



GSA TODAY

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**Increasing Undergraduate
Interest to Learn Geoscience
with GPS-based
Augmented Reality
Field Trips on
Students'
Own Smartphones**



A dramatic photograph of a volcanic eruption at night, with bright orange and red lava fountains and flows against a dark sky. The scene is illuminated by the intense heat of the lava, creating a stark contrast with the surrounding darkness.

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GSA Online: www.geosociety.org

GSA TODAY: www.geosociety.org/gsatoday

Printed in the USA using pure soy inks.



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Cover: A student playing "Grand Canyon Expedition: Geologic Time" orients herself before moving to the next field trip stop location. See related article, p. 4–10.



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Increasing Undergraduate Interest to Learn Geoscience with GPS-based Augmented Reality Field Trips on Students' Own Smartphones

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ABSTRACT

Field trips are a reliable method for attracting students into geoscience, yet for many high-enrollment college introductory courses, field trips are often impractical. Furthermore, introductory courses are often taught with a traditional lecture style that is poor at engaging students. This study examines the impact of augmented reality (AR) field trip exercises on the interest levels of students using readily accessible mobile devices (smartphones and tablets) as a means to provide simulated field trip experiences to a larger number of learners. The results of this study, involving 874 students from five different institutions, show that students who completed three geospatially oriented Grand Canyon field trip game modules were significantly more interested in learning the geosciences than control students and participants who completed only one module. More comprehensively, results from hierarchical linear modeling indicate three strong predictors of student interest in learning the geosciences: (1) the student's initial interest, (2) being a STEM major, and (3) the number of AR field trip modules students complete. Notably, the race and gender of participants are not factors. Augmented reality field trips for mobile devices have potential to be an accessible and financially viable means to bring field trips to a diversity of students who would otherwise experience none. Results indicate these AR field trips increase student motivation to pursue geoscience learning.

INTRODUCTION

There has been considerable investment in addressing low interest, poor preparedness, and the lack of student success in science, technology, engineering, and mathematics (STEM)—including the

geosciences (e.g., Seymour, 2001; Ashby, 2006; Fairweather, 2010). Recent reports claim that weak college STEM participation, especially among minorities, will negatively affect the U.S. economy (Ashby, 2006; National Research Council [NRC], 2011; Chang et al., 2014). Educators naturally desire to improve the participation and completion rates of all undergraduate students pursuing STEM degrees (Chang et al., 2014).

Most students enroll in introductory geoscience courses out of the need to fulfill their science requirement for graduation rather than being interested in learning geology (Gilbert et al., 2009; van der Hoeven Kraft et al., 2011; Gilbert et al., 2012). Moving from fulfilling graduation requirements toward promoting interest is important because research has shown that the best predictor of students taking additional classes in a subject is interest rather than performance (Harackiewicz et al., 2000; Hall et al., 2011; Gilbert et al., 2012). Unfortunately, many higher-education institutions teach high-enrollment (100+ students) introductory geoscience courses using online, broadcast, or lecture-based teacher-centered approaches that are relatively ineffective at stimulating interest in further learning (Andresen et al., 1996; Mazur, 2009; Deslauriers et al., 2011). Research has shown that one of the key factors in recruiting new geoscience majors is students having an engaging and positive experience in an introductory course (Levine et al., 2007; LaDue and Pacheco, 2013; Stokes et al., 2015). There is a clear need for learning experiences in introductory classes that increase the *interest* of students in order to inspire them to want to learn more about geoscience.

Field trips, when practical, are typically the most engaging and impactful

component of courses, because these hands-on experiences inspire students to become geoscience majors (Orion and Hofstein, 1994; Tal, 2001; McGreen and Sánchez, 2005; Fuller, 2006; Kastens et al., 2009; Mogk and Goodwin, 2012). The liability of travel and decreasing financial and administrative support at many colleges have made it so that it is becoming increasingly rare to have field trips. Furthermore, for high-enrollment lecture, online, or broadcast classes, the logistics of a field trip are just unfeasible. In contrast, smartphones and tablets are becoming ubiquitous and educational applications for them are numerous (Dahlstrom and Bichsel, 2014; Anderson, 2015). Considering students' high comfort level with smart devices and gaming, leveraging portable devices for education could have a positive impact on student interest and engagement (Bursztyn et al., 2015). Studies have shown that gaming features contribute to greater student self-confidence and self-efficacy through increased engagement in the activity (Mayo, 2009). The game-like features of the augmented reality (AR) field trips presented in this research, in combination with convenience, low cost, and broad accessibility, are anticipated to contribute to a greater learning experience. A companion series of field-trip game modules for smart devices, now publicly and freely available, was tested for impact on students' interests in introductory geoscience classes at a variety of post-secondary schools.

GRAND CANYON AR FIELD TRIP GAMES

Our field trip modules are based on relative GPS locations and conceptualized after the location-based GeePerS math games built by the IDIAS lab at Utah State

University, at a time before *Pokémon Go* was released to the public and became the most-downloaded app of all time (GSA Data Repository¹ expanded methodology; <http://idias.usu.edu/>; Shelton et al., 2012). For each AR field trip the entirety of Grand Canyon has been scaled down to a 100 m playing field. The absolute geographic location of the player does not matter; however, because GPS is integrated into the application, the module must be played outside (Fig. 1). The design takes advantage of the benefits of games that provide immersion-in-context, rewards for correctness, and immediate feedback in response to student interaction. Each module takes ~20 min to play, a length of time aimed to fit within a wide range of class types and capture the typical student's attention span (Middendorf and Kalish, 1996; Milner-Bolotin et al., 2007).

This study uses three fundamental geoscience topics that can easily be explored within Grand Canyon as the basis for the AR field trips: (1) geologic time, (2) geologic structures, and (3) hydrologic processes. For all three AR field trips the stops run downstream from Lees Ferry to Lake Mead with photographs, videos, questions, and interactive touchscreen activities (Table 1). As of 2016, these applications (called GCX Geologic Time, GCX Geologic Structures, and GCX Hydrologic Cycles) are available on both Android (Google Play) and iOS (App Store) platforms.

METHODS

Participants

Students at three educational institutions completed all three AR field trip modules to provide data for analysis ($n = 391$). Students at a fourth school completed two modules ($n = 138$), and students at a fifth school only completed one module ($n = 319$). Finally, additional students at two of the schools ($n = 291$) acted as control subjects, completing the pre- and post-tests and surveys for their regular labs without participating in the AR field trip modules. All of the classes utilized in this study were traditional lecture-based courses with accompanying labs. The data set overall represents diverse demographics and institutions (classed as teaching focus, teaching-research split, and research



Figure 1. Students play “Grand Canyon Expedition: Geologic Time” on the campus quad. Insets (left to right) are screen shots of the base map with visited locations (orange) and new location (green), and a screen shot of the Great Unconformity at Blacktail Canyon video, information, and question.

focus), reported in Data Repository Table S1 [see footnote 1].

Interest Index

All students, including intervention and control groups, completed a demographics survey, geoscience content questions (for the student learning component of this research, not reported in this paper), and the Geoscience Interest Survey. The evaluation instrument (the GeoIS) was used at the beginning of the semester and then after all interventions were complete. The GeoIS is a modified subset of the Motivated Strategies for Learning Questionnaire (MSLQ) using the task value component subscale and the situational interest subscale; see Data Repository Figure S1 [see footnote 1]. The MSLQ subset that comprises the GeoIS evaluates how interesting, useful, and important the course content is to the student, and should relate to student engagement by assessing changes in interest post-intervention (Pintrich et al., 1991; Harackiewicz et al., 2008). Motivation self-report subscales used to measure value beliefs (intrinsic goal orientation, extrinsic goal orientation, and task value beliefs) and self-report interest subscales (individual

interest: interest in the subject residing within the individual prior to taking the course; and situational interest: emerging spontaneously in response to exposure in the environment) have been validated by the educational psychology field, and have been adapted to suit the geosciences (Pintrich and DeGroot, 1990; Pintrich et al., 1993; McConnell et al., 2006, 2009; McConnell and van Der Hoeven Kraft, 2011; Harackiewicz et al., 2008; van der Hoeven Kraft et al., 2011; Gilbert et al., 2012). The MSLQ has robust reliability data with prior studies and has both predictive validity and construct validity in the form of a confirmatory factor analysis.

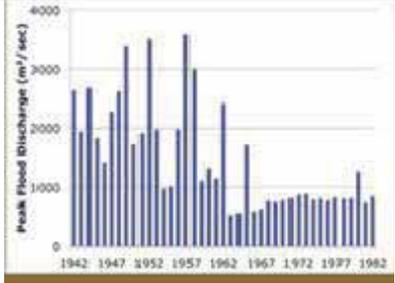
Two main research questions guided the analysis of data: (1) How do these AR field trips impact student interest in learning geoscience material? and (2) Which demographic and experiential factors combined with the AR field trips best predict student motivation and interest to learn geoscience material?

DATA ANALYSIS AND RESULTS

The data analysis used three steps: (1) determining reliability and validity of the data, and generating a correlation

¹ GSA Data Repository Item 2017056, expanded description of methodology, statistics, and geoscience interest survey, is online at <http://www.geosociety.org/datarepository/2017/>.

TABLE 1. Summary of Storyline, Concepts, and Example Tasks for AR Field Trip Modules

	GCX Geologic Time	GCX Geologic Structures	GCX Hydrologic Structures
Storyline	Grand Canyon raft trip with players eddy out at amazing places with features that help us decipher Earth's vast history. Some field trip stops involve short hikes up side canyons.	Players are rafting down the Colorado River through Grand Canyon with extensive hikes up and down side canyons, camping at amazing places that have been deformed by tectonic activity.	Raft trip through Grand Canyon with a USGS water monitoring crew, along the way taking measurements and conducting surveys of changes in water flow rates, pathways and usage.
Curriculum content	<p>Stratigraphic principles</p> <ul style="list-style-type: none"> -Original horizontality -Superposition -Lateral continuity -Cross cutting relations <p>Unconformities</p> <ul style="list-style-type: none"> -Disconformity -Nonconformity -Angular unconformity <p>Relative dating</p> <p>Numeric dating</p> <p>Human vs. geologic time</p>	<p>Tectonic forces</p> <ul style="list-style-type: none"> -Stress, strain, deformation <p>Folds</p> <ul style="list-style-type: none"> -Syncline -Monocline <p>Faults</p> <ul style="list-style-type: none"> -Normal -Reverse -Strike slip <p>Measuring structures</p> <ul style="list-style-type: none"> -Strike and dip -Geologic maps 	<p>Hydrologic cycle</p> <ul style="list-style-type: none"> -Discharge <p>Fluvial hydrology</p> <ul style="list-style-type: none"> -Channel types <p>Sediment transport</p> <ul style="list-style-type: none"> -Entrainment -Types of load -Transport capacity <p>Groundwater</p> <ul style="list-style-type: none"> -Springs <p>Human influence</p> <ul style="list-style-type: none"> -Dams
Example field trip stop	 <p>BLACKTAIL CANYON</p> <p>Rivermile 120.5. Let's eddy out here at Blacktail Canyon and see the most famous exposure of the "Great Unconformity" which separates the</p> <ul style="list-style-type: none"> A Disconformity B Nonconformity C Angular unconformity D Fault contact 	 <p>EMINENCE FAULT</p> <p>Rivermile 44.5, Day 3. Eminence Fault is clearly visible from Point Hanzbrough, and is evidence of the tectonic stress that this region has experienced.</p> <ul style="list-style-type: none"> A We can see cracks cutting across the rock layers. B The rock layers are folded. C There is visible offset of the rock layers. D The rock layers are tilted. 	 <p>VASEY'S PARADISE</p> <p>Rivermile 32, Day 5. Vasey's Paradise is an oasis in this desert with two cascading waterfalls emerging from the canyon walls and sustaining the lush vegetation below. These springs flow out of limestone beds within the Grand Canyon strata. The water feeding these springs comes</p> <ul style="list-style-type: none"> A An aquifer B Fall of water C An aquifer B A volcanic cone
Example iSpy activity	 <p>iSPY</p> <p>Identify and tap on the Great Unconformity in this scene.</p>	 <p>iSPY</p> <p>Swipe the direction of movement of the hanging wall in this image.</p>	 <p>iSPY</p> <p>Swipe to draw a line illustrating when the Glen Canyon Dam was completed.</p>

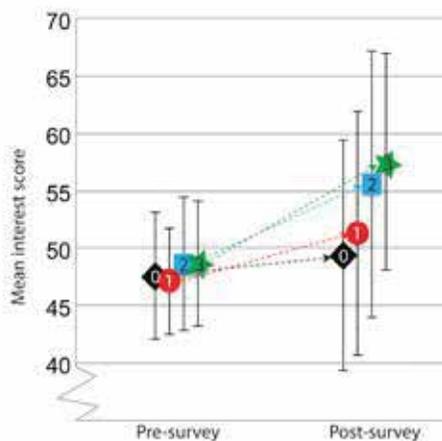


Figure 2. Results of pre- and post-intervention Geoscience Interest Survey scores for students having completed zero ($n = 104$), one ($n = 217$), two ($n = 55$), or three ($n = 218$) AR field trip modules (see Table 1).

matrix of the variables; (2) running an analysis of covariance (ANCOVA) to determine the degree of impact of the AR field trips on student interest; and (3) running a hierarchical linear model (HLM) to determine the predictors of student interest.

