don'ts.

ACCOMMODATIONS

Hotel registration deadline: 19 Feb. 2018
A block of rooms has been reserved at the Little Rock Marriott, 3 Statehouse Plaza, Little Rock, Arkansas 72201, USA, and the meeting rate is US$139 per night plus tax. Reservations should be made by calling the Little Rock Marriott at +1-877-759-6290 (toll free) or +1-501-906-4000 (local). Please be sure to mention that you are attending the GSA meeting.

REGISTRATION

Early registration deadline: 5 Feb. 2018
Cancellation deadline: 13 Feb. 2018

Registration opens in December. For further information or if you need special accommodations, please contact the meeting Chair, Michael DeAngelis, mtdeangelis@ualr.edu.

LOCAL COMMITTEE

Chair: Michael DeAngelis, mtdeangelis@ualr.edu

Technical Session Chair: Laura Ruhl, lsruhl@ualr.edu

Field Trip Chair: Angela Chandler, angela.chandler@arkansas.gov

Workshop/Short Course Chair: Kathy Knierim, kknierim@usgs.gov

Student Volunteer Coordinator: René Shroat-Lewis, rashroatlew@ualr.edu

Exhibits Coordinator: Joshua Spinler, jxspinler@ualr.edu

Sponsorship: Michael DeAngelis, mtdeangelis@ualr.edu

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This 12-month, 9.5" × 12.5" calendar showcases exceptional submissions to the 2018 GSA calendar photo search. Featuring landscapes and scenic images including an upside-down iceberg (Antarctic Peninsula), Drumheller hoodoos (Canada), Mammoth Hot Springs (Wyoming), Olkhon Island (Siberia), and even a photomicrograph of asbestiform anthophyllite (Idaho), this stunning calendar will spruce up your office or home.

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- Birthdates of famous geoscientists
- Calendar of GSA events, meetings, and deadlines

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Preliminary Announcement and Call for Papers

NORTHEASTERN SECTION

53rd Northeastern Section Annual Meeting, GSA
Burlington, Vermont, USA
18–20 March 2018

www.geosociety.org/ne-mtg

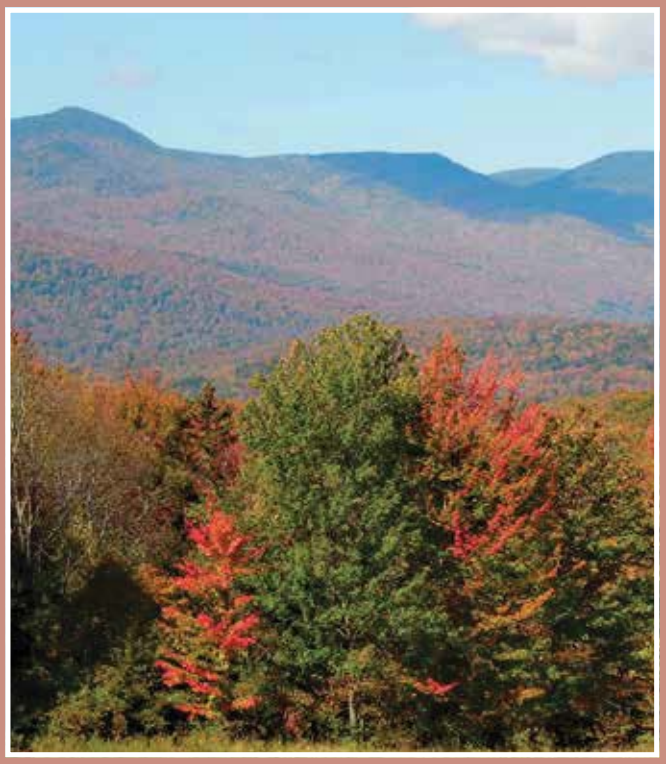

Photo by Stephen Wright.

LOCATION

Burlington, Vermont, USA, is a dynamic college town located on the shore of Lake Champlain between the Adirondack Mountains to the west and the Green Mountains to the east. Home to wonderful restaurants, boutiques, and microbreweries, Burlington is centrally located to many Vermont attractions, such as the Shelburne Museum, the ECHO science museum, the Ben & Jerry's Factory, as well as geological sites of interest, such as the Champlain Thrust at Lone Rock Point and the Chazy Reef on Isle la Motte.

CALL FOR PAPERS

Abstract deadline: 12 Dec.
Submit online at **https://gsa.confex.com/gsa/2018NE/cfp.epl**
Abstract submission fee: US$18 for students and US$30 for all others. If you cannot submit an abstract online, please contact Heather Clark, +1-303-357-1018, hclark@geosociety.org.

THEME SESSIONS

T1. **Practical Applications of Engineering Geology.** Krystle Pelham, Engineering Geologist, New Hampshire Dept. of Transportation, krystle.pelham@dot.nh.gov.

T2. **Applications of Geoscience to Government and Community Issues.** Marjorie Gale, State Geologist, Vermont Geological Survey, marjorie.gale@vermont.gov; Gale Blackmer, State Geologist, Pennsylvania Geological Survey, gblackmer@pa.gov; Frederick Chormann, State Geologist, New Hampshire Geological Survey, frederick.chormann@des.nh.gov.

T3. **Stories of Resilience: River Restoration and Recovery in the Northeast.** Kristen Underwood, Univ. of Vermont, southmountain@gmavt.net; John Field, Field Geology Services, jfield@field-geology.com.

T4. **Engineering and Environmental Applications in a Post-Glacial Northeast.** Kristen Underwood, Univ. of Vermont, southmountain@gmavt.net; John Field, Field Geology Services.

T5. **Critical Zone Processes, Function, and Resiliency: Challenges and Opportunities.** Julia Perdrial, Univ. of Vermont, jperdrial@uvm.edu; Tim White, Penn State Univ., tsw113@psu.edu.

