

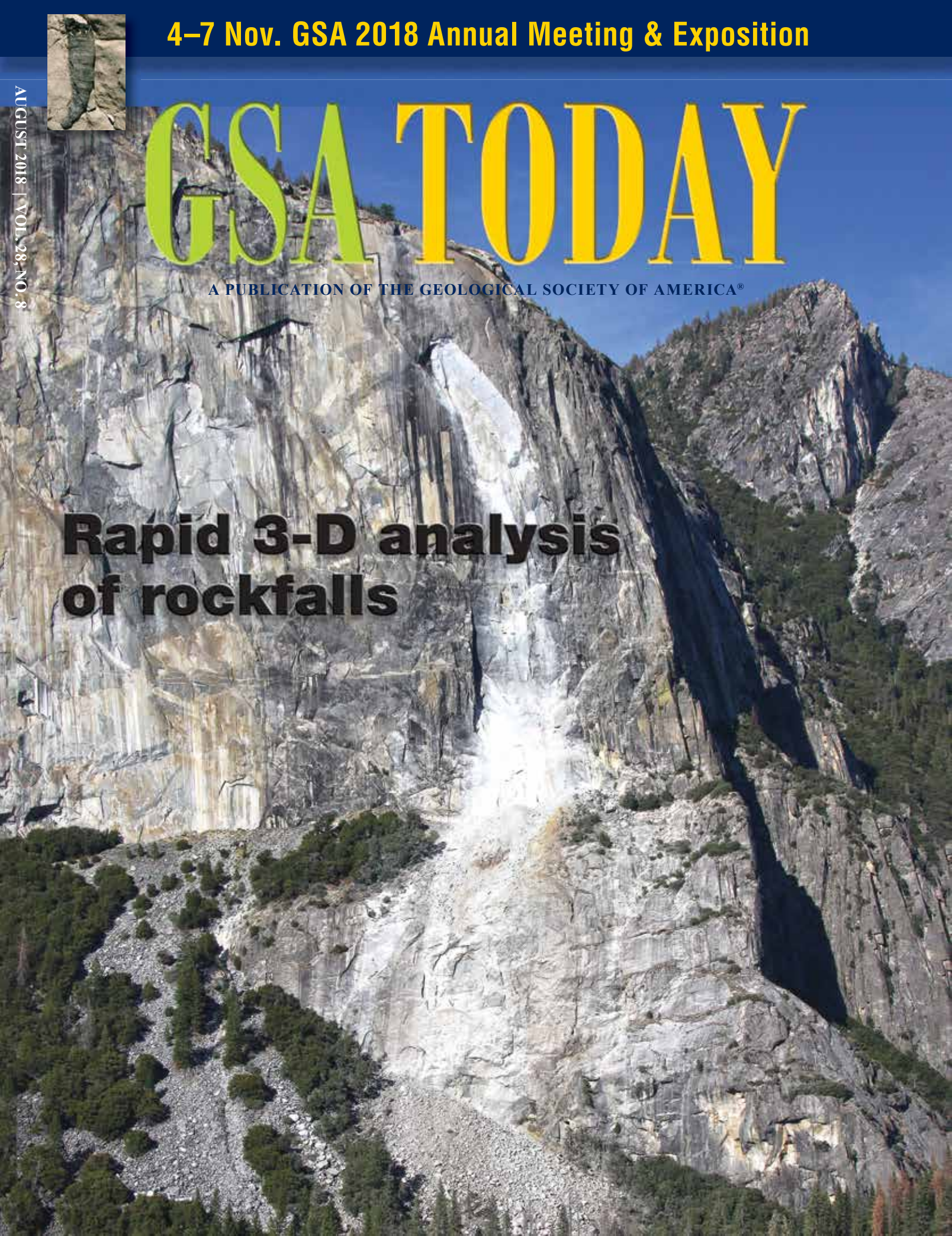
4-7 Nov. GSA 2018 Annual Meeting & Exposition

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## Rapid 3-D analysis of rockfalls