We assessed the inter-item reliability of the GeoIS by means of a Cronbach's alpha analysis. While test-re-test reliability between pre- and post-tests was a possibility, we felt that inter-item reliability was more insightful given that everyone was exposed, and change was anticipated. Positive values for alpha (up to a max of 1.00) indicate that there are greater differences of opinion between learners. The observed values of 0.91 for the pre-intervention and 0.93 for the post-intervention GeoIS instrument indicate a high level of reliability (Murphy and Davidshofer, 1988). Given the established nature and prior research conducted with the MSLQ, we chose to use a confirmatory factor analysis to assess instrument validity of the GeoIS. The fifteen GeoIS items coalesced onto a single factor based on 874 observations with loadings ranging from 0.17 to 0.83. Based on this combination of observations and loading values, the adapted MSLQ instrument appears to measure a single construct at a significant level (Stevens, 1999). The correlation matrix (Data Repository Table S2 [see footnote 1]) revealed four statistically significant variables: (1) the pre-intervention survey score; (2) institution; (3) STEM major; and (4) number of AR field trips completed. Despite a lack of statistical significance, race and gender were kept as

Table 2. Results of post-hoc analyses and ANCOVA

$F[3, 589] = 17.55, p < 0.01, \text{adj. } R^2 = 0.40$					
	n	pre-intervention		post-intervention	
		mean*	s.d.*	mean	s.d.
3 AR field trips (ARFTs)	218	48.8	5.3	58.1	9.3
2 ARFTs	55	48.6	4.7	55.0	11.0
1 ARFT	217	47.0	5.1	51.6	10.0
control	104	47.2	5.7	50.0	11.4
comparison of completed ARFTs	contrast	std. err.	t	$P > r $	
	1 vs 0	1.68	0.98	1.72	0.51
	2 vs 0	3.35	1.37	2.45	0.09
	3 vs 0	6.26	0.98	6.38	0.00
	2 vs 1	1.66	1.24	1.34	1.00
	3 vs 1	4.57	0.79	5.77	0.00
	3 vs 2	2.91	1.24	2.36	0.11

ARFTs—Artificial reality field trips.
*Mean and standard deviation (s.d.) on a scale from 0–70.

theoretically important variables for the nested regression analyses.

First-order examination of the pre- and post-intervention GeoIS scores shows a trend of increased student interest across all participants (Fig. 2). There is a distinctly greater increase in student interest among those participants who completed two and three AR field trips over those who completed only one or were in control groups (Fig. 2). In order to test for differences empirically, we used an Analysis of Covariance (ANCOVA). As recommended when students are not randomly assigned (Campbell and Stanley, 1963), we controlled for preexisting differences by using the pre-test as a covariate. The results of the ANCOVA (Table 2) indicate that the number of field trips completed does play a role in student interest: $F(3, 589) = 17.55, p < 0.01$. Pairwise comparisons in the same table suggest that students completing three AR field trips were significantly more interested in learning geoscience in the future than students completing one or zero AR field trips.

In an effort to determine what predicts students' interest in the geosciences, we ran a hierarchical linear model (HLM). Expanding on the basic idea of regression with a set of predictor variables and an outcome, HLM accounts for data that are nested (Raudenbush and Bryk, 2001). In this case, students came from different schools with different instructors and different regional geologic features that can play a role in curriculum decisions. The HLM adjusted for school differences by using two levels (site and student) with six predictors of geoscience interest: (1) GeoIS pre-intervention score; (2) number of AR field trips completed; (3) site classification; (4) gender; (5) race; and (6) STEM major. After a null model (Table 3) that ignored the predictors, subsequent models explored both student and site level variables. Goodness of fit (AIC and BIC) suggests that a parsimonious model with only significant predictors is a strong fit for these data. The results of the parsimonious model (Table 3) indicate that there are three strong predictor variables for student interest

Table 3. Results from HLM modeling

	Model 0 null model	Model 1 student level	Model 2 complete	Model 3 parsimonious
<i>Student Level</i>				
Constant	15.10	0.97	5.78E-19	4.64E-18
GeoIS score pre-intervention		1.07	1.08	1.08
Gender		0.79	0.78	
Race		0.29	-0.55	
STEM major		3.58	3.09	2.18
No. of ARFTs complete		2.00	1.47	1.72
Site classification		2.06	1.31	
Residual	101.94	65.98	65.09	65.47
<i>Site Level</i>				
GeoIS score pre-intervention			1.50	1.71
AIC	5390.09	4169.36	4158.09	4169.52
BIC	5403.83	4208.78	4201.89	4200.20

AIC—goodness of fit; ARFTs—augmented reality field trips; BIC—goodness of fit; GeoIS—geoscience interest survey; HLM—hierarchical linear modeling; STEM—Science, technology, engineering, and mathematics.



Figure 3. Campus quads and soccer fields filled with undergraduates during field-testing of augmented reality field trips with students exposing their digital devices to, and working through, conditions far more challenging than the normal lab room activity. Clockwise from top left: persistent heavy rain on a campus with topography, bright and sunny at 114° F on a soccer field, high winds and snow at 10° F on a campus quad, and dusk with bleacher obstacles during a night class on the soccer field.

toward learning the geosciences:

(1) GeoIS pre-intervention score at both the student and the site level; (2) being a STEM major; and (3) the number of AR field trip modules students are exposed to and complete (bolded in Table 3). The third predictor variable is of utmost importance to the study because this finding shows that interest gains associated with students completing all three AR field trips (Table 3: $3 \times 1.72 = 5.16$) are more than twice the gains associated with being a STEM major (Table 3: 2.18). Note that each of the values shown in bold in Table 3 represents a point value gain (out of 70) on the GeoIS post-intervention.

DISCUSSION

The AR field trip modules tested in this study incorporate within their design two fundamental field-trip features, primarily orienteering and physically moving between geo-referenced field trip locations. The nature of this design allows for the “get out of the classroom and contemplate geology with your peers” component of the field experience to be had by all, even if just on a campus quad or soccer field (Fig. 3). The focus of this research was to determine what impact on student

interest in learning geoscience material this AR field trip experience provides, because *interest* has been shown to be the best predictor of students pursuing additional classes in a subject area (Harackiewicz et al., 2000; Hall et al., 2011; Gilbert et al., 2012).

Exposure to and completion of all three mobile AR field trips had a significant impact on student interest to learn the geosciences. Specifically, HLM results indicate that completion of one single module increases student interest almost as much as does being a STEM major. Completion of two or three AR field trips further builds this interest.

The following factors were not at all significant: race, gender, and site classification. These results indicate that the AR field trips were effective despite variation in student demographics, which is similar to Gilbert et al. (2012), who found no variation in student motivation across gender or ethnicity in introductory geology classes. Note that the study conducted by Gilbert et al. (2012) was based on a single MSLQ survey of students at multiple institutions to ascertain *who* is enrolled in introductory geology courses and *why* they are enrolled in those classes; the authors

did not measure a change in student motivation or interest after an intervention.

Furthermore, the improvement in student interest irrespective of site classification group suggests that the modules are impactful regardless of teacher, type of institution, class size, or geographic location. These findings are in contrast with Chang et al. (2014), who found students had increased persistence (less attrition) at research universities and increased motivation at liberal arts colleges over public universities and community colleges. Chang et al. (2014) used large scale survey data to track student persistence in a STEM field from their freshman year to four years into their undergraduate education; thus, these authors also did not assess a change after an intervention.

Are these AR Grand Canyon field trips useful in comparison to real on-location field trips? The gains in student interest are expected (and desired), in part because of the game-like design of the field trip modules and in part because of the interactive out-of-the-classroom experience, emulating a real field trip. Geoscience educators have long known that field trips are major attractors of students to the science, and with ubiquitous smartphones, mobile technology, games, and apps for everything, it is not surprising to find that this medium appeals to the current generation of undergraduates. The AR field trips are flexible enough to be used during a lecture period, a lab period, as homework, or as supplementary activities for online learning. One could oversimplify the hypothesis and purpose of this research by saying that since field trips are fun and games are fun, of course gamified-augmented-reality-field trips are fun! Consequently, if the students are having fun while learning the course material, there is an expectation that their level of interest and motivation to pursue study in the field will increase. In the face of economic, geographic, and/or accessibility issues that some institutions face that are prohibitive of field trips, the AR field trips are an affordable and easily implemented solution.

CONCLUSIONS

Gilbert et al. (2012) state that many post-secondary geoscience educators rank student motivation as the most important indicator for student learning. This study presents a solution not only for increasing student interest and engagement in the

subject, but also the potential for increasing student learning. The AR Grand Canyon field trips for mobile smart devices are an accessible, inexpensive resource that can bring field trips to campus in lieu of students experiencing none at all. Furthermore, the findings described here are encouraging for this AR and other virtual field trip genre of pedagogy. Addressing if and how students may learn better using AR field trips is a critical question, with promising initial results (Bursztyn et al., 2016). The psychomotor aspect of AR field trips holds theoretical underpinnings that certainly require additional attention from researchers in how students remember and recall information. Teachers are experiencing the dawn of educational tools for mobile devices in the form of apps for all ages, including these Grand Canyon Expedition modules. Now that the efficacy of these AR field trips in motivating students to learn is established, the important question remaining is if they are effective at actually increasing student learning.

ACKNOWLEDGMENTS

We thank our collaborating geoscience faculty focus group: Dr. Michelle Fleck, Richard Goode, Dr. Eric Hiatt, and Dr. Laura Triplett. We also thank all faculty and their students at our participating test institutions who provided data for this research. We are most appreciative of the NSF TUES award #DUE-1245948 that made this research possible and allowed us to hire Sovrn Creative of Boise, Idaho, USA, to do professional programming of the apps.

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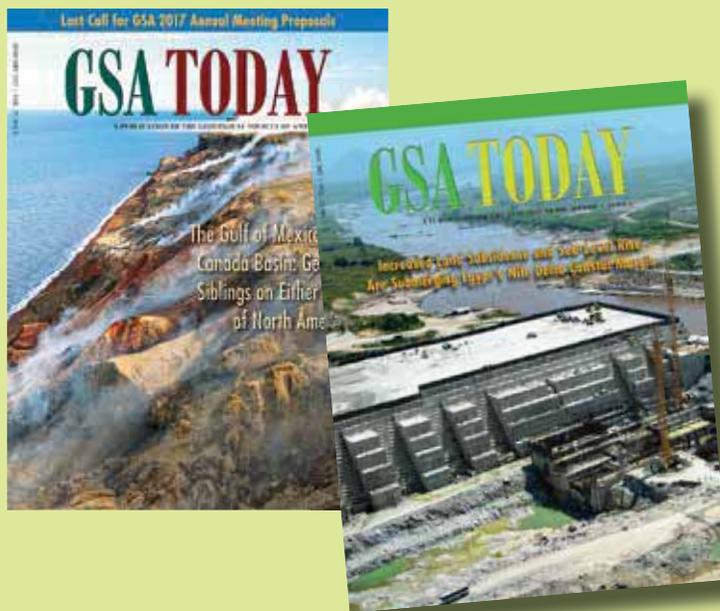
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MANUSCRIPT RECEIVED 1 JUNE 2016
 REVISED MANUSCRIPT RECEIVED 16 SEPT. 2016
 MANUSCRIPT ACCEPTED 17 NOV. 2016

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- **Rock Stars:** Into science bios? Each Rock Stars article, managed by GSA's History and Philosophy of Geology Division (<http://www.geosociety.org/RockStarGuide>), provides a two-page profile of a notable geoscientist whose contributions have impacted geoscience in a significant way (see p. 32).



www.geosociety.org/gsatoday

Erratum In the May 2017 issue of *GSA Today*, the National Association of Black Geoscientists was listed as the National Association of Black Geologists and Geophysicists in the Groundwork article, “Diverse Students Can be Attracted to Geoscience” (v. 27, no. 5, p. 76–77). *GSA Today* regrets this error.



22-25 October
Seattle, Washington, USA

Action Dates

Now open	Meeting room request system (non-technical, social, and business meeting room requests)
Now open	Abstracts submission
Now open	Housing opens (Orchid Events is the official housing bureau)
Early June	Registration and travel grant applications open
6 June	Meeting room request deadline—Fees increase after this date
1 Aug.	Abstracts deadline
Early Aug.	Student volunteer program opens (new timing this year)
18 Sept.	Early registration deadline
18 Sept.	GSA Sections travel grants deadline
25 Sept.	Registration and student volunteer cancellation deadline
27 Sept.	Housing deadline for discounted hotel rates

Message from the Meeting Co-General Chairs



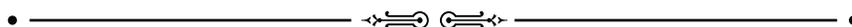
Don't Miss the GSA Annual Meeting in Seattle!