T6. **Emerging Contaminants in Fractured Bedrock Aquifers in the Northeast.** Jon Kim, Vermont Geological Survey, jon.kim@vermont.gov; Peter Ryan, Middlebury College, pryan@middlebury.edu; Ed Romanowicz, SUNY at Plattsburgh, romanoea@plattsburgh.edu; Tim Schroeder, Bennington College, tschroeder@bennington.edu.

T7. **Biogeochemical Cycling in Natural and Human-Altered Landscapes.** Jamie Shanley, U.S. Geological Survey, jshanley@usgs.gov; Doug Burns, U.S. Geological Survey, daburns@usgs.gov.

T8. **Private Wells—Current Challenges and Opportunities.** Sille Larsen, Vermont Department of Health, sille.larsen@vermont.gov; Liz Royer, Vermont Rural Water Association, lroyer@vtruralwater.org; Paul Susca, New Hampshire Department of Environmental Services, paul.susca@des.nh.gov; Patti Casey, Vermont Agency of Agriculture, patti.casey@vermont.gov.

T9. **Geological Characterization of Mudstones: Applications to Hydrocarbon Exploration and Production.** David R. (Randy) Blood, EQT Production, rblood@eqt.com; Ashley S.B. Douds, EQT Production, adouds@eqt.com.

T10. **Lake Champlain Research and Management.** Patricia Manley, Middlebury College, manley@middlebury.edu; Andrea Lini, Univ. of Vermont, alini@uvm.edu.

T11. **Current Research in Coastal and Marine Processes.** Mark Borrelli, Univ. of Massachusetts–Boston, mark.borrelli@umb.edu; Bryan A. Oakley, Eastern Connecticut State Univ., oakleyb@easternct.edu.

T12. **Paleolimnological Records of Landscape Change.** Laurie D. Grigg, Norwich Univ., lgrigg@norwich.edu; Timothy L. Cook, Worcester State Univ., tcook3@worcester.edu.

T13. **Deglaciation and Late-Glacial Climate Research, Northeastern U.S. and Eastern Canada.** Woodrow B. Thompson, Maine Geological Survey (retired), iceage-maine@myfairpoint.net; P. Thompson Davis, Bentley Univ.,

pdavis@bentley.edu; Brian K. Fowler, New Hampshire Geologic Resources Advisory Committee; b2fmr@metrocast.net.

T14. **Glacial Lakes: New Understandings of Their Extent, History, and Internal Dynamics.** John Rayburn, SUNY New Paltz, rayburnj@newpaltz.edu; Stephen Wright, Univ. of Vermont, swright@uvm.edu.

T15. **Fire Geomorphology.** Jennifer Callanan, William Paterson Univ., callananj@wpunj.edu.

T16. **Pleistocene to Anthropocene Surficial Processes in the Northeastern U.S.** Will Ouimet, Univ. of Connecticut, willouimet@gmail.com; Noah Snyder, Boston College, noah.snyder@bc.edu.

T17. **The Class that Time Forgot: Best Practices in Teaching Earth History.** Joseph F. Reese, Edinboro Univ. of Pennsylvania, jreese@edinboro.edu; Eric C. Straffin, Edinboro Univ. of Pennsylvania, estraffin@edinboro.edu.

T18. **Geolore: Local Geology Field Trips Merge Geology and History to Motivate Students, Teachers, and Community Members to Explore Natural Areas.** Tarin Weiss, Westfield State Univ., tweiss@westfield.ma.edu; Lori Weeden, Univ. of Massachusetts–Lowell, lori_weeden@uml.edu; Melissa Lombard, Fitchburg State Univ., melissalombard@alum.rpi.edu.

T19. **From Plane Tables to Drones: A Topography of Geologic Mapping in a Digital Landscape.** John Van Hoesen, Green Mountain College, vanhoesenj@greenmtn.edu; Rick Chormann, New Hampshire Geological Survey, frederick.chormann@des.nh.gov.

T20. **The Devonian Terrestrial Realm: Current Perspectives and New Research.** Charles Ver Straeten, New York State Museum, charles.verstraeten@nysed.gov; William Stein, Binghamton Univ., stein@binghamton.edu; Rose-Anna Behr, Pennsylvania Topographic and Geologic Survey, rosbehr@pa.gov.

T21. **Stratigraphic Studies along the Western Margin of the Appalachian Orogens.** Paul Washington, Marietta College, pw005@marietta.edu; James Ebert, SUNY at Oneonta, james.ebert@oneonta.edu.

T22. **The Adirondack Mountains and the Grenville Orogenic Cycle: New Results and Syntheses Regarding the Timing and Nature of Deformation, Metamorphism, Intrusion, and Formation of Ore Deposits.** Tim Grover, Castleton State, tim.grover@castleton.edu; Greg Walsh, USGS, gwalsh@usgs.gov; Mike Williams, Univ. of Massachusetts, mlw@umass.edu; Sean Regan, USGS, sregan@usgs.gov; Marian Lupulescu, New York State Museum, marian.lupilescu@nysed.gov; Peter Valley, SUNY at Potsdam, valleypm@potsdam.edu.

T23. **Application of Strain, Fabric, and Textural Analyses to Ductile Fabrics in Investigations of Orogenic Processes.** Jeffrey R. Webber, Stockton Univ., jeffrey.webber@stockton.edu; Keith A. Klepeis, Univ. of Vermont, keith.klepeis@uvm.edu; Michael L. Williams, Univ. of Massachusetts–Amherst, mlw@geo.umass.edu.

T24. **Orogenic Sutures—Recognition, Characterization, and Tectonic Implications.** Alain Tremblay, Univ. of Quebec at Montreal, tremblaya@uqam.gc.ca; Laura Webb, Univ. of Vermont, lewebb@uvm.edu.