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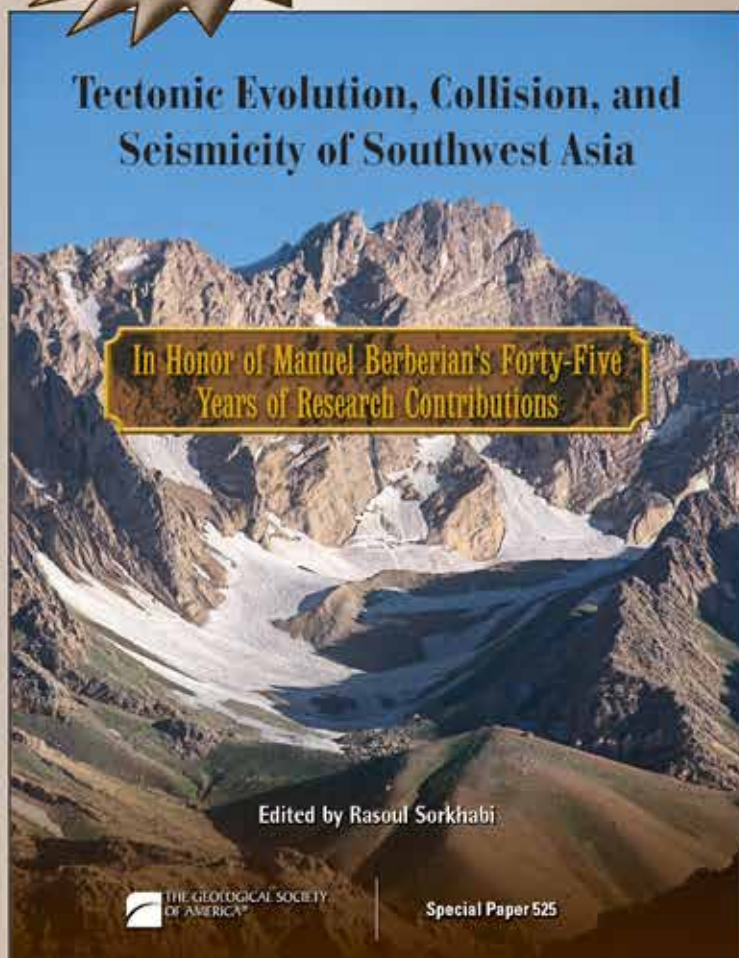
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**Cover:** Rockfall scar and runoff path from rockfalls on the southeast face of El Capitan, Yosemite Valley, USA, which occurred on 27–28 Sept. 2017. As determined from combined terrestrial lidar and “structure-from-motion” photogrammetry analysis, the scar resulting from the largest rockfall was 120 m tall, 45 m wide, and up to 8 m thick, with a total volume of  $10,241.2 \pm 476.2 \text{ m}^3$ . Rapid 3-D rockfall analysis informed National Park Service decisions to protect public safety. Photo by Greg Stock/National Park Service. See related article, p. 28–29.



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Cover inset photo: Horn coral. Photo by Stephen Greb.



# 2019 GSA Section Meetings



## Northeastern

17–19 March

Portland, Maine, USA

Meeting Chair: Steve Pollock, [spollock@maine.rr.com](mailto:spollock@maine.rr.com)

[www.geosociety.org/ne-mtg](http://www.geosociety.org/ne-mtg)



## Joint South-Central/North-Central/ Rocky Mountain

25–27 March

Manhattan, Kansas, USA

Meeting Chairs: Matthew Kirk, [cmehrten@uvm.edu](mailto:cmehrten@uvm.edu);

Tina Niemi, [niemit@umkc.edu](mailto:niemit@umkc.edu); Shannon Mahan,

[smahan@usgu.gov](mailto:smahan@usgu.gov)

[www.geosociety.org/sc-mtg](http://www.geosociety.org/sc-mtg)



## Southeastern

28–29 March

Charleston, South Carolina, USA

Meeting Chairs: Scott Harris, [HarrisS@cofc.edu](mailto:HarrisS@cofc.edu);

Katie Luciano, [LucianoK@dnr.sc.gov](mailto:LucianoK@dnr.sc.gov)

[www.geosociety.org/se-mtg](http://www.geosociety.org/se-mtg)



## Cordilleran

15–17 May

Portland, Oregon, USA

Meeting Chairs: Martin Streck, [streckm@pdx.edu](mailto:streckm@pdx.edu);

Jim O'Connor, [oconnor@usgs.gov](mailto:oconnor@usgs.gov)

[www.geosociety.org/cd-mtg](http://www.geosociety.org/cd-mtg)

Northeastern image: Portland waterfront, Portland, Maine, USA. Photo courtesy Maine Office of Tourism. Joint Meeting image: Manhattan, Kansas, USA. Photo courtesy K-State Photo Services. Southeastern image: Beach boardwalk, Charleston, South Carolina, USA. Photo courtesy Meetcharleston.com. Cordilleran image: Chaticleer Point, Portland, Oregon, USA. Photo by Martin Streck.



**4-7 November**

Indianapolis, Indiana, USA

**The abstracts deadline  
is almost here!**

Submit an abstract for GSA 2018 Indy no later than 11:59 p.m.  
Pacific time on Tuesday, 14 August.

**[community.geosociety.org/gsa2018/sessions](http://community.geosociety.org/gsa2018/sessions)**



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Deadline: 11:59 p.m. mountain time on 1 October.

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Green Mountain Beach dune near Holland, Michigan. Photo by Suzanne DeVries-Zimmerman.



# TOP 10 THINGS TO DO

# Indy



## INDIANAPOLIS ZOO & WHITE RIVER GARDENS

Pet sharks in the nation's largest shark touch tank, suit up for an in-water dolphin experience, or interact with birds at the "Flights of Fancy" exhibit. This TripAdvisor Top 10 Zoo is accredited as a zoo, aquarium and botanical garden.