Our rapidly developing city is in the news a lot as the home of Amazon, Microsoft, Starbucks, and, yes, the true future home of the Big One. But if you look beyond our culture built on coffee, aircraft, and technology, you'll agree it is set in a geological wonderland. Seattle itself is built on glacial/marine deposits left by a lobe of the Cordilleran Ice Sheet, which buried the site of the city under more than a kilometer of ice until just 16,500 years ago. Look only 100 km southeast of the Space Needle at the heavily glaciated, active stratovolcano of Mount Rainier rising to 4,392 m above sea level. Look west across Puget Sound, a great inland arm of the Pacific Ocean, at the Olympic Mountains, an accretionary wedge formed by the ongoing subduction of the Juan de Fuca oceanic plate beneath the continent on the notorious Cascadia megathrust.

Field trips for the meeting will radiate outward from the downtown convention center to visit bedrock terranes in the North Cascades, the course of the Missoula Floods, and tsunami deposits from Cascadia earthquakes. Field trips will also inspect the puzzling Mima mounds south of Seattle and tour the wine districts of south-central Washington. A special opportunity will be a trip into one of the tunnels being dug under the city to add new light-rail routes or to replace the aging Alaskan Way Viaduct along the waterfront.

Tired of geology? Take advantage of the Seattle Art Museum, local music, microbrews, eclectic restaurants, and, just maybe, the 2017 World Series featuring the Seattle Mariners. And, where else but at world-famous Pike Place Market on the waterfront can one learn to pitch and catch freshly caught salmon like a pro?

Alan Gillespie and Darrel Cowan
Co-General Chairs



Thanks to the GSA 2017 Organizing Committee

Co-General Chairs: **Alan Gillespie**, University of Washington; **Darrel Cowan**, University of Washington

Field Trip Co-Chairs: **Ralph Haugerud**, U.S. Geological Survey; **Harvey Kelsey**, Humboldt State University

Technical Program Chair: **Dick Berg**, Illinois State Geological Survey

Technical Program Vice-Chair: **Kevin Mickus**, Missouri State University

Sponsorship Chair: **Brian Butler**, Landau Associates Inc.

K-12 Chair: **Michael O'Neal**, University of Delaware

Host University: University of Washington



Student Committee Chair: **Linnea McCann**, University of Washington

Student Committee Members: **Madeleine Hummer**, University of Washington; **Michael Zackery McIntire**, University of Washington; **Virginia Littell**, University of Washington; **Keith Hodson**, University of Washington

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. (a great time to meet with poster presenters)
- 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. (a great time to meet with poster presenters)

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. (a great time to meet with poster presenters)

Post-meeting

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

Registration

- ▶ **Early registration deadline:** 18 September
- ▶ **Cancellation deadline:** 25 September

REGISTRATION FEES

	GSA Member & Associated Society Pricing		Non-Member Pricing	
	Early	Standard/ Onsite	Early	Standard/ Onsite
Professional — Full Meeting	\$410	\$495	\$595	\$680
Professional — 1 Day	\$250	\$290	\$355	\$430
Professional — >70 Full Meeting	\$290	\$375	These categories are only available for Member pricing. Please register as a Professional Non-Member or join GSA.	
Professional — >70 1 Day	\$190	\$215		
Early Career Professional — Full Mtg	\$260	\$330		
Early Career Professional — 1 Day	\$160	\$195		
Student — Full Meeting	\$130	\$165	\$185	\$220
Student — 1 Day	\$85	\$99	\$120	\$140
High School Student	\$50	\$50	\$50	\$50
K-12 Teacher — Full Meeting	\$60	\$70	\$60	\$70
Field Trip or Short Course Only	\$40	\$40	\$40	\$40
Guest or Spouse	\$90	\$99	\$90	\$99

*Participants from countries classified as “Low or Lower Middle Income Economies” by the World Bank need only pay 50% of the category fee for full meeting or one day registration. Online registration is not available for “Low or Lower Middle Income Economy” registrants. Please fill out a printable version of the registration form and mail it to GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

STUDENT VOLUNTEERS

NEW timing this year: The Student Volunteer Program sign-up will open in early August. Please wait to register for the meeting until you sign up as a volunteer, unless you want to reserve a space on a Field Trip or Short Course.

TRAVEL GRANTS

Need assistance getting to the Annual Meeting? GSA Sections, Divisions, and Associated Societies are ready to help! Various groups are offering grants to help defray your costs for registration, field trips, travel, etc. Note: Eligibility criteria and deadline dates may vary by grant.

For meeting attendees who reside outside of North America, check the International Travel Grant page at community.geosociety.org/gsa2017/funding. The deadline to apply is **7 July**.

INTERESTED IN HELPING STUDENTS PARTICIPATE IN THE MEETING?

Every year, a large percentage of students apply for travel grants for the meeting but do not receive an award due to a limited number of funds. You can help reduce this number by donating as

little as US\$10 to the Student Travel Fund when you register. 100% of funds collected go to students.

ADDITIONAL ASSISTANCE

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 box when you register online and describe your need in the space provided.

EVENTS REQUIRING TICKETS/ADVANCE REGISTRATION

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



GSA Meetings **RISE** to the top.

We support **Respectful Inclusive Scientific Events** and are committed to ensuring a safe and welcoming environment for all participants.

We expect all meeting participants to abide by the GSA Events Code of Conduct Policy in all venues at our meetings, including ancillary events, field trips and official and unofficial social gatherings.

*The complete GSA Events Code of Conduct can be found on the GSA Website.

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. The airport is the main hub for Alaska Airlines and its regional subsidiary Horizon Air. It is also a hub for Delta Airlines, serving as a gateway to Europe and Asia. Multiple transportation options connect SeaTac to the metro area: rail, Prince Island Sound transit, metro bus, and taxi.

www.seattle-airport.com

Amtrak has three lines that serve Seattle. The Cascades Line travels between Vancouver (Canada)–Seattle–Tacoma–Portland–Salem–Eugene. The Empire Builder travels between Chicago–Milwaukee–Minneapolis–Portland–Seattle. The Coast Starlight travels between Seattle–Portland–Los Angeles.

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.

<http://www.soundtransit.org/Schedules/Link-light-rail>

King County Metro Transit provides bus service in downtown Seattle and outlying neighborhoods. Timetables 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. In downtown Seattle, Uber, Lyft, Sidecar, and metered taxis offer in-city transportation from local drivers. All rides can be scheduled using smartphone apps. 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/



The Pacific Northwest. Photo taken 28 Feb. 2015 courtesy NASA, <https://earthobservatory.nasa.gov/IOTD/view.php?id=86041>.

Hotels



22-25 October
Seattle, Washington, USA

► **Reservation deadline:** 27 September

GSA has negotiated special hotel rates for GSA 2017 Seattle attendees. We appreciate your support by staying in the official GSA hotels; your patronage enables GSA to secure the meeting space at a greatly reduced cost, which in turn helps lower the cost of the meeting and your registration fees.

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

Booking through OE means you will receive:

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

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

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

Critical Dates

18 Sept.: The last day to cancel rooms without a penalty;

27 Sept.: Reservations must be received by this date in order to guarantee rooms at special meeting rates;

13 Oct.: All changes, cancellations, and name substitutions must be finalized through OE; and

After 13 Oct.: You must contact the hotel directly with any changes or for new reservations.

Reservation Options

Online: <https://aws.passkey.com/go/GSA17ANNUAL> For a new reservation, modifying an existing reservation, or cancelling;
Phone: Agents available Mon.–Fri., 7 a.m.–6 p.m. MST: +1-855-657-0547 (U.S. toll-free), +1-801-433-0661 (international); and
Print: Download the form and fax (+1-801-355-0250; do not mail after faxing) or mail the completed form to Orchid Events, 175 S. West Temple, Suite 30, Salt Lake City, UT 84101, USA.

Special Requests

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

Acknowledgments

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



ALERT: Orchid Events (OE) is the official GSA housing bureau. To receive the GSA group rate at each hotel, reservations must be made through OE and not directly with the hotels. GSA and OE will NOT contact attendees directly to solicit new reservations. If you are contacted by a vendor who claims to represent GSA, please notify the GSA Meetings Department at meetings@geosociety.org or +1-303-357-1041. Please do not make hotel arrangements or share any personal information through any means other than a trusted, reliable source.

Deposits, Cancellations, and Changes

All reservation requests must be accompanied by a credit card guarantee or check equaling the amount of one night's room and tax for each room reserved. Reservations cancelled after 18 Sept. OR prior to 72 hours of your scheduled arrival will be subject to a US\$25 fee for each room cancelled. You will be charged one night's room and tax if you cancel within 72 hours of your arrival date. Through 13 Oct., please send requests for changes and cancellations via email to OE (help@orchideventsolutions.com) or in writing by fax to +1-801-355-0250. After 13 October, contact hotels directly to make changes and cancellations.

Upgrade/Suite Raffle

To thank you for booking your hotel reservation through OE, you will be entered into a raffle to win a room upgrade for your entire hotel stay. This is valid for reservations booked with a three-night stay or longer. Your reservation must be made by **24 July** in order to qualify for the raffle. The winners will be notified via email within 7–10 days.

Room Sharing

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

Hotels

Below is the list of hotels and group rates for our block. Rates are in U.S. dollars and do not include the current applicable tax of 15.60% plus a US\$2 fee per room, per night. Complimentary basic Internet will be provided in all guest rooms booked through GSA/Orchid Events. Please check the GSA website, community.geosociety.org/gsa2017/hotels, for details.

Hotel	Rate (Single/Double)	Each Additional Adult	Distance to WSCC	Parking Daily/24 hr**
Sheraton Seattle Hotel (HQ)	\$219	\$25	0.5 blocks	\$57 Valet
Crowne Plaza Seattle Downtown	\$169	\$25	3.5 blocks	\$50 Valet
Hilton Garden Inn Seattle Downtown	\$174	\$10	5.0 blocks	\$43 Valet
Homewood Suites Seattle Convention Center–Pike Street*	\$179	\$25	2.0 blocks	\$45 Valet
Paramount Hotel Seattle	\$185	\$25	1.0 block	\$39 Valet
Renaissance Seattle Hotel	\$182	\$25	5.5 blocks	\$43 Self/\$55 Valet
Roosevelt Hotel Seattle	\$185	\$25	1.0 block	\$45 Valet
Seattle Hilton	\$189	\$25	2.5 blocks	\$45 Self
Springhill Suites by Marriott Seattle Downtown/South Lake Union*	\$184	\$10	6.0 blocks	\$26 Valet
Westin Seattle	\$185	\$30	4.5 blocks	\$45 Self/\$57 Valet

*Breakfast included in rate

**Parking rates subject to change; additional fees for oversized vehicles



Childcare by KiddieCorp



Location: Washington State Convention Center (WSCC)

Hours: Sat.–Wed., 7 a.m.–6 p.m. daily

Ages: Six months to 12 years

Cost: US\$9 per hour per child with a 1-hour minimum per child. At least one parent must be registered for the meeting.

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

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

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

Cancellations: For a full refund, cancellations must be made to KiddieCorp prior to 18 Sept. Cancellations made after 18 Sept. will incur a 50% fee. No refunds after 4 Oct.

GSA Meetings: meetings@geosociety.org

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

Contact: KiddieCorp

+1-858-455-1718

info@kiddiecorp.com



Local Tours

The following local tours are **open to all registered GSA Annual Meeting attendees and guests**. For short visits and historical tours, it is valuable to have an experienced and knowledgeable 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



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

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.



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

Guest Program

Penrose Guest Hospitality Suite

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.

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Seattle Neighborhood Spotlight: Fremont

► Eat

Enjoy a culinary walkabout in Fremont, where lively venues showcase the flavors of France at **Pomerol**, Korea at **Revel**, and Sicily at **Agrodolce**, one of the organic outposts of James Beard Award–winning chef Maria Hines. For less formal eats, savor the Russian dumplings at **Pel Meni Dumpling Tzar** or the raved-about fish and chips at dive bar **Pacific Inn Pub**. Bright and airy **Eve** serves up a bison burger (with aged cheddar, sweet onion jam, and pickled apple), while **Ha!** delivers neighborly laughs alongside comfort food. Nearby, **RockCreek** is a delicious weekend brunch destination for seafood-centric dishes like bacon and oyster benedicts.

► Shop

On 34th Street, vendors set up shop year-round at the colorful **Fremont Sunday Market**; discover goodies, from fresh flowers and whimsical tees to eclectic “well-worn” finds in the (covered)

flea market section. Find locally designed women’s clothing and accessories at **Show Pony** and thoughtful gifts at **Portage Bay Goods**. In Upper Fremont, stock up on cookbooks at **Book Larder** and vinyl LPs at just-opened **Daybreak Records**, which reminds one of a simpler, sweet-sounding era.

► Play

Active folks can cruise through Fremont on the bustling **Burke-Gilman Trail**, hopping off to hydrate at dog- and kid-friendly **Fremont Brewing** or **MiiR**, a hip bike-store-meets-coffee-shop-meets-beer mecca. In Upper Fremont, intimate performance venue **Fremont Abbey** exposes talents ranging from singer-songwriters to captivating narrators, who awe the crowd during monthly “story slams.” Dog lovers take their four-legged friends to **Norm’s**, while beer lovers peruse the lengthy list at **Brouwer’s Cafe**. For international “football” games on the telly, try storied British watering hole **George & Dragon Pub**.