T25. **Post-Rift Tectonism and Landscape Evolution in Eastern North America.** Will Amidon, Middlebury College, wamidon@middlebury.edu; Dave West, Middlebury College, dwest@middlebury.edu; Ryan McKeon, Dartmouth College, ryan.e.mckeon@dartmouth.edu.

T26. **Evolution of the Taconic Foreland: Insights into Active Margins and Global Climate Change.** Charles E. Mitchell, SUNY at Buffalo, cem@buffalo.edu; Robert D. Jacobi, SUNY at Buffalo, 1rdjacobi@gmail.com; Francis A. Macdonald, Harvard Univ., fmacdon@fas.harvard.edu; and Jeff Pietras, SUNY at Binghamton, jpietras@binghamton.edu.

T27. **New Perspectives on the Evolution of Brittle and Ductile Fault Zones: A Session Honoring the Work of Robert D. Jacobi.** Keith Klepeis, Univ. of Vermont, keith.klepeis@uvm.edu; Jon Kim, Vermont Geological Survey, jon.kim@vermont.gov; Jean Crespi, Univ. of Connecticut, jean.crespi@uconn.edu.

T28. **Petrologic, Structural, and Tectonic Interpretations in Northern New England: A Session Honoring the Work of Jo Laird and Peter J. Thompson.** Ian W. Honsberger, Carleton Univ., ian.honsberger@carleton.ca; Wallace A. Bothner, Univ. of New Hampshire, wally.bothner@unh.edu; Peter Robinson, Geological Survey of Norway, peter.robinson@ngu.no.

T29. **Petrologic Insights on Modern and Ancient Plate Margins I: The Volcanic and Plutonic Record.** Sara Mana, Salem State Univ., smana@salemstate.edu; Emily Peterman, Bowdoin College, epeterma@bowdoin.edu; Alicia M. Cruz-Uribe, Univ. of Maine; alicia.cruzuribe@gmail.com.

T30. **Petrologic Insights on Modern and Ancient Plate Margins II: The Metamorphic Record.** Emily Peterman, Bowdoin College, epeterma@bowdoin.edu; Howell Bosbyshell, West Chester Univ., hbosbyshell@wcupa.edu; Victor Guevara, Skidmore College, vguevara@skidmore.edu.

T31. **Igneous Processes in the Shallow Crust: A Session Honoring the Work of David Scott Westerman.** Christopher Koteas, Norwich Univ., gkoteas@norwich.edu.

T32. **Combining Geology and Geophysics in the Appalachians.** Maureen D. Long, maureen.long@yale.edu; Yvette D. Kuiper, ykuiper@mines.edu.

FIELD TRIPS

No NEGSA-sponsored field trips will be offered; however, there will be field guides to local geologically significant sites available at the meeting

WORKSHOPS

1. **Core Tools: Techniques and Software for Collection and Analysis of Core Samples.** Anders Noren, Continental Scientific Drilling Coordination Office/LacCore Facility, Univ. of Minnesota, noren021@umn.edu.
2. **Science Practice Integration for Your Classroom.** Organizers: Melissa Lombard, Fitchburg State Univ., melissalombard@alum.rpi.edu; Lara Gengarelly, Univ. of New Hampshire, lara.gengarelly@unh.edu.
3. **Turning Drone Data Into Information.** Organizer: Jarlath O'Neil-Dunne, Univ. of Vermont Spatial Analysis Laboratory, jarlath.oneil-dunne@uvm.edu.

OPPORTUNITIES FOR STUDENTS AND EARLY CAREER PROFESSIONALS

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STUDENT VOLUNTEERS

The committee and officers of the Northeastern Section rely on student volunteers to help meetings run smoothly, and we are pleased to offer student volunteers complimentary registration for the meeting in return for ~7 hours of work. Contact student volunteer coordinator David West, dwest@middlebury.edu, for more information.

REGISTRATION

Early registration deadline: 13 Feb.
Cancellation deadline: 20 Feb.

Online registration begins in early December. For more information, or if you have special requirements, please contact the local committee chairs: Andrea Lini, andrea.lini@uvm.edu, and Charlotte Mehrtens, charlotte.mehrtens@uvm.edu. Updates and details will be posted online when they become available.

ACCOMMODATIONS

A block of rooms has been reserved at the Sheraton Hotel and Conference Center in Burlington at US$139 per night single or double, with US$20 extra for the third and fourth occupants. To make a reservation, call +1-800-325-3535 and be sure to mention the group code of NEGSA18. This convention rate is guaranteed until Friday, 23 Feb. Parking is included.

GSA's Geosphere and Lithosphere to be Open Access in 2018

***Claudia Mora**, GSA Past President*

In 2014, GSA Council announced its commitment to transitioning GSA journals to full open access beginning in 2017 with *Geology*. The motivation for this decision was largely aspirational: to provide a valuable service to our membership and extend the reach and impact of our publications by making them accessible to the global research community and to the public and policymakers, worldwide. This plan was delayed to allow Council time to fully understand the positive and negative impacts of this decision to our members, to the Society, and to authors. Over the past year, Council made an internal review of our publication options and business changes that would support adoption of open access. We brought in experts to assess our publication model, to survey our authors (including members and nonmembers), to share research on factors favoring a successful transition to open access, and to provide us with informed input on how GSA could move toward implementation of open access. After thorough discussion, Council voted at its 2017 spring meeting to change GSA's phased transition to open access. We will now transition *Lithosphere* and *Geosphere* to open access in 2018. Transition of *GSA Bulletin* and *Geology* is postponed.

What last year's work has shown us is that the open-access movement is progressing, and we continue our commitment to this exciting possibility, but implementation of full open access requires changes across commercial, nonprofit, and university business models that are not yet well-synced, as well as adaptations and changes in the perceptions and experience of authors and GSA membership. We believe the transition to open access poses great opportunities for *Lithosphere* and *Geosphere* to reach new audiences and to develop and evolve in perspective and impact. This is also opportunity for GSA to better educate itself on the management of open-access journals not only for the success of the journal and its authors, but also for the benefit of the Society's membership. We look forward to beginning GSA's move to journal open access and welcome your input and feedback as we begin this initial step.