## INDIANAPOLIS MOTOR SPEEDWAY & HALL OF FAME MUSEUM

The iconic 2.5-mile oval is host to the world's largest single-day sporting event, the Indy 500, and captures the rich 100-year old history of the Racing Capital of the World.



## EITELJORG MUSEUM

Home to the one of the finest collections of American Indians and Western art in the world and the only one in the Midwest. It is renowned for immersing visitors in the art, history and culture of the American West and indigenous peoples of North America.



## CHILDREN'S MUSEUM

The world's largest children's museum is right here in Indy and provides a one-of-a-kind experience which has made it one of the most respected and loved in the nation. Discover the stories and science behind more than 120,000 artifacts on five levels.



## CENTRAL CANAL

Relax along White River State Park's Central Canal in a Venetian-style gondola, surrey, cruiser bike, Segway, pedalboat, or on foot. Take in the sights of public art, war memorials, and vast urban green space as you pass numerous museums and cafes.

## INDIANA STATE MUSEUM & IMAX THEATER

Uncover Indiana's secrets through hands-on exhibits exploring the state's diverse history at this world-class institution constructed from Indiana limestone, steel and glass. Captivate your imagination on the towering IMAX screen.



## RHYTHM! DISCOVERY CENTER

Beat on drums and learn how rhythm and percussion are a part of our daily lives at this museum for kids of all ages. Explore a wide variety of instruments and artifacts from around the world.



## VICTORY FIELD

Take your family and friends out to the ballpark for some fun at Victory Field, named Best Minor League Ballpark in America by *Sports Illustrated*. Enjoy excellent views of downtown from the stands or a picnic on the outfield lawn.



## INDIANAPOLIS MUSEUM OF ART

This top 10 largest encyclopedic art museum features a collection of 54,000 works spanning 5,000 years and sits on 152 acres of beautiful gardens and grounds, including a 100-acre sculpture park that invites you to play with art.



## MONUMENTS & MEMORIALS

Aside from Washington, D.C., Indy is home to more monuments and memorials than any other U.S. city. Experience an eagle-eye view of the city from atop the Soldiers & Sailors Monument or visit the Indiana War Memorial Plaza.





# TOP 10

## Things To Do In Indy



## Be a Part of the Movement

**504 OTF Scholars + 145 Mentors = On To the Future**

Support from members is instrumental in shaping careers, changing lives, and diversifying our profession. Join us as we look forward to another successful year of On To the Future.



Support a student: [www.gsafweb.org/fund/on-to-the-future-fund](http://www.gsafweb.org/fund/on-to-the-future-fund).

Learn more: <http://bit.ly/2q0iCCT>.



## K-12 GSA Experience Comes to Indy!

*How do we recruit the next generation of geoscience students to our field?*

*Get 'em while they're young!*



**4-7 November**  
Indianapolis, Indiana, USA

Building on last year's success in Seattle, GSA is pleased to announce that we will be inviting K-12 teachers from the Indianapolis area to bring their classes to the GSA Annual Meeting & Exposition this November for the K-12 GSA Experience. Participating students will experience the diversity of geoscientists, improve their understanding of how science actually occurs, and build upon their current studies and future college and career choices by visiting the exhibit and poster halls.

The K-12 GSA Experience will be available to classes on Monday, Tuesday, and Wednesday, 5-7 November, between 10 a.m. and 3 p.m. (2 p.m. on Wed.). Interested teachers should complete the form at <https://goo.gl/forms/w50DAAtjtIGfp2hp2> by 30 September. Class pre-registration is REQUIRED to participate. Exhibitors (businesses, agencies, and universities) with demonstrations or content specifically of interest to a K-12 audience should complete the form at <https://goo.gl/forms/W0qiYujid1UF47yi1>.

**For more information contact** Dean Moosavi at [smoosavi@geosociety.org](mailto:smoosavi@geosociety.org) or +1-303-357-1015.






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## Make an Impact— Be a Mentor

“I gained a wonderful sense of satisfaction knowing that the next generation of geoscientists is bright, resourceful, optimistic, and enthused.” —2015 Mentor



Now offering even more ways to mentor at the GSA Annual Meeting  
<https://bit.ly/2GIBenV>.

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**Questions?**

Contact Jennifer Nocerino,  
[jnocerino@geosociety.org](mailto:jnocerino@geosociety.org).