MiiR. Photo by Amelia Skinner.



Burke-Gilman Trail. Photo by Amelia Skinner.

Copy credit: Visit Seattle: www.visitseattle.org/neighborhoods/fremont/.



Event Space & Event Listing Requests

There is still time to reserve a room for your business meetings, luncheons, award ceremonies, parties, alumni receptions, and more. Please complete and submit the event space request form via the link at community.geosociety.org/gsa2017/spacerequest along with your payment (if applicable). Your request will also allow GSA to include your event listing on the personal scheduler and mobile app. Please let us know about your event—even if it’s being held at a restaurant or other venue in the city.

Join GSA's Family of Sponsors

Be recognized as a supporter of the meeting and of the geoscience community.

GSA sponsors play a vital role in supporting the success of the annual meeting while gaining productive opportunities to represent their companies, products, and services to our members. Nearly 26,000 members, not just meeting attendees, will see your company's support, fostering the growth of current and future leaders in the geosciences.



Benefits include

- Visibility before, during, and after the meeting—online, on site, and in print—to a relevant audience
- Awareness of your company as a partner supporting GSA programs and doing business in our members' communities
- Contact with thousands of the best and brightest geoscience students soon to be entering the workforce
- A convenient place at the meeting to visit with students from numerous schools outside your company's usual recruiting areas

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or contact

Debbie Marcinkowski at +1-303-357-1047,
dmarcinkowski@geosociety.org,
for help in selecting the best fit for your company.

Submitting An Abstract

Discipline Sessions

Discipline sessions are created by pooling together abstracts submitted to a particular discipline category. These sessions are formed in order to establish a very stimulating session. Start your abstract submission by going to community.geosociety.org/gsa2017/discipline.

Topical Sessions

Topical sessions are topically focused for a motivating exchange of science. If you are interested in submitting a session to a particular topical session, you can review the list at community.geosociety.org/gsa2017/topical.

Pardee Keynote Symposia

Pardee Keynote Symposia represent leading-edge, interdisciplinary science and address broad, fundamental geoscience issues and/or areas of public policy. Speakers in these sessions are of high standing in their fields. Learn more at community.geosociety.org/gsa2017/pardee.

► Key Things To Know

Submitting an Abstract

- Submission deadline: Tuesday, 1 August.
- To begin your submission, go to community.geosociety.org/gsa2017/abstracts.
- A non-refundable abstracts submission fee of US\$50 for professionals and US\$25 for students will be charged.
- Abstracts are editable until the 1 August submission deadline.
- When submitting an abstract to a discipline session, a list of possible topical sessions may pop-up during the submission process. This list is provided as an option for you, in case you feel your abstract might fit well into one of those sessions.
- **Please be patient!** When submitting an abstract, the first page is slow-loading. We thank you for your patience.
- The Two-Abstract Rule: (1) You may submit two volunteered abstracts, as long as one is for a poster presentation; (2) each submitted abstract must be different in content; and (3) if you are invited to submit an abstract to a Pardee Keynote Symposium or topical session, the invited abstracts do not count against the two-abstract rule.

Abstract Content and Presentation

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

Authors

- Please adhere to the Code of Ethics describing content, authorship, and scholarship (p. 23).
- PRESENTERS: Presenting authors can deliver two (2) abstracts during the meeting, which can consist of one volunteered oral presentation and one volunteered poster presentation, or two poster presentations. The only exemption to this policy occurs when the presenter is also invited to give a presentation in either a Pardee Keynote Symposium or a Topical Session, because invited abstracts are not counted. Invited presenters will receive a PIN to exempt that abstract. If the session to which a presenting author is invited is cancelled, that abstract will lose its exempted status.
- CO-AUTHORS: You may be listed on additional abstracts as a non-presenting co-author. There is no limit to the number of abstracts one can co-author.
- All presenting authors, including invited speakers, are responsible for paying their abstract submission fees. All authors must pay their registration fees, plus any other expenses they might incur associated with the GSA meeting.
- Acceptance notifications are delivered three to four weeks after the abstract deadline to allow sufficient time to make travel arrangements.
- Enhance your professional reputation by submitting a refined abstract. Then, deliver an admirable presentation.





GSA Code of Ethics for Abstracts Publication and Meeting Presentation

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

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

Poster Presenters

- Hours for poster presentations: Posters should be on display from 9 a.m. to 5:30 p.m. on Sunday, with authors present 3:30–5:30 p.m. On Monday through Wednesday, posters should be on display from 9 a.m. to 6:30 p.m., with authors present from 4:30–6:30 p.m.
- You will be provided with one horizontal, freestanding 8-ft-wide × 4-ft-high display board, and Velcro for hanging your display is provided at no charge.
- Each poster booth will share a 6-ft-long × 30-inch-wide table.
- Electricity is not available, so please plan your presentation accordingly.
- Wi-Fi will be available in the poster hall area.
- Want to present your poster digitally? As a poster presenter, you will be given the opportunity to present your poster in a digital format. Information on this will be provided in the acceptance notices. Presenters are responsible for all fees associated with this type of presentation.

Oral Presenters

- All oral presentations should be prepared using a 16:9 screen ratio.
- The normal length of an oral presentation is 12 minutes plus three minutes for questions and answers.
- You must visit the Speaker Ready Room at least 24 hours before your scheduled presentation.
- All technical session rooms will be equipped with a PC using MS Office 2013.

► **Learn what makes a story newsworthy** at community.geosociety.org/gsa2017/requestpr. You can even request that a press release be written about your presentation via a link on that page.

ASSOCIATION OF EARTH SCIENCE EDITORS





22-25 October
Seattle, Washington, USA

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GEOCAREERS

Opportunities for students and early career professionals...

Just getting started? Get a well-rounded introduction to industry and government careers by attending this special program.

GEOCAREERS DAY

Sunday, 22 Oct., 8 a.m.–1 p.m. All-inclusive fee: \$25; registration is 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 Booths: This is your opportunity to ask questions and talk one-on-one with corporate and government representatives, learn about their unique work cultures, and types of careers available.
- **10:30 a.m.–noon:** Career Mentor Roundtables: Mentors from a variety of sectors will answer your career questions at table stations throughout the afternoon.

- **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 ticket provided.

The following GeoCareers Day events may be attended separately:

- **Career Pathways Panel:** Lunch is included but limited to first come, first served. All-day participants receive priority.
- **Career Workshop:** US\$10 fee if attending separately. Registration required. Sign-up online or contact GSA Sales & Service, +1-800-443-4472.

NETWORKING AND PANEL EVENTS

Women in Geology Career Pathways Reception

Sunday, 22 Oct., 5:30–7 p.m.

This informal gathering begins with remarks from a few key women speakers who will address issues faced by women in geology. A roundtable mentoring session follows, providing time for networking, sharing ideas, and getting to know other women geoscientists.

Early Career Professionals Coffee

Monday, 23 Oct., 9:30 a.m.–10:30 a.m.

This informal gathering will have remarks from representatives of several non-profits that 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

Monday, 23 Oct., 11:30 a.m.–1 p.m.

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

Monday, 23 Oct., 12 p.m.–1 p.m.

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

Hydrogeology Division Careers and Networking Event

Tuesday, 24 Oct., 2:30–4:30 p.m.

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 follows, providing time for individuals to network, share ideas, ask questions, and discuss careers in hydrogeology.

MORE WORKSHOPS

Publishing: “What’s Your Problem; What’s Your Point?”

Sunday, 22 Oct., 11:30 a.m.–2 p.m., lunch provided

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 community.geosociety.org/GSA2017/workshops.

Career Short Courses

Saturday, 21 Oct. (see page 28 for descriptions)

- Preparing for a Career in the Geosciences
- Review and Preparation for the National Association of State Boards of Geology (ASBOG) Fundamentals of Geology Examination

EMPLOYMENT ASSISTANCE

Résumé Clinic

Sunday, 22 Oct., 9 a.m.–5 p.m. Fee: US\$10 (cash only).

Stop by the Résumé Clinic for a private consultation with a geoscience professional to review your résumé (please bring a current copy) and discuss strategies to better market yourself to potential employers. Space is limited; first come, first served.

Geoscience Job Board

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

Continuing Education Credits

The annual meeting offers an excellent opportunity to earn CEUs toward your general continuing education requirements for your employer or K–12 school. Credits are available for technical sessions, short courses, and field trips. Ten contact hours are required for one CEU. For example, one day (eight hours) of technical sessions offers 0.8 CEUs. After the meeting, there will be a link posted on the annual meeting website by which you can print out your CEU certificate.



Mentors Needed

GSA is looking for mentors at the annual meeting to help students understand the breadth of careers available to students and provide advice as they navigate their next steps, academically and professionally. Mentoring opportunities range from one-on-one pairings to 30-minute consultations.



22-25 October
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Learn more at
<https://goo.gl/LrpOCP>.

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. 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.

405. Mesozoic Terranes of the Central Cascades: Geology of the Hicks Butte Complex, Easton Metamorphic Suite, Peshastin Formation, and Ingalls Serpentine.

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.

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.

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



Economic Geology



Engineering



Hydrogeology and
Environmental Geology

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. 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. Leaders: Jon J. Major, Volcano Science Center; Charles M. Crisafulli.

414. Accessible Field Geology of Western Washington.

Sat., 21 Oct. By invitation only. Cosponsors: *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. 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. 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.

SCIENCE & CAREERS



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Contact: Becky Sundeen, bsunde@geosociety.org | www.geosociety.org




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Short Courses

Learn and explore a new topic.

- ▶ **Early registration deadline:** 18 September
- ▶ **Registration after 18 September** will cost an additional US\$30.
- ▶ **Cancellation deadline:** 25 September

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 non-registrant 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.

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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.**

Fri., 20 Oct., 9 a.m.–4 p.m. US\$128. Limit: 40. CEU: 0.6.
Instructors: Tom Martlev Pallesen, I•GIS; Lucia Maria Petersen, I•GIS. **Cosponsor:** I•GIS.

 **502. High-Resolution Topography and 3D Imaging II: Introduction to Terrestrial Laser Scanning.**

Fri., 20 Oct., 8 a.m.–5 p.m. US\$52. Limit: 24. CEU: 0.8.
Instructors: Marianne Okal, UNAVCO; Christopher Crosby, UNAVCO. **Cosponsor:** UNAVCO.

 **503. Modeling Magmatic Processes Using MELTS.**

Fri., 20 Oct., 8 a.m.–5 p.m. US\$185. Limit: 40. CEU: 0.8.
Instructors: Mark Ghiorso, OFM Research; Paula Antoshechkina, California Institute of Technology.

 **504. Sequence Stratigraphy for Graduate Students.**

Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m. US\$25. Limit: 55. CEUs: 1.6.
Instructors: Morgan Sullivan, Chevron; Bret Dixon, Anadarko; Tonya Brami, ExxonMobil. **Cosponsors:** ExxonMobil; Chevron; Anadarko.

 **505. Structural and Stratigraphic Concepts Applied to Basin Exploration.**

Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m. US\$25.
Limit: 30. CEUs: 1.6. **Instructors:** Bob Stewart, ExxonMobil Exploration Co.; Tonya Brami, ExxonMobil Exploration Co.
Cosponsors: ExxonMobil Exploration Co.; GSA Sedimentary Geology Division.

 **506. The Magma Chamber Simulator, a Phase Equilibria Modeling Tool for Magma Recharge, Crustal Assimilation, and Crystallization (RAFC).**

Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m. US\$120. Limit: 30. CEUs: 1.6.
Instructors: Wendy Bohrson, Central Washington Univ.; Frank Spera, Univ. of California Santa Barbara; Jussi Heinonen, Univ. of Helsinki; Guy Brown, Rocking Hoarse Professional Services.
Cosponsor: GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division.

 **507. Field Safety Leadership.**

Fri.–Sat., 20–21 Oct., 8 a.m.–5 p.m. US\$25.
Limit: 30. CEUs: 1.6. **Instructors:** Kevin Bohacs, ExxonMobil Upstream Research Company; Greer Barriault, ExxonMobil Upstream Research Company. **Cosponsor:** ExxonMobil Upstream Research Company.

 **508. Petrochronology 2017.**

Fri., 20 Oct., 8 a.m.–5 p.m., and Sat., 21 Sept., 8 a.m.–noon.
Professionals: US\$135; students: US\$25. Limit: 53. CEUs: 1.2.
Instructors: Matthew Kohn, Boise State Univ.; Martin Engi, Univ. of Bern; Pierre Lanari, Univ. of Bern. **Cosponsors:** Cameca; ESI; Geochemical Society; National Science Foundation.

 **509. Landlab Earth Surface Modeling Toolkit: Building and Applying Models of Coupled Earth Surface Processes.**

Sat., 21 Oct., 8 a.m.–5 p.m. US\$130. Limit: 40. CEUs: 0.8.
Instructors: Erkan Istanbuloglu, Univ. of Washington; Christina Bandaragoda, Univ. of Washington; Sai Nudurupati, Univ. of Washington; Amanda Manaster Univ. of Washington.
Cosponsor: National Science Foundation.