Manuscripts submitted to *Geosphere* or *Lithosphere* on or after 1 Sept. 2017 that are ultimately accepted for publication will be assessed an article publication charge (APC) of US$1,750. GSA members will receive a US$100 discount on this APC. There will be no other color or page charges, and a waiver system will be in place. No manuscript will be rejected for an inability to pay. (More details on journal fees and options are posted at www.geosociety.org/AuthorInfo.)

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.

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Fellowship Opportunities	$9.25	$9.00
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First 25 lines	$0.00	$5.00
Additional lines	$5.00	$5.00

Positions Open

TENURE TRACK
ASSISTANT PROFESSOR OF GEOLOGY
BELOIT COLLEGE

The Beloit College Department of Geology invites applicants for a tenure-track position in the area of Earth History and Climate (Paleoclimatology) to begin August 2018. The successful applicant will teach courses in climate and historical geology for geology majors and non-majors. Additional courses taught will reflect the applicant's area of specialty, and might include paleontology, sedimentology, geochemistry, and geoarchaeology. We seek candidates that can contribute to the departments' commitment to increasing access and opportunities for populations under-represented in the geosciences. The successful candidate will develop a research program that engages undergraduates, contribute to all-college programs such as first-year seminars, interdisciplinary studies, and international education, and serve in leadership roles in campus governance. An ability to contribute to an interdisciplinary Environmental Studies program is considered an asset.

Because equity and inclusion are central to our students' liberal education and vital to the thriving of all members of our residential learning community, Beloit College aspires to be an actively anti-racist institution. We recognize our aspiration as ongoing and institution-wide, involving collective commitment and accountability. We welcome employees who are committed to and will actively contribute to our efforts to celebrate our cultural and intellectual richness and be resolute in advancing inclusion and equity. We encourage all interested individuals meeting the criteria of the described position to apply.

Located in a diverse community close to Madison, Milwaukee, and Chicago, Beloit is a selective undergraduate liberal arts college that attracts students from across the United States and the world. The college emphasizes excellence in teaching, learning beyond the traditional classroom, international perspectives, and collaborative research among students and faculty. It is recognized as one of the Colleges That Change Lives.

Inquiries may be addressed to Susan Swanson, department chair (swansons@beloit.edu). Interested individuals may submit a letter of interest, curriculum vitae, statements of teaching and research interests, graduate transcripts, and contact information for three references to geologysearch17@beloit.edu. To ensure full consideration, please submit all materials by November 15, 2017. The search will remain open until the position is filled.

VISITING ASSISTANT PROFESSOR
OF GEOLOGY, BELOIT COLLEGE

Beloit College invites applications for a one-semester Visiting Assistant Professor of Geology beginning in January, 2018. The successful candidate will teach two laboratory courses: introductory evolution of the earth and oceanography.

Because equity and inclusion are central to our students' liberal education and vital to the thriving of all members of our residential learning community, Beloit College aspires to be an actively anti-racist institution. We recognize our aspiration as ongoing and institution-wide, involving collective commitment and accountability. We welcome employees who are committed to and will actively contribute to our efforts to celebrate our cultural and intellectual richness and be resolute in advancing inclusion and equity. We encourage all interested individuals meeting the criteria of the described position to apply.

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Inquiries may be addressed to Sue Swanson, department chair (swansons@beloit.edu). Interested individuals may submit a letter of interest, curriculum vitae, statements of teaching and research interests, graduate transcripts, and three letters of reference to geologyvisitorsearch@beloit.edu. To ensure full consideration, please submit all materials by September 15, 2017. The search will remain open until the position is filled.

Do you have a group of topical papers that you dream of seeing in a GSA book?

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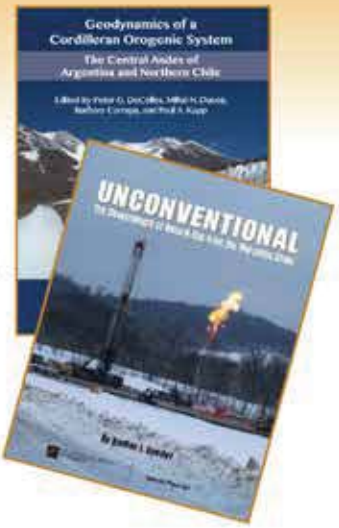

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The GSA Foundation is eagerly preparing some surprises and special announcements for our booth during the 2017 Annual Meeting in Seattle, Washington, USA (22–25 October). We invite you to take a journey through time, starting in field camp days of yore, stepping into current mapping examples and field camps, and traveling into the future of field geology, including planetary exploration.