[community.geosociety.org/gsa2018/courses](https://community.geosociety.org/gsa2018/courses)



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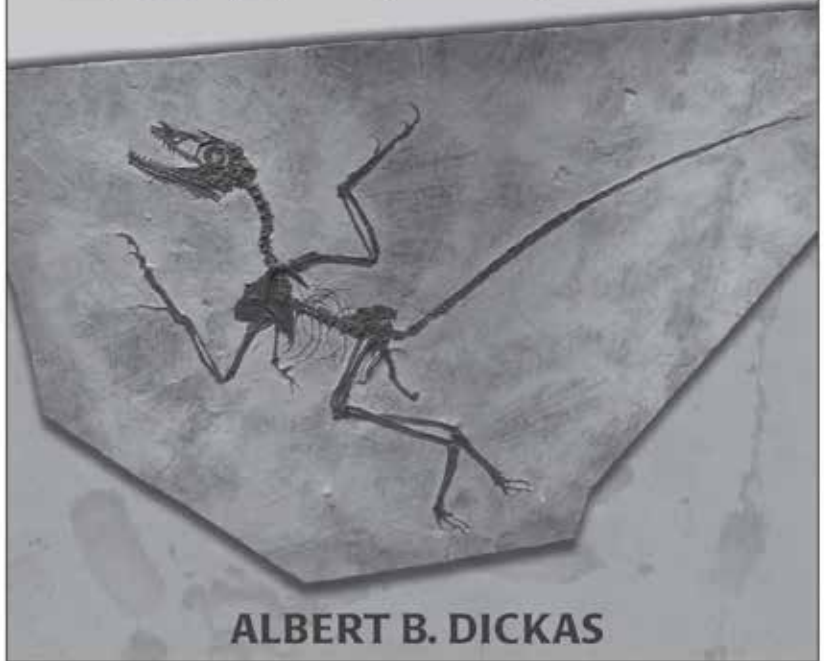
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## GeoTeachers K-12 Teacher Professional Development Workshops at Indy



Crossbedding in Mississippian Sandstone, Turkey Run State Park, Indiana, USA. Photo by Dean Moosavi.



Groundwater discharge from Mississippian Sandstones, Turkey Run State Park, Indiana, USA. Photo by Dean Moosavi.

**Indiana—Indianapolis:** Annual Meeting Mini-Workshop, 2–4 November

### Highlights of the Indiana Workshop:

- Day field trip to Turkey Run State Park
- Post-glacial entrenchment of streams in Mississippian sandstones
- Keynote presentation on Indiana geology
- Sunday Annual Meeting Technical Session attendance

For workshop details, prices, and registration, check the GeoTeachers website at [www.geosociety.org/geoteacherspd](http://www.geosociety.org/geoteacherspd) or contact Dean Moosavi, [smoosavi@geosociety.org](mailto:smoosavi@geosociety.org), +1-303-357-1015.



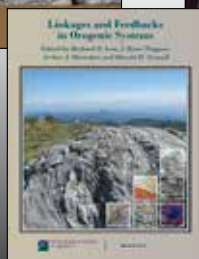
**4-7 November**  
Indianapolis, Indiana, USA

## Put Your Annual Meeting Presentation to Work

Your well-received technical presentation at the GSA Annual Meeting can go far. Submit a manuscript to one of GSA's top-rated journals. Or, if you have a whole session's worth of great papers, consider submitting a book proposal.

With six journals and three book series, GSA has a range of publication outlets to meet your needs for speed of publication, article size, targeted collections, and distribution. Author information can be found at [www.geosociety.org/AuthorInfo](http://www.geosociety.org/AuthorInfo).

For details on submitting to any of these publications, contact us at [editing@geosociety.org](mailto:editing@geosociety.org).



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# GSA Launches New Mentoring Program at the Annual Meeting

This year, GSA is offering a new one-on-one mentoring program at the Annual Meeting in Indianapolis, Indiana, USA, 4–7 November, for students and early career professionals who would like to be paired with a professional for the duration of the meeting. This new mentoring program will be launched using an online platform where mentees and mentors will create profiles and have the ability to view and select matches.

At the meeting, pairs will:

- Expand personal networks through daily interaction;
- Brainstorm session and events that will complement the mentee’s discipline interests; and
- Share potential academic and career paths.

GSA will also offer the following mentorship opportunities:

- Small-group mentoring sessions at the GeoCareers Day event;
- Drop-in mentoring in the Mentoring Center; and
- 30-minute résumé consulting in the Mentoring Center.

Mentees can learn more and sign up online at <http://bit.ly/2JtDtXK>.

GSA welcomes graduate students, early career professionals, professionals, and retirees to serve as mentors. Learn more and sign up online at <http://bit.ly/2GIBenV>.

Questions? Contact Tahlia Bear, GSA diversity and career officer, at [tbear@geosociety.org](mailto:tbear@geosociety.org).

*“I enjoyed the mentorship program, and I would certainly do it again in the future at other GSA meetings.” —Student Mentee*

*“It was an excellent experience for me, and I will definitely recommend this program to other students in the future.” —Mentor*





# GSA Member Benefit

Interior Federal Credit Union (IFCU) serves their members 24/7 through online and mobile banking, call-center employees, 5,500 shared-branches, and 55,000 ATMs nationwide. With some of the best rates in the country, you can become a member with just a US\$25 deposit into a savings account. As an ongoing incentive for GSA members, IFCU will fund the first US\$25 deposit into a savings account to establish membership.