 **510. Collecting Structural Geology Data Using the StraboSpot Data System.**

Sat., 21 Oct., 8:30 a.m.–5 p.m. US\$30. Limit: 40. CEUs: 0.75.
Instructor: Doug Walker, Univ. of Kansas. **Cosponsors:** GSA Geoinformatics Division; GSA Structural Geology and Tectonics Division.

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


Economic Geology


Energy


Engineering


Hydrogeology and
Environmental Geology

\$ **🔌** **💧** 511. **Ground-Penetrating Radar: Principles, Practice, and Processing.**

Sat., 21 Oct., 8 a.m.–5 p.m. US\$80. Limit: 25. CEUs: 0.8.
Instructor: Greg Johnston, Sensors & Software Inc. **Cosponsor:** *Sensors & Software Inc.*

512. **Helping Students Thrive in Geoscience at Two-Year Colleges: Selected Strategies.**

Sat., 21 Oct., 8:30 a.m.–4:30 p.m. US\$40. Limit: 40. CEUs: 0.7.
Instructors: Norlene Emerson, Univ. of Wisconsin–Richland; Eric Baer, Highline College. **Cosponsors:** *National Association of Geoscience Teachers (NAGT); Geo2YC Division of NAGT; GSA Education Division.*

\$ **🔌** **🔌** **💧** 513. **High-Resolution Topography and 3D Imaging II: Introduction to Structure from Motion (SfM) Photogrammetry.**

Sat., 21 Oct., 8 a.m.–5 p.m. US\$52. Limit: 40. CEUs: 0.8.
Instructors: Edwin Nissen, Colorado School of Mines; Ramon Arrowsmith, Arizona State Univ.; Christopher Crosby, UNAVCO. **Cosponsor:** *UNAVCO; OpenTopography.*

\$ **🔌** **🔌** **💧** 514. **High Resolution and Correlative Microscopy and Spectroscopy for the Geosciences.**

Sat., 21 Oct., 8 a.m.–5 p.m. US\$100. Limit: 40. CEUs: 0.8.
Instructors: K. Leo Pullin, Consultant; Matthew Andrew, Carl Zeiss X-Ray Microscopy; Sreenivas Bhattiprolu, Carl Zeiss X-Ray Microscopy. **Cosponsor:** *Zeiss Raw Materials.*

\$ **🔌** **🔌** **💧** 515. **Review and Preparation for the ASBOG Fundamentals of Geology Examination.**

Sat., 21 Oct., 8:30 a.m.–4:30 p.m. US\$144. Limit: 40. CEUs: 0.7.
Instructor: Aaron Johnson, American Institute of Professional Geologists. **Cosponsor:** *American Institute of Professional Geologists.*

🔌 **🔌** 516. **Subaqueous Paleoseismology Methods.**

Sat., 21 Oct., 8 a.m.–5 p.m. US\$25. Limit: 40. CEUs: 0.8.
Instructors: Chris Goldfinger, Oregon State Univ.; Randy Enkin, Geological Survey of Canada; Audrey Dallimore, Geological Survey of Canada; Jason Patton, Humboldt State Univ.

\$ **🔌** 517. **U-Pb Geochronology, O and Hf Isotopes, and Trace Element Geochemistry Applied to Detrital Minerals.**

Sat., 21 Oct., 9 a.m.–5 p.m. US\$30. Limit: 40. CEUs: 0.7.
Instructors: George Gehrels, Univ. of Arizona; John Valley, Univ. of Wisconsin.

🔌 **💧** 518. **What's in My Lake: The Changing Face of Limnogeology.**

Sat., 21 Oct., 8 a.m.–5 p.m. Professionals: US\$150; students: US\$50. Limit: 40. CEUs: 0.8. **Instructors:** Scott Starratt, USGS; Amy Myrbo, LacCore; Lisa Park Boush, Univ. of Connecticut; Michelle Goman, Sonoma State Univ.; David Finkelstein, Hobart and William Smith Colleges; Johan (Joop) C. Varekamp, Wesleyan Univ. **Cosponsors:** *GSA Limnogeology Division; GSA Sedimentary Geology Division; SEPM (Society for Sedimentary Geology).*

🔌 519. **Fundamentals to Well Log Interpretation and Reservoir Characterization of Petroleum Systems.**

Sat., 21 Oct., 8 a.m.–noon. US\$125. Limit: 40. CEUs: 0.4.
Instructor: Matthew Johnson, Enhanced Oil Recovery Institute. **Cosponsor:** *Enhanced Oil Recovery Institute.*

520. **Preparing for a Career in the Geosciences.**

Sat., 21 Oct., 8 a.m.–noon. US\$50. Limit: 40. CEUs: 0.4.
Instructors: Paul Klipfel, Mineral Resource Services Inc.; Heather Houlton, American Geosciences Institute. **Cosponsor:** *American Geosciences Institute.*

🔌 **🔌** **💧** 521. **Tools for Water Data Discovery, Publication, and Collaboration.**

Sat., 21 Oct., 8 a.m.–noon. US\$25 (a GSA bookstore voucher for US\$25 will be provided upon completion of the course). Limit: 40. CEUs: 0.4. **Instructors:** Liza Brazil, Consortium of Universities for the Advancement of Hydrologic Sciences Inc.; Anthony Castronova, Consortium of Universities for the Advancement of Hydrologic Sciences Inc. **Cosponsor:** *Consortium of Universities for the Advancement of Hydrologic Sciences Inc.*

522. **Global Geoheritage: Examples and Applications.**

Sat., 21 Oct., 1–5 p.m. US\$107. Limit: 40. CEUs: 0.4. **Instructors:** Benjamin van Wyk de Vries, Blaise Pascal Univ.; Terri Cook, Down to Earth Science LLC; Erika Vye, Michigan Technological Univ.

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.**

Sat., 21 Oct., 1–5 p.m. US\$129. Limit: 40. CEUs: 0.4. **Instructors:** Amy Myrbo, Univ. of Minnesota; Avery Shinneman, Univ. of Washington–Bothell; Shane Loeffler, Univ. of Minnesota. **Cosponsors:** *GSA Geoinformatics Division; GSA Geoscience Education Division; GSA Limnogeology Division.*

\$ **🔌** 524. **Using the Geochron.org Database to Archive, Compile, and Retrieve Geochronology and Thermochronology Data.**

Sat., 21 Oct., 8 a.m.–5 p.m. US\$30. Limit: 25. CEUs: 0.8.
Instructor: Noah McLean, Univ. of Kansas. **Cosponsors:** *GSA Geoinformatics Division; GSA Structural Geology and Tectonics Division.*

Associated Society Course

GSA 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.

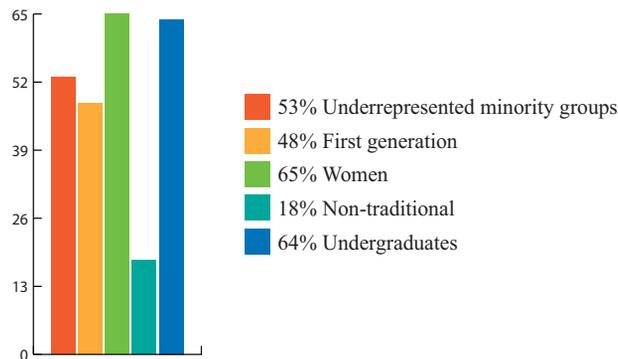
Instructors: Kena Fox-Dobbs, Univ. of Puget Sound; Erik Gulbranson, Univ. of Wisconsin–Milwaukee; Sora Kim, Univ. of Kentucky.



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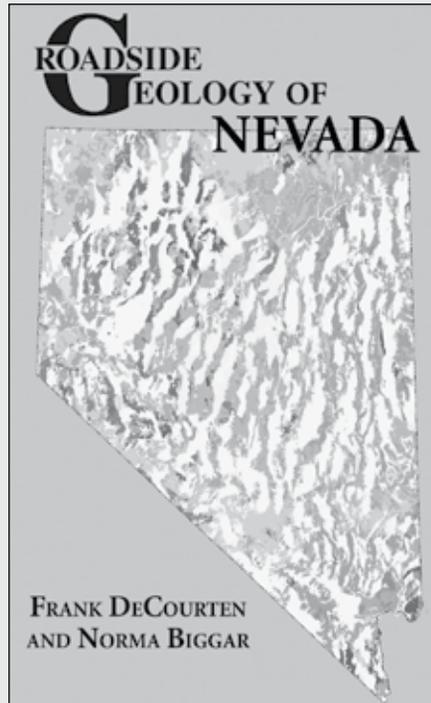
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- Lake Tahoe's granitic eastern shore
- Red Rock Canyon's Jurassic sandstone
- Cathedral Gorge's lakebed badlands
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ROCK STARS

Marie Tharp—Plate Tectonics Pioneer

Hali Felt, Assistant Professor of Creative Writing, University of Alabama, Tuscaloosa, Alabama 35487, USA



Marie Tharp during her college days. Image courtesy Hali Felt.

YOUTH

Marie Tharp was born in Ypsilanti, Michigan, USA, to William Edgar Tharp and Bertha Louise Newton. William worked in a plant nursery until the U.S. Department of Agriculture's Bureau of Soils hired him in 1904. Bertha had been a high school German teacher before, as Tharp says her father always used to remark, she "traded one job for another." She died when Tharp was 15. As parents, William and Bertha seem to have been past an age (50 and 40, respectively, when Tharp was born) where coddling their only child was an option. They were devoted, but they trusted her to find her own way and let her explore the unknown so she'd gain confidence. This proved handy, as William's job required them to move nearly every season, following soft soil: winters spent in the south, summers spent in the north. They spent every four years in Washington, D.C., so William could go to the Soil Bureau's main office to oversee the printing of the maps he had worked on since his last visit.

For most of her early life, Marie Tharp did not display much interest in science as a formal pursuit, but she loved going into the field with her father. As a small child, she would sit in the back of her father's truck "making mudpies and generally being a

nuisance." She loved to tell one particular story about trekking out into the Midwestern countryside with her father, who on this occasion had his camera and took a photograph of Tharp pointing to a tumor on a tree. Her father's itinerant job meant that Marie attended more than a dozen schools before graduating from high school, of which her full school year in Florence, Alabama, USA, was influential. In Florence, she took school field trips on weekends to study trees and rocks, and collected a big bag of snake skeletons and skins and took them home, terrifying her mother. Florence was also where she had a class called Current Science, in which she and her classmates learned all about what contemporary scientists were working on, which she loved, but it had an optimistic tone that discouraged her from thinking that there was anything left to discover.

EDUCATION

Science as a discipline to be studied eluded Tharp until college. She entered Ohio University in the fall of 1939, started out an art major, then took music, German, zoology, paleobotany, philosophy, and English classes before discovering her love of geology. A semester after her introduction to geology she took physical geology and met the "nearest to a mentor I ever saw." His name was Dr. Dow, and his office door was always open; he must have recognized a blossoming talent when he saw it. He was the one who suggested that Tharp take drafting, a skill not usually necessary to become a geologist, but one which he knew would improve her chances of getting a job in a discipline dominated by men and old traditions: If she could draft, she might be able to work in an office. She got a C in the class (of 73 students, only three were women), but said that she learned a lot. "It was very important to learn the tools, and it was a beginning of learning to see things in three dimensions."

As a senior, Tharp saw a flyer hanging on the bulletin board outside of Dow's office. The University of Michigan, it said, was offering an accelerated geology degree with the guarantee of a job in the petroleum industry upon graduation. Because most of the men were off fighting in WWII, it was understood that most of the students would be women. When Tharp asked Dow, he told her to try it: "It only takes two years," she remembered him telling her, "you don't like it, you can do something else." By the beginning of 1943, she was enrolled in the University of Michigan's petroleum geology program, one of a group of women called the "PG [Petroleum Geology] Girls."

It was a confusing time to be training as a geologist. Alfred Wegener had published *The Origins of the Continents and Oceans* 28 years prior, but his ideas had been largely dismissed, and there was still no definitive theory that explained how Earth's crust formed. Mountains, oceans, continents, islands, valleys—even Earth's simplest features were still a source of contention. One

textbook from the time “admitted” that “the cause of crustal deformation is one of the great mysteries of science and can be discussed only in a speculative way” (Longwell et al., p. 18). Tharp recalled being taught in grad school what continental drift was—but not in a way that suggested it was a realistic possibility.

In one of the few stories she related about her time at Michigan, Tharp recalled a talk and visit from the state geologist. At a post-presentation tea, the PG Girls were given the chance to ask him questions. What was it like to be in this field? What would a job in the real world be like? Just what, their questions implied, were they getting themselves into? “And lo and behold what did this geologist say?” Tharp remembered, “He said the geologist is the best one on the spot to make an educated guess.” The geologist’s best tool, in other words, was the ability to look at an incomplete picture and make a hypothesis about what that picture meant.