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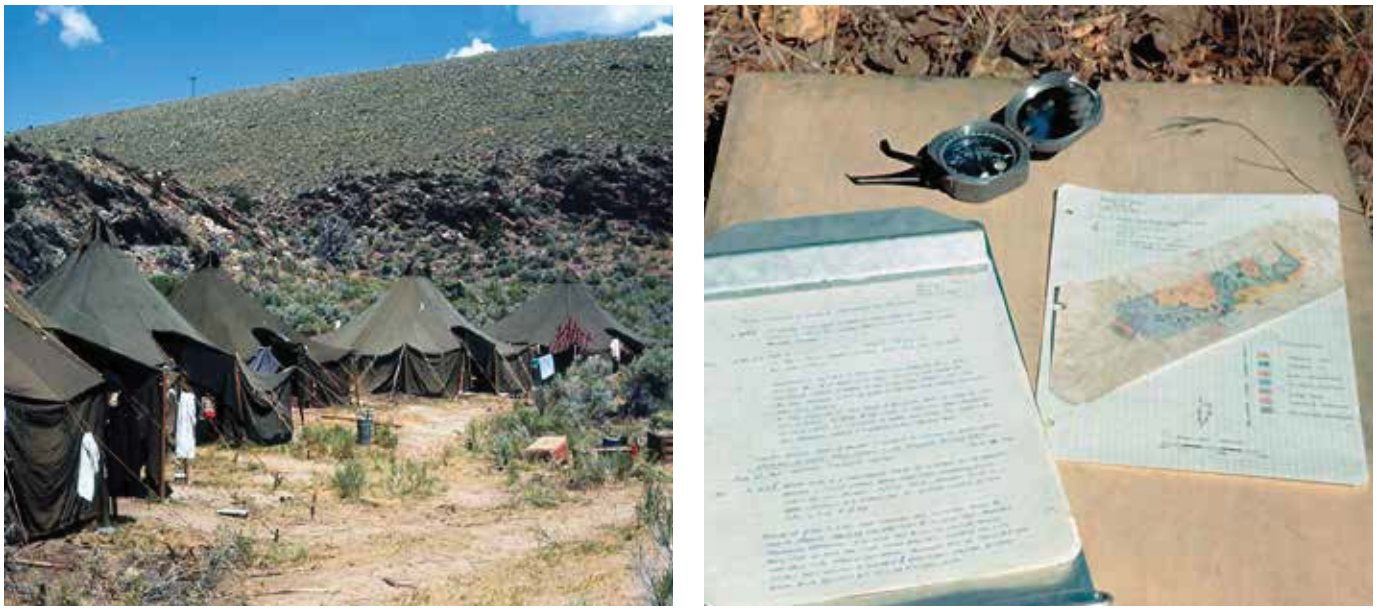
Be the first in line for an assortment of limited giveaways at various times throughout the meeting to commemorate our special announcement! We look forward to seeing you in Seattle.



Stanford field camp, Raft River Mountains, Utah, USA, 1965. Courtesy Darrel Cowen.

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GROUNDWORK
Furthering the Influence of Earth Science

A New Subsidence Map for Coastal Louisiana

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Coastal Louisiana has experienced catastrophic rates of wetland loss over the past century, equivalent in area to the state of Delaware. Land subsidence in the absence of rapid accretion is one of the key drivers of wetland loss. Accurate subsidence data should therefore form the basis for estimates of and adaptations to Louisiana's future. Recently, Jankowski et al. (2017) determined subsidence rates at 274 sites along the Louisiana coast. Based on these data we present a new subsidence map and calculate that, on average, coastal Louisiana is subsiding at 9 ± 1 mm yr^{-1}.

COASTAL SUBSIDENCE

Low-elevation coastal zones (LECZs) are among the most vulnerable landscapes within the context of climate-driven accelerated sea-level rise, often exacerbated by other human impacts as well as high subsidence rates. Predictions of rates of relative sea-level rise (RSLR) in such settings depend to a considerable extent on our ability to monitor present-day subsidence rates—including their spatial pattern—at the land surface. Obtaining such data is challenging; space-based techniques (e.g., InSAR) struggle in non-urbanized landscapes and to date only few of such studies have provided useful results (e.g., Strozzi et al., 2013). Here we combine recently published subsidence data, collected by different yet complementary methods, to produce a novel subsidence map for coastal Louisiana, one of the world's most vulnerable LECZs.

While a variety of factors have contributed to Louisiana's wetland loss problem, the fundamental culprit is the isolation of the sediment-delivery system (the Mississippi River) from its delta plain and the adjacent coastal zone due to the construction of flood-protection levees. As a result, the majority of the sediment carried by this system is funneled into the deep waters of the Gulf of Mexico, rather than offsetting the naturally occurring high subsidence rates. A landmark study (Blum and Roberts, 2009) has shown that this problem is likely to worsen in the future due to limited sediment loads and accelerated sea-level rise.

SUBSIDENCE DATA

Tide gauges are frequently used to obtain records of RLSR. However, tide gauges in coastal Louisiana, and likely many other LECZs, have major limitations because they typically measure RSLR with respect to benchmarks anchored tens of meters below the land surface. Subsidence rates are highest in the uppermost 5–10 m, but the average depth of the benchmarks associated with National Oceanic and Atmospheric Administration (NOAA) tide gauges in coastal Louisiana (n = 31) is ~23 m. Tide gauges therefore do not capture the component that accounts for 60%–85% of the total subsidence as observed at the land surface (Jankowski et al., 2017).

Our recent work (Jankowski et al., 2017) offers a novel approach to determining total subsidence rates at 274 sites along the Louisiana coast, based on data collected through the Coastwide Reference Monitoring System (CRMS) program. The centerpiece of this analysis consists of rod surface-elevation–marker horizon records, 6–10 years long, enabling us to calculate present-day shallow subsidence rates (i.e., shallow compaction) by subtracting the rate of surface-elevation change from the vertical accretion rate at each site (Cahoon, 2015). Recently published GPS time series (Karegar et al., 2015) complement this information; because these GPS stations (n = 13) are typically anchored >15 m below the land surface, they capture the "deep" subsidence component that includes glacial and sedimentary isostatic adjustment (Wolstencroft et al., 2014) plus compaction and faulting in deeper strata.