Their young adult account ([www.interiorfcu.org/accounts/young-adult-accounts/](http://www.interiorfcu.org/accounts/young-adult-accounts/)) also has a number of benefits ideal for GSA student members:

- 3% annual percentage rate (APR) on a checking account, with no fees for ATM transactions and a free “oops” coupon;
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- US\$50 gas card with first car loan;
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## Notice of GSA Council Meetings

### 2018 GSA Annual Meeting & Exposition Indianapolis, Indiana, USA

- ▶ **Day 1:** Saturday, 3 Nov., 8 a.m.–noon
- ▶ **Day 2:** Wednesday, 7 Nov., 8 a.m.–noon

GSA Headquarters Hotel: JW Marriott\*  
10 S. West Street, Indianapolis, Indiana 46204, USA

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

\*Meeting room to be announced. Updates will be posted on the GSA website.



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- **Groundwork:** Two pages, free color, and also posted online ahead of print at [www.geosociety.org/gsatoday/groundwork/](http://www.geosociety.org/gsatoday/groundwork/).
- **Rock Stars:** Into science bios? Each Rock Stars article, managed by GSA’s History and Philosophy of Geology Division ([www.geosociety.org/RockStarGuide](http://www.geosociety.org/RockStarGuide)), provides a two-page profile of a notable geoscientist whose contributions have impacted geoscience in a significant way.

[www.geosociety.org/gsatoday](http://www.geosociety.org/gsatoday)





# New and Revised Position Statements

At its May 2018 meeting, GSA Council adopted a new position statement, “Removing Barriers to Career Progression for Women in the Geosciences.” Council also adopted minor revisions to two statements, “Promoting Earth Science Literacy for Public Decision Making” and “Critical Minerals and Materials,” and endorsed a joint statement by the Seismological Society of America and American Geophysical Union titled “The Capability to Monitor the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Should be Expanded, Completed, and Sustained.” Summaries are below. Full versions of these and other position statements are available at [www.geosociety.org/PositionStatements](http://www.geosociety.org/PositionStatements).

## REMOVING BARRIERS TO CAREER PROGRESSION FOR WOMEN IN THE GEOSCIENCES

The Geological Society of America (GSA) strongly endorses the right for all to work in a safe, supportive, non-discriminatory, and reprimand-free environment where trust, respect, equity, fairness, accountability, and justice are honored. Data reveal that women are underrepresented in the geoscience workplace and women of color even more so. Women frequently face systemic challenges: they are often paid less than men for the same jobs; receive fewer professional awards to recognize their accomplishments; are disproportionately burdened by service roles; are disadvantaged if they follow alternative career paths due to life circumstances; and often are perceived as less competent than males with identical accomplishments and qualifications. In addition, women of color experience the double bind of gender and racial discrimination, which provides additional challenges to equity. As noted in GSA’s position statement, “Diversity in the

Geosciences Community,” discrimination and loss of equity can be further amplified by LBGQT intersectionality with gender and race. GSA considers sexual harassment, violence, and all forms of discrimination unacceptable and is committed to policies, programs, and services that will ensure the success of women in the geoscience professions.


## PROMOTING EARTH SCIENCE LITERACY FOR PUBLIC DECISION MAKING

The Geological Society of America (GSA) recognizes the critical need for citizens and policy makers to understand important aspects of the earth system as they face issues related to natural resources, energy, natural hazards, and human impacts on the environment. GSA supports the active involvement of geoscientists and geoscience educators in helping to improve knowledge and understanding of the geosciences among members of the general public in order to support informed decision making by Earth’s citizens and communities. GSA and GSA members should contribute to education and outreach about fundamental concepts of earth science, issues related to long-term human sustainability on Earth (such as the use and availability of water, minerals, and energy resources), and socially prominent topics (such as climate change and natural hazards preparedness).

## CRITICAL MINERALS AND MATERIALS

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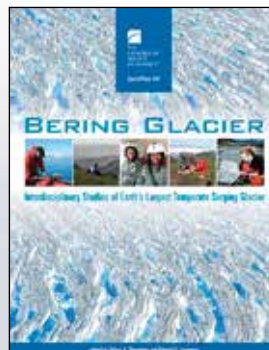
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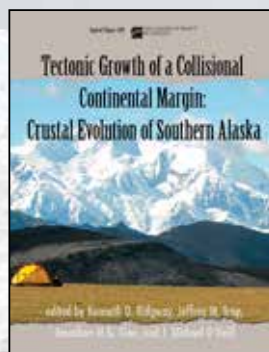


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Twenty-four chapters integrate new geophysical and geologic data, including many field-based studies, to better link the sedimentary, structural, geochemical, and magmatic processes that are important for understanding the development of collisional continental margins.