DISCOVERIES AND IMPACT

Tharp’s unconventional educational history made possible her 1952 discovery of the worldwide mid-oceanic rift valley. In addition to her eclectic undergraduate coursework, she rounded out her scientific training while at Michigan, taking extra classes in physics, math, and chemistry. Before landing a job at Maurice Ewing’s newly formed geophysical lab at Columbia University in 1948, she worked for a time at Standard Oil in Tulsa, Oklahoma, USA, during which time she earned a degree in math to combat the boredom of being stuck in an office. Despite her extensive education, she was hired at Lamont to draft and compute—a research assistant to younger male graduate students. Boredom became a problem for Tharp there, too. Only after she quit did Ewing realize that she needed more stimulating work; he asked her to come back and assigned her to work with Bruce Heezen.

Tharp and Heezen began their 25-year-long partnership in 1952 by processing thousands of unexamined sounding records of the North Atlantic Ocean floor. While Heezen spent much of his time at sea and working on other projects, Tharp used the sounding records to compile six profiles that stretched across the North Atlantic; even if she had wanted to go to sea, women at that time were not permitted on Lamont’s or most ships. The northernmost profile began at Martha’s Vineyard, the southernmost one at Recife, Brazil. But the picture was incomplete. What was happening in the hundreds of miles separating each profile? To fill in the blanks, Tharp used temperature readings, salinity measurements, and cores to reveal, for the first time, a rift valley trending down the center of the Mid-Atlantic Ridge. The (American) scientific establishment was still hostile to any implication that Wegener’s continent drift hypothesis might be true—and the rift valley was a 10,000-mile-long piece of evidence. Afraid of possible repercussions, Heezen called Tharp’s work “girl talk” the first time he saw it. Only after she re-drew the profiles twice and showed him that the valley’s pattern correlated with newly mapped earthquake epicenters in the North Atlantic did he accept the valley’s existence—a correlation that also allowed Tharp to extend the rift valley out of the Atlantic and across the entire world.

The discovery of a 40,000-mile-long, worldwide mid-oceanic rift valley shocked scientists and the public, both groups worrying that their worlds might be shattered. For the public it was quite literal; in a letter to one concerned woman, Heezen wrote, “I do not believe that you have any immediate worry. The earth seems to have been ‘ripping at the seams’ for a long time now (millions

of years).” For the scientific community it was figurative; Tharp recalled that her first depiction of the ocean floor was called “a bunch of lies,” and Bill Menard remarked in a letter to Heezen that he was “increasingly distressed to read one account after another in the press and magazines of this fabulous rift valley.”

The first detailed physiographic diagram of the ocean floor was published by the Geological Society of America in 1957; diagrams of the other oceans followed in quick succession, each one revealing a newly discovered feature that helped scientists develop the interlocking hypotheses that together revolutionized Earth history. With the hope that the public might become as fascinated with inner space as they were with outer space, Tharp and Heezen collaborated with *National Geographic* on a series of accessible artistic renderings of the ocean floors, the first of which appeared in 1967. By the late 1960s, the plate tectonics revolution was complete; a few years later, grade-schoolers were learning why South America and Africa looked like they’d fit together if an ocean wasn’t dividing them. And by 1977, Tharp and Heezen published their *World Ocean Floor Panorama*, a map that’s still ubiquitous in the textbooks and halls of geology departments today.

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Marie Tharp and her globe of the seafloor. Image courtesy Lamont-Doherty Earth Observatory.



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■ LIMNOGEOLOGY

Kerry Kelts Student Research Award

Deadline: 30 June

This award for undergraduate or graduate student research is named in honor of Kerry Kelts, a visionary limnogeologist and inspiring teacher. Send your application to Division Chair Joop Varekamp with "Kelts Award application" in the subject line. For more information, go to community.geosociety.org/limnogeologydivision/awards/kerrykelts.

■ PLANETARY GEOLOGY

Ronald Greeley Award for Distinguished Service

Deadline: 30 June

This award may be given to those members of the Planetary Geology Division or those outside of the Division and GSA who have rendered exceptional service to the Division for a multi-year period. For more information, go to <http://rock.geosociety.org/pgd/distinguished-service.html>.



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COMMENTARY

Is it “the earth” or Earth?—A Response to Şengör’s Commentary

James R. Ebert, Dept. of Earth and Atmospheric Sciences, State University of New York–Oneonta, Oneonta, New York 13820-4015, USA, james.ebert@oneonta.edu

Humpty Dumpty: “When I use a word, ... it means just what I choose it to mean—neither more nor less.”

—Lewis Carroll, 1872, *Through the Looking Glass*

In an interesting commentary, A.M. Celâl Şengör (*GSA Today*, v. 27, no. 3–4, p. 19) poses the question: Which is proper, “the earth” or “Earth”? Şengör argues that “the earth” is preferable because it distinguishes our planet from the others in the Solar System, which are named after Roman gods. The names of the other planets are capitalized because they are proper nouns, which Şengör argues is not the case with our home planet.

The English word “earth” is derived from the Middle English *erthe*, which comes from the Old English *eorthe*. In the kindred Scandinavian languages the word is *jord*, which is visually similar to the Old Norse *jörð*, which would be pronounced something like “yurth,” phonetically similar to the modern English earth.

The Old Norse *jörð* is relevant because in the Norse/Germanic pantheon, *Jörð* (capitalized) is a goddess who was the mother of Thor (Lindow, 2001). So, Earth, like the other planets in the Solar

System, does have a divinely inspired name, and so should be capitalized. Şengör’s concerns regarding when to capitalize Earth are easily solved. Earth (capitalized) should refer only to the planet as a whole. “The earth” should be reserved for regolith, soil, and sediment.

Earth is preferable to Şengör’s suggestion of the Greek *Gaia*, because *Gaia* is not in common usage, whereas Earth is.

Şengör states that “there is a much weightier reason that we should continue calling our planet ‘the earth’ and not ‘Earth’: it is our abode, not any old planet in the Solar System.” Earth is, indeed, a unique place and it is a specific place. As such it deserves the dignity accorded to proper nouns (capitalized) and not the more pedestrian status of common nouns. After all, when we refer to our own Mother, we capitalize the word to distinguish the specific from the more general, all mothers. Should we not do the same for Earth and by doing so acknowledge the origin of the word as well?

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Lindow, J., 2001, *Norse Mythology: A Guide to the Gods, Heroes, Rituals, and Beliefs*: New York, Oxford University Press, 365 p.

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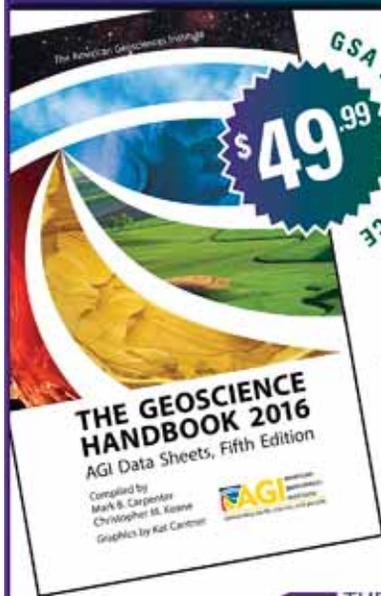
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Education (B/E/M)	1	Graduate Educator	4
	1	Undergraduate Student	4
	1	Informal Science Educator (museum, visitor center)	2
Geologic Mapping Award (E)	1	Member-at-Large (Government)	3
Geology and Public Policy (B/E/M)	2	Members-at-Large	3
	1	Student Representative	2
GSA International (E/M)	1	Member-at-Large (International Associated Society)	4
	1	Member-at-Large (North America)	
	1	Member-at-Large (outside North America)	
Joint Technical Program (E) (term begins December 2017)	1	Member-at-Large Paleoclimatology & Paleoceanology	2
	1	Member-at-Large Precambrian Geology	2
Membership and Fellowship (B/T)	1	Member-at-Large (Government)	3
	1	Councilor/Former Councilor	3
Nominations (B/E)	2	Members-at-Large	3
Penrose Conferences and Thompson Field Forums (E)	2	Members-at-Large (convener of a past Penrose Conference or Thompson Field Forum)	3
Penrose Medal Award (E/T)	2	Members-at-Large	3
Professional Development (E)	1	Member-at-Large	3
Publications Committee (B/E/M)	1	Member-at-Large	4
	1	Councilor (at time of appointment)	
	1	Member-at-Large (young professional)	
Research Grants (B/T)	11	Members-at-Large (intensive time commitment Feb.–Mar.)	3
	1	National Science Foundation Delegate	
Young Scientist Award (Donath Medal) (E/T)	1	Member-at-Large	3
GSA Representative to the AAAS Consortium of Affiliates for International Programs (B/E)	1	GSA Representative (term begins 1 Jan. 2018)	3
GSA Representative to the AGI Environmental Geoscience Advisory Committee (E/M)	1	GSA Representative (term begins 1 Jan. 2018)	3
North American Commission on Stratigraphic Nomenclature (E/M)	1	GSA Representative (term begins Nov. 2018)	3
GSA Representative. to the U.S. National Committee for Soil Science (B/E)	1	GSA Representative	3

Note: Terms begin 1 July 2018 unless stated otherwise. Nominees for Division/Section positions will come from the Divisions and Sections. B—meets in Boulder or elsewhere; E—communicates by phone or electronically; M—meets at the Annual Meeting; T—extensive time commitment required during application review period.