A NEW SUBSIDENCE MAP

Our subsidence map (Fig. 1) shows a spatially continuous pattern of subsidence rates as recorded at the land surface, based on the sum of the two data sources discussed above. While spatial variability between our discrete monitoring sites is high, the map shows that the expected average subsidence rate is relatively uniform across coastal Louisiana, with a mean rate of 9 mm yr^{-1} and a standard error of the mean of 1 mm yr^{-1}. It should be noted, however, that uncertainties at individual monitoring sites are significantly higher, and we therefore stress that both model (Fig. 1C) and data (Fig. 1D) uncertainties should be taken into account when estimating subsidence rates at specific localities, including those that coincide with CRMS sites. The map predicts slightly higher than average subsidence rates in the eastern Chenier Plain, the Atchafalaya and Wax Lake Deltas, and along the Mississippi River downstream of New Orleans. The lowest rates are found in the western portion of the Chenier Plain, the region with the lowest vertical accretion rates (Jankowski et al., 2017). These two findings are in all likelihood related;

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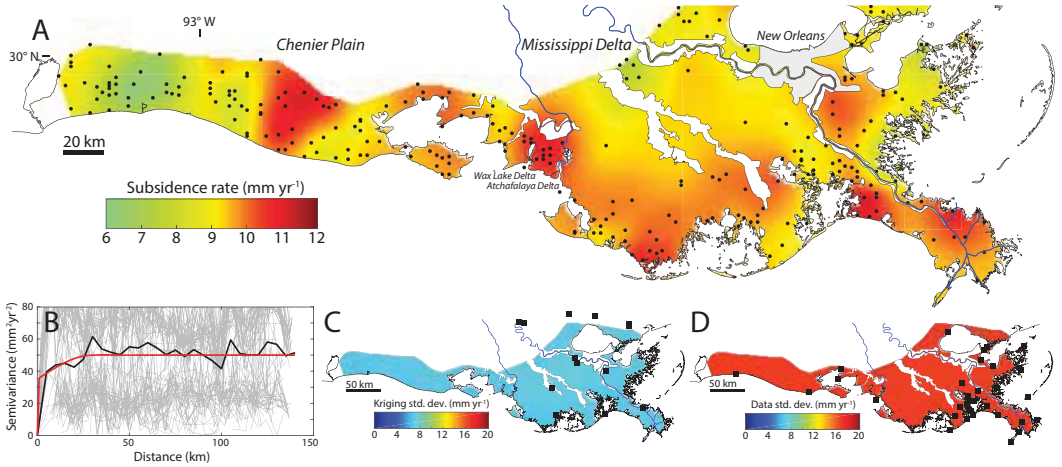

Figure 1. (A) Subsidence map for coastal Louisiana based on geostatistical interpolation (kriging) of 274 observations (black dots) of land-surface subsidence rates over the past 6–10 years. Areas in white and gray are agricultural and urban, respectively, and located outside of the wetlands. (B) Semivariogram of the data using 100 draws from different kriging options (gray), the data mean (black), and the kriging model (red). (C) Uncertainty (standard deviation) of the kriging estimate. Black squares show GPS stations. (D) Uncertainty (standard deviation) of the underlying data. Black squares show National Oceanic and Atmospheric Administration (NOAA) tide gauges. Note that the subsidence map can easily be converted into a relative sea-level rise map by adding the climate-driven sea-level component.

shallow compaction rates are known to be highly sensitive to overburden loading. The high subsidence rates in coastal Louisiana likely mostly reflect natural processes that have operated over the past millennia. Despite the associated high rates of RSLR, the abundant sediment supplied by the Mississippi River allowed its delta to evolve into one of the world's largest.

The new subsidence map should be considered a first step; substantial efforts are needed to refine this analysis. For example, our findings are not relevant for embanked urban settings with artificial drainage and localized groundwater extraction (Jones et al., 2016), most notably the New Orleans metropolitan area, as well as the agricultural land that occupies well-drained alluvial ridges. We omitted these areas from our subsidence map. Other caveats include the possibility of underestimated rates in the birdfoot delta around the mouth of the Mississippi River, which is known to exhibit anomalously high subsidence rates (Fisk et al., 1954). We also cannot rule out that active growth faults and hydrocarbon extraction may locally cause higher rates not captured by the GPS stations.

Our newly calculated present-day subsidence rates are considerably higher than what has been reported by recent studies that relied partly or entirely on tide gauges and that inferred rates of 1–6 mm yr^{-1} for the past few decades (Kolker et al., 2011; Karegar et al., 2015). As a result, "worst case scenarios" with subsidence rates of 8–10 mm yr^{-1} that have been used in predictions for the Mississippi Delta throughout the 21st century (Blum and Roberts, 2009; Kim et al., 2009) are in fact reflecting the conditions that exist in coastal Louisiana today. Perhaps worst case scenarios should be considered the new normal in other LECZs worldwide as well.

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REFERENCES CITED

Blum, M.D., and Roberts, H.H., 2009, Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise: Nature Geoscience, v. 2, p. 488–491, doi:10.1038/ngeo553.

Cahoon, D.R., 2015, Estimating relative sea-level rise and submergence potential at a coastal wetland: Estuaries and Coasts, v. 38, p. 1077–1084, doi:10.1007/s12237-014-9872-8.

Fisk, H.N., Kolb, C.R., McFarlan, E., and Wilbert, L.J., 1954, Sedimentary framework of the modern Mississippi delta: Journal of Sedimentary Petrology, v. 24, p. 76–99, doi:10.1306/D4269661-2B26-11D7-8648000102C1865D.

Jankowski, K.L., Törnqvist, T.E., and Fernandes, A.M., 2017, Vulnerability of Louisiana's coastal wetlands to present-day rates of relative sea-level rise: Nature Communications, v. 8, 14792, doi:10.1038/ncomms14792.

Jones, C.E., An, K., Blom, R.G., Kent, J.D., Ivins, E.R., and Bekaert, D., 2016, Anthropogenic and geologic influences on subsidence in the vicinity of New Orleans, Louisiana: Journal of Geophysical Research, Solid Earth, v. 121, p. 3867–3887, doi:10.1002/2015JB012636.

Karegar, M.A., Dixon, T.H., and Malservisi, R., 2015, A three-dimensional surface velocity field for the Mississippi Delta: Implications for coastal restoration and flood potential: Geology, v. 43, p. 519–522, doi:10.1130/G36598.1.