SPE431P, ISBN 9780813724317, 648 p. | \$9.99



### ***Tectonic Evolution of the Bering Shelf–Chukchi Sea–Arctic Margin and Adjacent Landmasses***

Edited by Elizabeth L. Miller, Arthur Grantz, and Simon L. Klemperer

This volume presents seismic, paleomagnetic, structural, stratigraphic, paleontologic, geochronologic, and geochemical data from this region, and concludes with a plate-tectonic reconstruction of the evolution of the Arctic region.

SPE360P, ISBN 0813723604, 393 p. | \$9.99

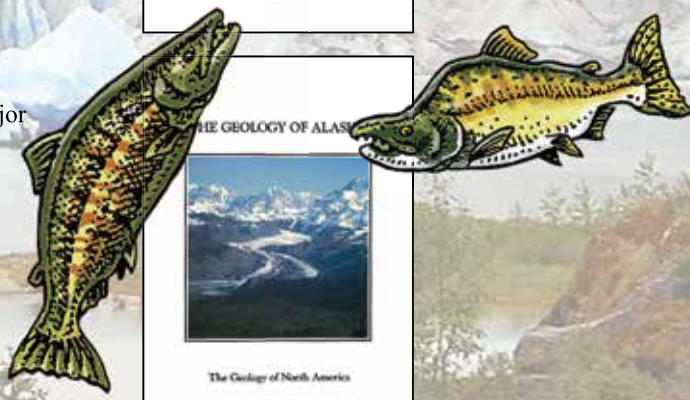


### ***The Geology of Alaska***

Edited by George Plafker and Henry C. Berg

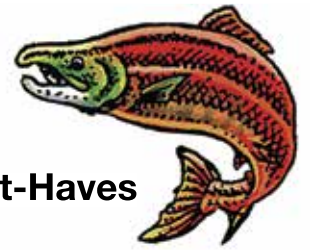
Twenty chapters synthesize data on metamorphic and igneous rocks; major onshore and offshore sedimentary basins; the paleomagnetism evidence for latitudinal displacements and rotations, glacial history and periglacial phenomena; and the occurrence, evolution, and potential of Alaska's vast resources of petroleum, coal, and metallic minerals.

DNAGGNAG1, ISBN 0813752191, 1055 p. | \$9.99





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Salmon art © 2003 by Ray Troll ([www.trollart.com/](http://www.trollart.com/)), illustrator of *Cruisin' the Eternal Coastline*.



# GEOCAREERS Mentoring Tomorrow's Geoscience Leaders at the 2018 Section Meetings

The Geological Society of America GeoCareers Program provides mentoring and career pathway events at all meetings. At Section Meetings, students are invited to participate in the Roy J. Shlemon Mentor Program in Applied Geology and the John Mann Mentors in Applied Hydrogeology Program. These popular events, supported by the GSA Foundation through gifts from Roy J. Shlemon and John Mann (with additional financial assistance from GSA's Northeastern Section), are designed to extend the mentoring reach of individual professionals. Together, mentor volunteers and students meet in a relaxing, informal setting to discuss careers in geology over lunch.

This past spring, 435 students and 52 mentors participated in the Shlemon Program and 164 students and 21 mentors attended the Mann Program. Both mentors and students left the events expressing feelings of personal and professional growth. As a

result of these programs, new friendships were made and professional contacts were established that will last well into the future.

In addition to mentoring, GSA provided three career workshops for students designed to help them plan and prepare for their job search. The workshops covered career planning and informational interviewing, career exploration, and cover letters, résumés, and CVs. Working professionals from academia, government, and industry were invited to answer questions and help attendees maneuver the career exploration process.

GSA gratefully acknowledges the following mentors for their individual gifts of time and for sharing their insight with students. To learn more about these programs, or to be a mentor at a future Section Meeting, please contact Jennifer Nocerino, [jnocerino@geosociety.org](mailto:jnocerino@geosociety.org).

## The Roy J. Shlemon Mentor Program in Applied Geology *Helping Mentor Students Since 1996*

### SOUTH-CENTRAL SECTION

**Whitney Campbell**, Laredo Petroleum Inc.  
**Angela Chandler**, Arkansas Geological Survey  
**ReBecca Hunt-Foster**, Utah Bureau of Land Management  
**Robert Scott**, Precision Stratigraphy Associates

### NORTHEASTERN SECTION

**Erika Amir-Lin**, AECOM  
**Matthew Baird**, Larson Design Group  
**Rose-Anna Behr**, Pennsylvania Dept. of Conservation & Natural Resources  
**Jessi Blanchette**, Virginia State Geological Survey  
**Shane Csiki**, New Hampshire Geological Survey  
**Daniel Dabrowski**, Loureiro Engineering Associates  
**Lindsay Davis**, Geological Society of America  
**Colin Dowey**, Vermont Geological Survey  
**Erik Friede**, GZA GeoEnvironmental Inc.  
**Dave Gauthier**, BGC Engineering Inc.  
**Craig Heindel**, Waite-Heindel Environmental Management  
**Paul Heisig**, U.S. Geological Survey  
**Jinesh Jain**, AECOM