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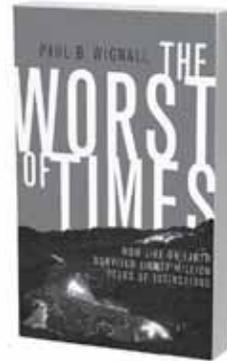
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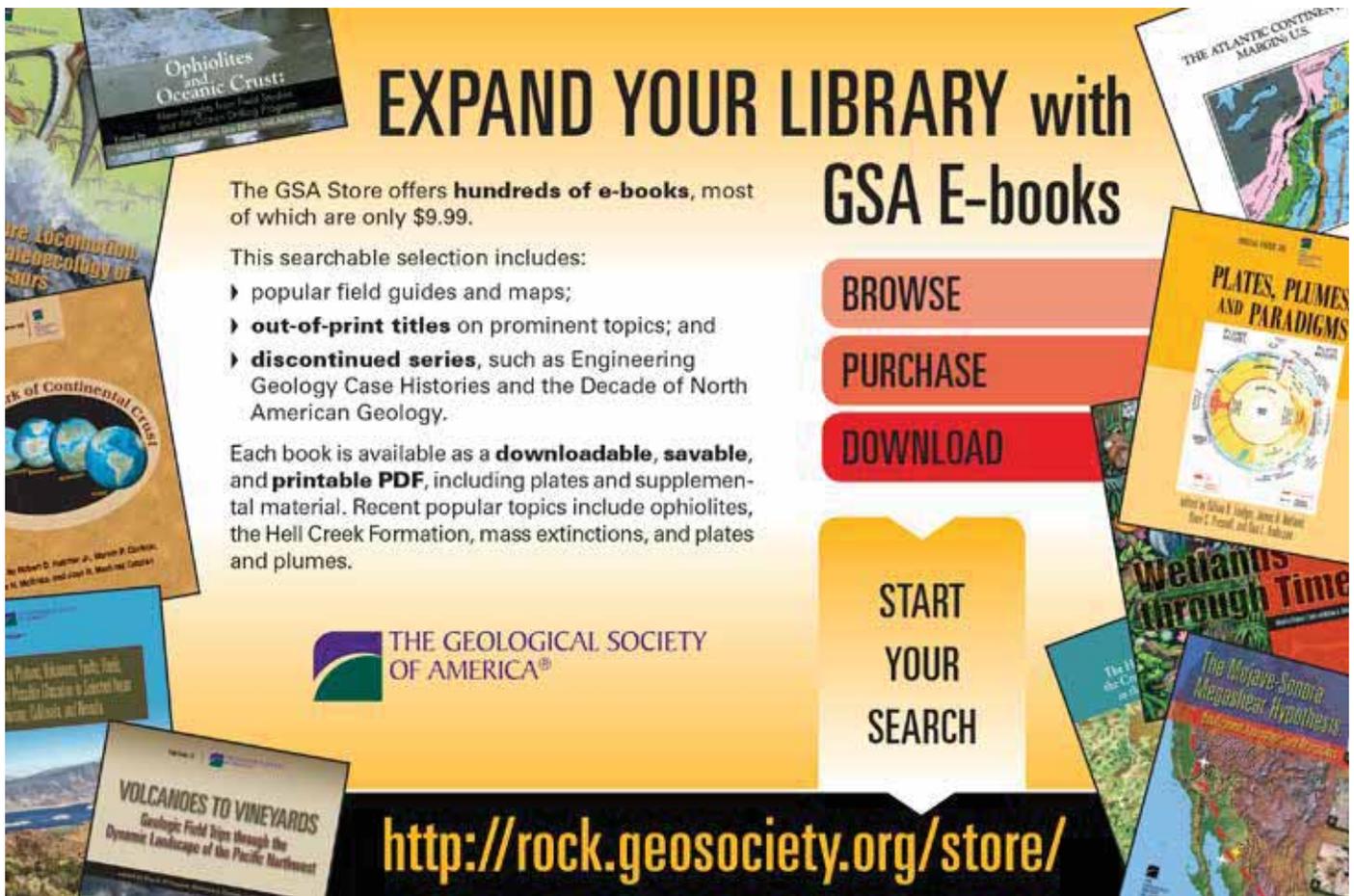
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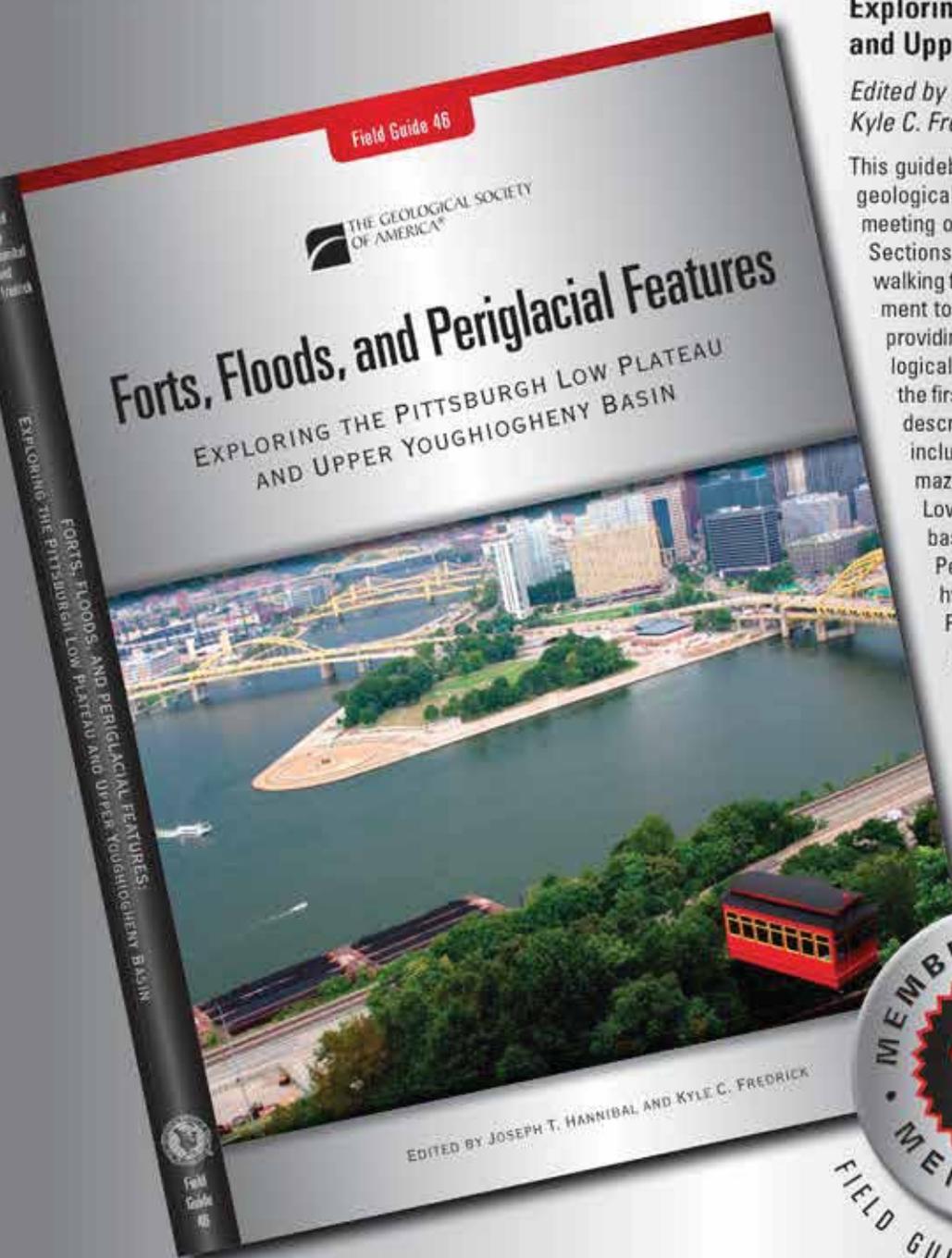
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Edited by Joseph T. Hannibal and
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Encouraging Non-Traditional Students in the Geosciences

We often mention GSA student programs like the On To the Future (OTF) diversity initiative and Graduate Student Research Grants, but there is a lesser-known opportunity that makes Section Meetings available to a broader student population: The Northeast Urban Metro Travel Grant.

Since its launch in 2013, the travel grant program has supported 37 non-traditional students from urban metropolitan universities to attend their first GSA Section Meeting. GSA defines non-traditional as a student who has delayed enrollment in an undergraduate degree program, is financially independent, and/or may care for dependents. The universities that these students attend typically do not have funding to help them attend a meeting.

In 2014, Martha Miller was a 34-year-old single mother of two returning to college for an undergraduate degree in geochemistry. Understanding that professional meetings would help reach her expanding goals of pursuing an advanced degree, but without means to attend the GSA Northeastern Section Meeting, she applied for a Northeast Urban Metro Travel Grant. Martha received funds to travel to Bretton Woods, New Hampshire, USA: “The meeting was inspiring! It was my first experience making connections in a large geological community. Being able to attend increased my resolve to present my research at a professional meeting before I graduated.”

Martha did, indeed, go on to present her research—at GSA’s 2015 Annual Meeting in Baltimore, made possible with a GSA On To the Future travel grant.

While doing all I could to push forward in my undergraduate career, I was struggling to support my family. Receiving funds to offset some of my travel costs was an enormous relief. A valuable piece for me was having a mentor at the meeting. I was impressed that GSA matched me with one who had similar research interests, but was thrilled to read Dr. Carol de Wet’s writing on women in geosciences and to have such a thoughtful, broad-minded scientist who also understood what it meant to raise a family. The day I nervously presented my work, I looked into the audience and saw faces of scientists who had inspired me, those I seek to emulate. It was a moment I would not have been afforded without the support of programs like OTF and the Urban Travel Grant (LLNL-MI-727944).

Martha graduated in 2016 with a B.S. in geochemistry from SUNY Oswego, followed by a twelve month post-college appointee position for the Nuclear and Chemical Sciences division at Lawrence Livermore National Laboratory (LLNL). Next, she will enter the Ph.D. program at the University of Rochester, joining Dr. Dustin Trail’s experimental geochemistry group.

A generous supporter of the Urban Travel Grants and OTF, Paula Gural, explains,

I was an unconventional student, completing most of my education while a stay-at-home mom with three

children. I had a very positive experience studying geology in the CUNY system (City University of New York) at the Queens College Campus. I love the science component along with the outdoor experience that geology afforded. I was fortunate to be able to attend many local and national GSA meetings. Later on, my husband’s job allowed us to be able to give back. I support geology programs in general because I believe we should understand the earth and do our part to take care of it. I support the NE Urban Travel program so that university students can have the same experience that I had in attending geology meetings and seeing the broad possibilities in the field. The OTF students mirror the varied population in a city university system and represent the future caretakers of our country and our earth. I am very happy that we are able to support these programs.

If you are interested in helping non-traditional students pursue careers in the geosciences, please contact Bill Tortorici at +1-303-357-1007 or btortorici@geosociety.org.



Martha in 2014 at SUNY Oswego; photo by James Russell.



Martha and her children at her May 2016 graduation.

Color Vision Deficiency and the Geosciences

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ABSTRACT

Color Vision Deficiency (CVD) is a common workplace disability. People with CVD read our papers and are most likely in all of our classes. Here we discuss the common forms of CVD, assistive technologies, instructional strategies, and guidelines for illustrations that will look great to everyone.

INTRODUCTION

In his 1973 hit *Kodachrome*, Paul Simon sang,

“They give us those nice bright colors / They give us the greens of summers /... everything looks worse in black and white ...”

However, everyone does not see colors identically. *GSA Today* has 25,000 subscribers, so statistically, that will include more than 1,300 individuals with CVD¹. When authors neglect this in drafting illustrations, many readers miss key points. A reader of De Paor (2016) pointed out that one figure used a dark red line against a dark green background, prompting this article. The paper proceeded through review to publication because those involved had fully functioning trichromacy, despite awareness of CVD and a strong commitment to accessibility. Here, we aim to increase awareness among authors, referees, editors, presenters, instructors, students, and administrators, pointing to new optical and digital assistive technologies, and highlighting guidelines for CVD-compliant instruction and illustration.

TYPES AND PREVALENCE OF CVD

Common forms of CVD are called red-green (RG) CVD. Protan (red) or deutan (green) photopigment molecules work incorrectly (anomaly) or not at all (anopia). Some 8% of men of mainly European, North African, and Middle Eastern ancestry have RG-CVD. Prevalence is lower among other males and ~0.5% among all females. Male rates reach 15% in consanguineous populations (Shah et al., 2013). Rare Blue CVD and monochromacy affect men and women equally. Effects range from minor spectral shifts to total dichromacy.

CVD can be acquired but is usually inherited. Dalton (1798) published the first account of the condition that he discovered in himself after causing familial scandal by gifting his mother racy red lingerie, seeing it as beige (qi.com/info-cloud/color-blindness). His brother could not see the problem either, leading Dalton to conclude that CVD was hereditary. We now know that the relevant genes are coded on the X-chromosome. Men inherit from parents or grandparents, whereas women must inherit from both parents, hence the 16:1 ratio.

TESTING AND ACCOMMODATING STUDENTS WITH CVD

Instructors should include CVD in the special needs sections of their syllabi and should present students with a pseudoisochromatic plate—a circle of multicolored dots that reveal a number given normal vision (Ishihara, 1917). Students who cannot see the number can take more sophisticated tests such as anomaloscopes (Nagel, 1907).

According to Maule and Featonby (2016), most instructors underestimate the number of their students with CVD and do little to accommodate them. Institutions provide accommodations to 88% of students with disabilities who self-disclose, but only 40% of such students do so (Wagner et al., 2005). Students strive to fit in and avoid special treatment, fearing bias and stereotype. Research suggests that the willingness of instructors to provide accommodations is based solely on how disabled a student appears (Rao and Gartin, 2003). Professors may think students with non-apparent conditions are malingering—trying to receive preferential treatment, rather than reasonable accommodation to complete an activity. Whereas a student can pretend not to see a Ishihara plate number, it is impossible to fake an anomaloscope. Students with verifiable CVD deserve support in lecture, laboratory, and the field.

OPTICAL AND DIGITAL ASSISTIVE TECHNOLOGIES

Glasses such as O2AMP™ and EnChroma® may benefit some anomalous trichromats. Today, microscopes often output to monitors, and images can be spectrally shifted with Photoshop™ or Fiji (fiji.sc). Visolve (ryobi-sol.co.jp/visolve/en) transforms images to help distinguish ranges of colors. The Chrome browser’s Daltonize extension enhances contrast and intensity, and there are bookmarklets for Firefox and Safari (daltonize.appspot.com). Mobile apps such as *Color Blind Pal* identify colors in the field of view, filter or shift them, and highlight matching colors.

GSA Today, v. 27, doi: 10.1130/GSAT322GW.1

¹ We eschew the common term “colorblind” to avoid implying monochromacy, to support person-first language (“persons with CVD,” not “colorblind people”), and to distinguish CVD from racially inclusive policies.

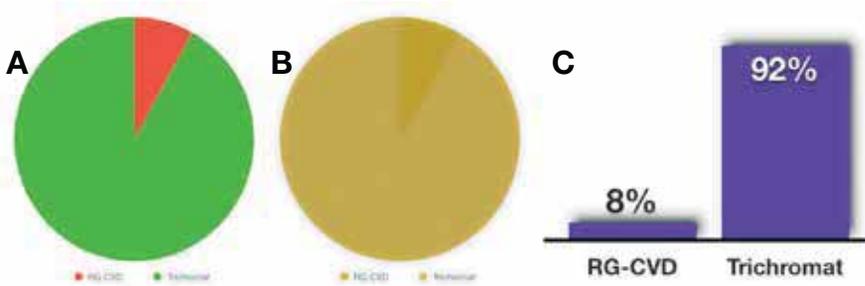


Figure 1. Color presentation styles. (A) Pie chart: difficult to quantify because the size of the red pie slice is not specified and the legend is inscrutably small. (B) Colors in (A) are almost indistinguishable to people with RG-CVD. (C) The same data are clear to all in an annotated bar chart.