Kim, W., Mohrig, D., Twilley, R., Paola, C., and Parker, G., 2009, Is it feasible to build new land in the Mississippi River Delta?: Eos, v. 90, p. 373–374, doi:10.1029/2009EO420001.

Kolker, A.S., Allison, M.A., and Hameed, S., 2011, An evaluation of subsidence rates and sea-level variability in the northern Gulf of Mexico: Geophysical Research Letters, v. 38, L21404, doi:10.1029/2011GL049458.

Strozzi, T., Teatini, P., Tosi, L., Wegmüller, U., and Werner, C., 2013, Land subsidence of natural transitional environments by satellite radar interferometry on artificial reflectors: Journal of Geophysical Research, Earth Surface, v. 118, p. 1177–1191, doi:10.1002/jgrf.20082.

Wolstencroft, M., Shen, Z., Törnqvist, T.E., Milne, G.A., and Kulp, M., 2014, Understanding subsidence in the Mississippi Delta region due to sediment, ice, and ocean loading: Insights from geophysical modeling: Journal of Geophysical Research, Solid Earth, v. 119, p. 3838–3856, doi:10.1002/2013JB010928.

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GROUNDWORK
Furthering the Influence of Earth Science

Meeting Changing Workforce Needs in Geoscience with New Thinking about Undergraduate Education

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What enables a geoscience undergraduate to be successful in the workforce? This is the core question for an NSF-sponsored effort to develop a community vision for undergraduate geoscience education.

Two immediate trends impacting the geosciences have motivated this effort. As the current workforce retires, there is an increasing shortage of geoscientists, even as the overall demand for geoscientists continues to grow (Martinsen et al., 2012). Traditional geoscience jobs are evolving rapidly, requiring geoscientists to expand both their breadth and flexibility to be successful in their careers. Mapping and interpretation tasks are increasingly automated, and geoscientists are increasingly called on to inform the solution of significant societal issues, such as hazard resiliency, public health and the environment, access to resources, and global security. At the same time as workforce needs are changing, undergraduate education is transforming. Educators have developed new ways to enhance student learning and new pedagogies for STEM education (Singer et al., 2012). Additionally, the academic community has a broader awareness of the need to prepare students for the next generation of geoscience careers. Finally, despite continued efforts by educators and industry, the geoscience community still struggles to recruit and retain underrepresented individuals in our programs and professions compared to other STEM disciplines (O'Connell and Holmes, 2011).

To develop a common vision that addresses this changing landscape, the NSF-sponsored effort focused on three key topics: (1) content, competencies, and skills that undergraduates need to be successful in graduate school and the future workforce; (2) the best methods of teaching and using technology to enhance student learning; and (3) broadening participation and retention of underrepresented groups and preparing K–12 science teachers to prepare the pathway to a robust geoscience workforce and an earth-literate public. The effort started in early 2014 with a summit that drew together a wide spectrum of the undergraduate geoscience education community to outline critical priorities for improving the quality of undergraduate education. This summit led to an ongoing community survey that now has over 460 responses. A follow-up Geoscience Employers Workshop in 2015 and departmental heads and chairs Summit in 2016 tested the initial results of the 2014 summit with geoscience employers and engaged department heads and chairs to develop methods for implementing change. Documentation of the summits, workshop, and the community survey can be found at http://www.jsg.utexas.edu/events/future-of-geoscience-undergraduate-education/.

The process of engaging a spectrum of employers together with the input of critical priorities from the undergraduate education community proved to be especially enlightening. Workforce discussions generated a remarkable consensus among both academics and employers, whether employers were from the energy sector, environmental and engineering consulting, mining, or public agencies: The demand for new geoscientists in the workforce continues to be strong, but the skill sets of newly graduated geoscientists do not always match employers' evolving requirements. The community survey yielded initial data on the skills and concepts considered critical to both employers and academics (Fig. 1). The Geoscience Employers Workshop further expanded input from employers regarding the skills and concepts they viewed as critical for the current and future workforce, as well as their role in helping departments implement the developing community vision. Overall, the responses from the 2014 Summit, Employers' Workshop, and survey were strongly aligned. However, the workshop participants also provided greater definition and granularity regarding the use of specific skills and concepts in their respective work environments. During those discussions, they consistently emphasized: (1) systems thinking and multidisciplinary approaches to applied problems, with a strong understanding of fundamental processes, and their linkages, and feedbacks; (2) experience in cross-disciplinary teamwork and communication; (3) appropriate quantitative skills to manipulate and apply the governing physical, chemical, and biologic equations used to solve multidisciplinary problems; (4) the ability to manage and analyze large quantities of diverse data; and (5) an appreciation for the interfaces between geology and society, including business practices, ethics, risk, environmental sensitivity, cultural diversity, and a global outlook. These employer priorities were viewed as reflective of the ongoing evolution in geoscience employment and will increase in importance over the foreseeable future. Complete documentation of the employers' discussions can be

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* Retired from ExxonMobil Upstream Research Company, Senior Technical Consultant.