**Aaron Johnson**, American Institute of Professional Geologists  
**Stephanie Kangas**, Conoco Engineers & Scientists  
**John Kelliher**, NRC  
**Lydia Lee**, VHB  
**Brandon Luther**, CME Associates Inc.  
**Stephen Mabee**, Massachusetts Geological Survey  
**David Maclean**, GeoInsight Inc.  
**Liz Royer**, Vermont Rural Water Association  
**Jay Smerekanicz**, Golder Associates  
**Peter Valley**, University of Houston  
**Greg Walsh**, U.S. Geological Survey  
**John Williams**, U.S. Geological Survey  
**Yaicha Winters**, JMT of New York Inc.

### SOUTHEASTERN SECTION

**Charlotte Abrams**, U.S. Nuclear Regulatory Commission  
**W.R. (Will) Doar**, South Carolina Geological Survey  
**Ross Hartleb**, Lettis Consultants International Inc.  
**Robert Morrow**, South Carolina Department Natural Resources  
**Corey Scheip**, AECOM  
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**Beth Johnson**, Braun Intertec Corporation  
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**Stephanie Tassier-Surine**, Iowa Geological Survey  
**Karen Thorbjornsen**, APTIM  
**Kathleen Woida**, USDA Natural Resources Conservation

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**Benjamin Ciampa**, Ninyo & Moore Geotechnical & Environmental Sciences Consultants  
**Joe Cook**, Arizona Geological Survey  
**Brian Gootee**, Arizona Geological Survey  
**Julia Howe**, Bureau of Reclamation  
**Bryn Kimball**, INTERA Inc.  
**Eric McDonald**, Arcadis  
**Angela Roach**, Freeport-McMoRan Morenci Operations  
**Kathleen Springer**, U.S. Geological Survey  
**Erick Weiland**, Freeport-McMoRan



## The John Mann Mentors in Applied Hydrogeology Program

### *Helping Mentor Students Since 2004*

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**Mark Hudson**, U.S. Geological Survey  
**Katherine Knierim**, U.S. Geological Survey

#### NORTHEASTERN SECTION

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**Tim Follensbee II**, Vermont Electric Power Company  
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**Johanna Blake**, U.S. Geological Survey  
**Bonnie Frey**, New Mexico Bureau of Geology & Mineral Resources  
**Marc Mayes**, Earth Research Institute  
**Erick Weiland**, Freeport-McMoRan

## Geoscience Career Exploration Workshops

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**Katherine Knierim**, U.S. Geological Survey  
**Joshua Spinler**, University of Arkansas at Little Rock

#### NORTHEASTERN SECTION

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**Jay Smerekanicz**, Golder Associates  
**Ethan Thomas**, Vermont Agency of Transportation

#### SOUTHEASTERN SECTION

**Larry McKay**, University of Tennessee, Knoxville  
**Alan Troup**, Bechtel  
**Anne Carter Witt**, Virginia Department of Mines, Minerals and Energy

#### NORTH-CENTRAL SECTION

**Ashlee Dere**, University of Nebraska Omaha  
**Jim Eidem**, Barr Engineering Company  
**Mindy Erickson**, National Water Quality Assessment Project

#### ROCKY MOUNTAIN/ CORDILLERAN SECTION

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**Nicolas Barth**, University of California Riverside  
**Angela Roach**, Freeport-McMoRan Morenci Operations



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## GSA THOMPSON FIELD FORUM

14–21 September 2019

### *Age and Carving of Grand Canyon: Toward a Resolution of 150 Years of Debate*

An eight-day, 280-mile field conference by raft through the Grand Canyon, USA.

#### CONVENERS, AFFILIATIONS, AND TOPICS

**Karl Karlstrom**, *University of New Mexico (Grand Canyon geology and tectonics)*

**Laura Crossey**, *University of New Mexico (hydrochemistry, mantle-to-groundwater)*

**Eugene Humphreys**, *University of Oregon (Colorado Plateau, geodynamics)*

**David Shuster**, *University of California Berkeley (thermochronology)*

**Kelin Whipple**, *Arizona State University (geomorphology)*

The age and evolution of the 1.6-km-deep, 270-mile-long Grand Canyon have been debated since J.W. Powell's exploration of the Colorado River in 1869. This GSA Thompson Field Forum honors the 150th anniversary of Powell's trip. It will involve 28 researchers and young scientists who will discuss the evidence for the age and incision history of Grand Canyon in the context of recent advances and ongoing debates. The objective is to promote a next generation of research on the evolution and tectonic geomorphology of this iconic region, as well as similar studies globally, and debate the evidence for and against mantle-driven dynamic topography. The field forum will start and end in Las Vegas, Nevada, USA, and will be run under a charter with Grand Canyon Expeditions (<https://www.gcex.com/motorized/>). Rigorous hiking is planned.