PREPARING IMAGES FOR ALL TO SEE

Assistive technologies notwithstanding, there is no substitute for well-designed illustrations. Whether destined for presentation or publication, images should always be tested using vischeck.com, colorblindness.com, colorbrewer2.org, contrast-checker.com, [Sim Daltonism](http://SimDaltonism.com), [Adobe Illustrator](http://AdobeIllustrator.com), etc. An extensive literature review is beyond the scope of this article, but we here summarize the most frequently cited best practices for publication, presentation, and instruction:

1. *Select graphic styles for accessibility:* Figure 1 shows two presentation styles. The pie chart (A) is difficult to quantify and the legend is inscrutably small. (B) Colors in (A) are almost indistinguishable to people with RG-CVD. The same data are clear to all in an annotated bar chart (C). On GSA's web page www.geosociety.org/documents/gsa/about/MbrDemographics.pdf, the *Professional Interests* chart is clear to all but the *Employment Type* chart is totally illegible to some. Numerous other good and bad examples can be found via Google.
2. *Redundancy:* Distinguish items by more than color. Use circles and squares and solid and dashed lines. Label items directly, not in a key.
3. *Color choice:* Colors differing only in hue, especially percentage red or green, cause problems. Dark red–dark green, blue–violet, red–orange, and yellow–green confusion is common. Magenta and turquoise are good choices because people with RG-CVD can see the blue component.
4. *Thickness, brightness, and contrast:* People with RG-CVD cannot see thin lines or small polygons because insufficient functioning retinal cones are activated. Make lines thick and use high-contrast text, arrows, or other

shapes. Drop-shadows and boxes make text stand out. Saturation and brightness variations are critical.

5. *Avoid rainbow color maps:* Despite copious research showing that it is the worst possible choice (e.g., Light and Bartlein, 2004), the rainbow color map continues to be popular (Borland and Taylor, 2007). Although violet and red are the extremes of visible light, they do not convey different magnitudes to the brain. A diverging color map does (<http://www.kennethmoreland.com/color-maps/>).

PRESENTING AND INSTRUCTING

In addition to preparing illustrations well, a presenter's words, gestures, and actions are important. Individuals with RG-CVD commonly cannot identify colors, even if they can distinguish them. Instead of referring to a "pink curve," say "the pink, dashed curve at top left."

Red laser pointers are extremely difficult for some to see (Okabe and Ito, 2008). Green ones are superior (conference organizers please note!) and are also good for pointing to stars and planets.

DISCUSSION AND CONCLUSIONS

Gene therapy offers hope for a cure (Gudgel, 2015; Saey, 2016), but for the foreseeable future, RG-CVD will remain prevalent. Government agencies have Section 508 Standards including guidelines for CVD-compliant documents. See, for example: section508.va.gov, colorusage.arc.nasa.gov/indiv_diffs.php, and nws.noaa.gov/sec508.

People with CVD typically prefer black and white to color. In fact, in his 1982 album, *Concert in Central Park*, Paul Simon changed the "Kodachromes" lyrics to "everything looks *better* in black and white."

However, we must recognize that trichromats will continue to prefer color whenever available. The key is to design for inclusivity. Color images crafted to be clearly visible

to individuals with CVD will look better to everyone. To continue the discussion, please visit: <http://www.theiagd.org/resources/color-vision-deficiency>.

ACKNOWLEDGMENTS

We thank Rick Murray of Boston University and two anonymous reviewers for very useful suggestions. Our research was supported by NSF DUE 1323419.

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MANUSCRIPT RECEIVED 6 OCT. 2016

REVISED MANUSCRIPT RECEIVED 11 DEC. 2016

MANUSCRIPT ACCEPTED 14 DEC. 2016

The High Plains Aquifer: Can We Make It Last?

Susan Stover and Rex Buchanan, Kansas Geological Survey, University of Kansas, 1930 Constant Ave., Lawrence, Kansas 66047, USA

Nearly a third of the United States' irrigated crops depend on one massive but dwindling water source: the High Plains aquifer. Declining water levels in the High Plains aquifer and responses to those declines are resource challenges that necessitate input from geoscientists.

The High Plains aquifer, which underlies parts of eight states from South Dakota to Texas, consists of several interconnected aquifers, including the Ogallala aquifer. Unequally distributed, most of the southern two-thirds is in serious decline; water levels have dropped >150 ft since pre-development in areas of Texas and Kansas (Fig. 1; McGuire, 2014). Roughly 19.6 million acre-feet were pumped in 2005, primarily for irrigation (McGuire, 2009), a quantity that exceeds the basin-wide average annual inflow of the Colorado River (Bureau of Reclamation, 2011). In 2013, three times more water was pumped from the aquifer in Kansas than the estimated natural recharge rate (Buchanan et al., 2015). Kansas warns that without changes, “70% of the aquifer [in Kansas] will be depleted within 50 years” (Kansas Water Office and Kansas Department of Agriculture, 2015). Water quality also impairs the aquifer in some regions (Whittemore, 2012).

The High Plains aquifer is the source for a highly productive region of corn, alfalfa, soybeans, wheat, sorghum, and cotton (Cruse et al., 2016). Crops support the numerous cattle feedlots and large dairies that overlie the High Plains aquifer. Meat-packing, milk processing, ethanol plants, and domestic users also rely on the aquifer. It supports the region's economy and the U.S. food supply. Can the aquifer's use be slowed and its life extended? The aquifer's availability to future generations depends on decisions by policy makers, water managers, and especially irrigators. The geoscience community is continually

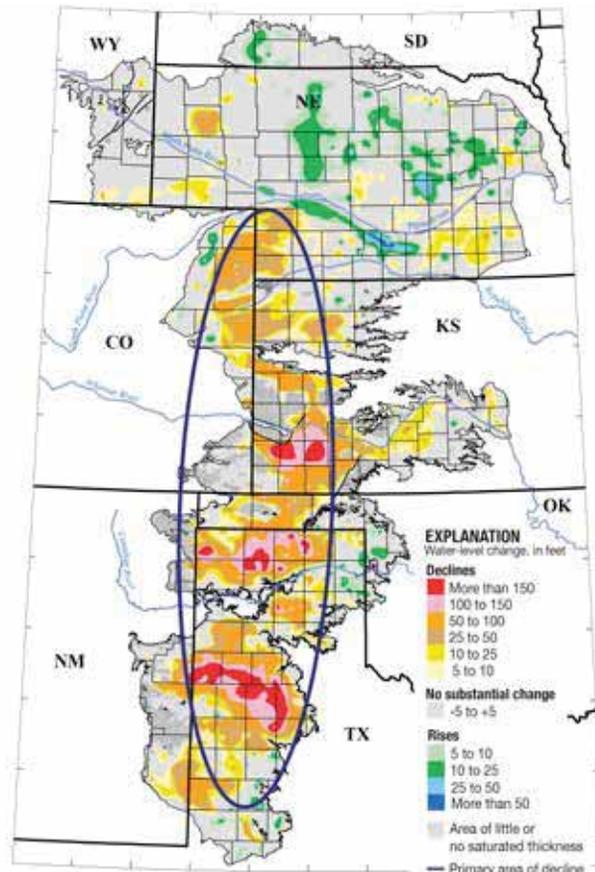


Figure 1. Water level changes in the High Plains aquifer from pre-development (about 1950) to 2013, with primary area of declines circled. Modified from McGuire (2014).

improving its knowledge of its current and projected future conditions, information essential for its sound management.

In Kansas, Colorado, and Texas, states with large aquifer declines, regulators gave irrigators the right to pump far more water than the aquifer can sustain. In Kansas and Colorado, water right permits are governed by seniority. When there is not enough water to meet the needs of all water right holders, priority is given to those who own the oldest, most senior rights, a system summarized as “first in time, first in right.”

However, both states accept regional groundwater declines, allowing more use to get the economic benefits of the aquifer, a management approach sometimes called “planned depletion.” Texas governs groundwater by the rule of capture, which gives landowners the right to use groundwater beneath their property. Local groundwater conservation districts manage the High Plains aquifer in Texas, and most districts require well meters and annual water use reports from well owners. Because water rights have legal standing,

regulators in these states have limited ways to cut back on use. Thus, future conservation rests mostly with individual water right owners, who will make decisions about reducing their use.

THE TECHNOLOGY POTENTIAL

States encourage locally developed efforts to conserve the aquifer supply. Texas requires groundwater conservation districts that share a common aquifer to set “desired future condition” aquifer goals. Once these goals are set, the Texas Water Development Board (TWDB) uses groundwater availability models to estimate how much groundwater can be pumped to achieve the goals (TWDB, 2016). In Colorado, the Republican River Water Conservation District (RRWCD) encourages landowners to enroll irrigated acres into USDA programs for conversion to dryland acres, in exchange for payments. The RRWCD charges farmers an annual water use fee of US\$14.50 per irrigated acre, which helps fund payments for fallowing acres (D. Daniels¹, 2016, personal commun.).

Precise water management has the potential for irrigators to maintain crop yields and revenues on less water by using efficient irrigation systems and optimizing when to water. Kansas is testing this approach at “water technology farms” (Kansas Water Office, 2016). The Texas Water Plan has an irrigation water savings goal of 639,000 acre feet annually by 2020 through implementing more efficient irrigation systems and methods (TWDB, 2016).

Irrigation systems improve efficiencies, with more water taken up by the crop and less lost to evaporation, surface runoff, or deep percolation. Inefficient flood irrigation (gravity flow down furrows) has largely given way to more efficient center pivots (large circular sprinklers). Highly efficient subsurface or mobile drip irrigation is gaining popularity. Soil moisture probes in fields with data accessible on a smart phone or tablet allow farmers to monitor moisture in the crop root zone and apply water at the most effective times. Precise crop water management is a big shift from the typical pattern of turning on an irrigation system in the spring and turning it off at the end of the growing season.

More efficient irrigation does not necessarily result in water conservation, a

common assumption. The adoption of more efficient irrigation systems in Kansas led to more irrigated acres of water-intensive crops (Perry, 2006). More efficient irrigation systems can operate with lower-capacity wells. Many farmers invest in more efficient systems when their well capacities decline to be able to continue irrigation of the same type of crops (Peterson and Golden, 2005). When well capacities declined in the past, producers abandoned wells and switched to dryland farming; new systems allow irrigation to continue from lower-yielding wells. In effect, it allows operators to drain the aquifer more completely. Unless irrigation is done with real conservation, not just the limits of the well capacity, new technologies could exacerbate aquifer declines.

Aquifer data is critical to conservation efforts. It provides a strong foundation for policy makers, water managers, and water users to evaluate options and add confidence to their decisions. It also allows evaluation of the impact of decisions, which may range from business as usual to cutbacks in water use. Data on Kansas water wells, annual water use by water right, irrigation systems, and water levels in a network of 1,400 wells in the High Plains aquifer goes back several decades. The data is publically available online, with tools for mapping of water level trends in a well or area of interest (www.kgs.ku.edu/HighPlains/index.shtml). The data is a powerful resource for understanding the aquifer and modeling future aquifer conditions. Colorado, Texas, and other states also collect and post data online and are rapidly expanding their water databases and models. The U.S. Geological Survey uses the state data to report on the entire High Plains aquifer conditions. Information transparency with the public builds trust and increases awareness.

Widespread conservation may hinge on voluntary, collective commitments to goals that extend the water resource further into the future. In a 99 mi² area of northwestern Kansas, irrigators entered into a voluntarily proposed, but mandatory once adopted, five-year conservation plan with reductions of water use by 20%. Now in its fourth year, reports are encouraging; irrigators are staying within the reduced water use levels and reasonable crop yields are being achieved,

while extending the life of the aquifer significantly (Golden, 2015; Butler et al., 2016). Whether that commitment happens over a wider area remains to be seen.

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MANUSCRIPT RECEIVED 31 AUG. 2016

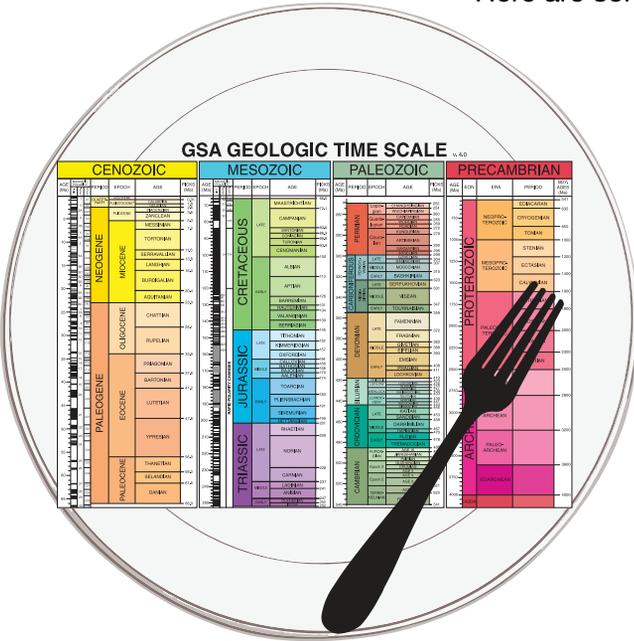
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¹ D. Daniels is general manager of the Republican River Water Conservation District in Colorado.

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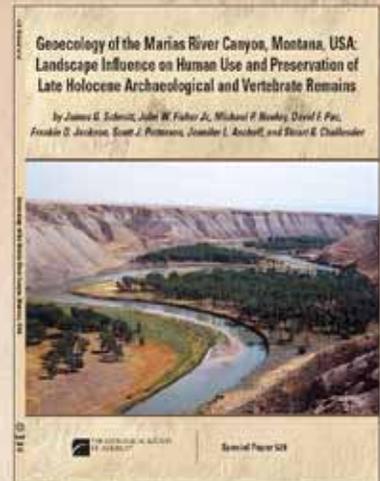


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