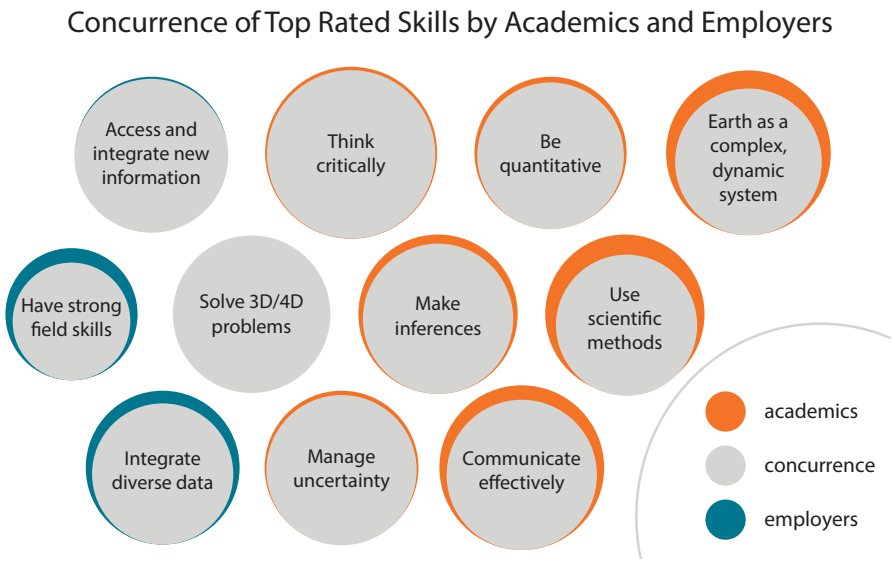

Figure 1. Highest priority skills and concepts from the community survey. Responders included ~95 employers and ~345 academics. Participants were asked to rank individual skills from 1 (very important) to 5 (not important). The size of the circles corresponds to the percentage of respondents who placed a skill in the top two categories (very important/important). The largest circle (Think Critically) had 95% very important/important responses, and the smallest circle (Strong Field Skills) had ~75% very important/important responses. Skills that received less than 75% very important/important responses were not included in the graph. The colors of the circles reflect similarities and differences between academic and employer responses. Gray centers show the percent of concurrence between academics and employers. Where the rims are blue, employers gave the skill a slightly higher weight than academics, and where the rims are orange, academics gave the skill a slightly higher weight than employers. A complete summary of the survey responses can be found at http://www.jsg.utexas.edu/events/files/HCWebinar_Sept2016_Summit-Sharon-Mosher.pdf.

found at http://www.jsg.utexas.edu/events/files/Employers_Workshop_outcomes.pdf.

As workforce needs evolve, student learning must change. Educators at the summits and contributors to the community survey agreed with employers that to prepare students for successful careers, geoscience curriculum should build around skills, competencies, concepts, and learning outcomes rather than specific disciplinary content (Fig. 2). A number of geoscience departments have already modified their curriculum and developed proven approaches for effecting change; e.g., experiential learning, independent research, problem solving and use of real data in classes, integration of math and computational methods into geology courses, incorporation of intensive written and oral communication, and implementation of robust assessment tools. There will, however, be challenges to putting these changes into practice throughout the geoscience community. Most importantly, faculty will need time, educational resources, and financial support to pilot and document new instructional approaches.

What are the next steps? More than 90 institutions have now developed individual action plans for their geoscience departments. In addition, the community survey remains open to anyone who wishes to participate: https://apps.jsg.utexas.edu/form/survey-future-of-undergraduate-geoscience-education. Employer input would be particularly welcome. Feedback from the survey, results of the summits, workshop, institutional plans, and extensive input from education conferences (e.g., Earth Educators Rendezvous) will be used to develop a formal Vision and Change document that lays out the shared community vision for undergraduate geoscience education and the actions needed to realize that vision. Sustained change in geoscience education will, however, require the persistent, coordinated efforts of administrators, educators, students, employers, and professional societies. Nonetheless, the prize remains large: it is nothing less than the opportunity to demonstrate that geoscience departments are an essential source of students to address a new generation of workforce and societal issues.

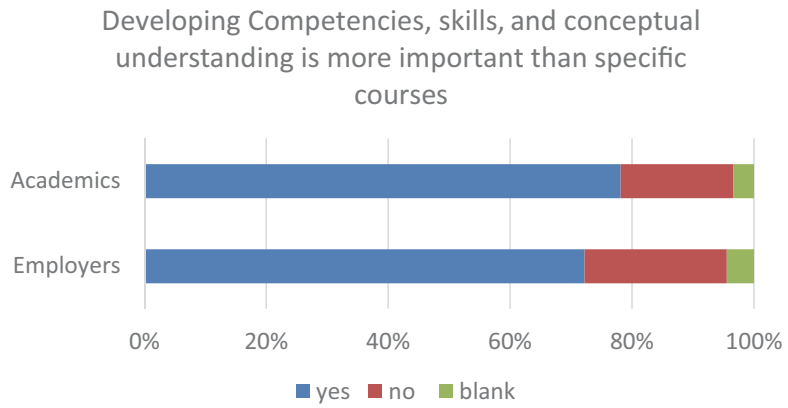

Figure 2. Results from the community survey supporting the major conclusion that developing competencies, skills, and conceptual understanding is more important than taking specific courses. Among both academics and employers, at least 75%–80% of respondents gave a positive answer to this question.

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REFERENCES CITED

Martinsen, O.J., Talwani, M., Levander, R, Dengo, C., Barkhouse, B., Dunn, J.F., Link, C., Mosher, S., Tatham, R., Orcutt, J., Paul, D., and Talley, R., 2012, A U.S. human resource challenge for Earth science education and energy exploration and exploitation: The Leading Edge, 30th Anniversary Volume, v. 31, p. 714–716, doi:10.1190/tle31060714.1.

O'Connell, S., and Holmes, M.A., 2011, Obstacles to the recruitment of minorities into the geosciences: A call to action: GSA Today, v. 21, no. 6, p. 52–54, doi:10.1130/G105GW.1.

Singer, S.R., Nielsen, N.R., and Schweingruber, H.A., editors, 2012, Discipline-based education research: Understanding and improving learning in undergraduate science and engineering: National Academies Press, 282 p.

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This artist's concept shows a celestial body about the size of our moon slamming at great speed into a body the size of Mercury. NASA's Spitzer Space Telescope found evidence that a high-speed collision of this sort occurred a few thousand years ago around a young star, called HD 172555, still in the early stages of planet formation. The star is about 100 light-years from Earth. 26 August 2009. www.nasa.gov/multimedia/imagegallery/image_feature_1454.html. Credit: NASA/JPL-Caltech.

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