#### Objectives

This Thompson Field Forum will build on synergistic land sessions to showcase field research advances and remaining research questions in this iconic field laboratory. Karl Karlstrom and Laura Crossey will coordinate field stops and discussions of incision data, neotectonics, and lava dam studies. Eugene Humphreys will coordinate geodynamics discussions to debate the hypothesis for mantle-driven uplift of the Colorado Plateau–Rocky Mountain region. David Shuster will coordinate discussions of thermochronologic studies of now-eroded landscapes. Kelin Whipple will coordinate geomorphology discussions of bedrock strength controls on river and canyon morphology and debate evidence for steady versus transient incision.

This research has global reverberations in terms of Cenozoic neotectonics, landscape evolution, and mantle-driven dynamic topography. The objective is to stimulate next steps on these topics.

#### Description

River trips allow several types of interactive sessions: (1) discussions on the outcrop; (2) “plenary” discussions at morning and evening seminars; and (3) short talks and discussions on boats while floating past key areas. Each participant will be asked ahead of time to prepare and lead a seminar or outcrop discussion, with poster-type materials to hold up or pass out. The eight-day river trip covers 280 miles from Lees Ferry to Pearce Ferry such that there is also ample time for one-on-one and small-group informal discussion as we travel downriver. Distance is measured in river miles (RM) downstream from Lees Ferry. On average, we cover about 35 RM per day (four hours per day of motoring through spectacular geology). Numerous hour-long to half-day hikes are planned. Key half-day hikes may be dated strath-to-strath incision history locations at Kwagunt, Palisadea, and Elves Chasm; high terraces near Unkar Rapids; travertines on Tonto Platform near Hermit Creek; dated landslide river diversions near Deer Creek Falls; and lava dam dates and incision points in western Grand Canyon.

#### Logistics

The trip will be run by commercial charter rafting company Grand Canyon Expeditions. Participants arrive in Las Vegas, Nevada, USA, on Friday, 13 Sept., in time for an evening orientation meeting at 7 p.m. An early start with a bus takes us to Lees Ferry for a midday launch on 14 Sept. Camping gear, dry bags, and life jackets are provided to participants. The trip will take out at Pearce Ferry midday on Saturday, 21 Sept., and participants are bused to Las Vegas. Grand Canyon Expeditions uses a jet boat to pick up participants at Separation Canyon (RM 240), which allows more rapid boat transit across the abrupt boundary between the Colorado Plateau and Basin and Range provinces at RM 270 enroute to the take out at RM 280 and discuss the “Muddy Creek constraint.” There will be a final get together that evening, but many participants may want to proceed to Phoenix (a 1.5-hour flight) to check in for the GSA Annual Meeting icebreaker.

#### Preliminary Agenda

13 Sept.: Arrive in Las Vegas; group orientation at Residence Inn Las Vegas Hughes Center (hotel covered in trip cost);

14 Sept.: Bus to Lees Ferry and launch midday;



15–21 Sept.: Group will travel downriver 20–50 river miles (RM) per day, camping on beaches. Possible itinerary:

1. 14 Sept.: RM 0–30: Lees Ferry knickpoint and rock strength discussions;
2. 15 Sept.: RM 30–66: Incision rate measurements and Little Colorado River;
3. 16 Sept.: RM 66–94: Thermochronology of eastern Grand Canyon;
4. 17 Sept.: RM 94–120: Hike to Tonto Platform, carving of inner gorge;
5. 18 Sept.: RM 120–137: Hike Surprise Valley landslide;
6. 19 Sept.: RM 137–178: Muav Gorge and mantle-uplift discussions;
7. 20 Sept.: RM 178–225: Lava dams and Hurricane-Toroweap faults and fault-dampened incision;
8. 21 Sept.: RM 225–280: Western Grand Canyon thermochronology and Muddy Creek constraint; and
9. 21 Sept.: Take out at Pearce Ferry and bus to Las Vegas, arriving by 4–5 p.m. (hotel covered in trip cost).

#### Attendees and Estimated Costs

The registration fee will cover all lodging, including camping gear, all meals, and field trip transportation. The lodging is made up of hotel for two nights (double occupancy) and camping. Participants are responsible for their own transportation to and from Las Vegas, and optional additional travel insurance ([www.tripmate.com/wpF432G](http://www.tripmate.com/wpF432G)). Cost estimate: US\$2,800–US\$3,200 per person. Please check the GSA website for updates at [www.geosociety.org/fieldforums](http://www.geosociety.org/fieldforums). Once the registration fee is finalized, participants will pay a first half deposit by 1 Jan. 2019 and a final payment by 1 June 2019.

#### Application and Registration

1 July: Applications accepted

1 Sept.: Application deadline

1 Oct.: Notification of acceptance (or wait list)

10 Dec.: Registration deadline

All interested participants must apply and be accepted to attend. We invite U.S and international researchers, young investigators, and students to apply. To apply, please email Karl Karlstrom ([kek1@unm.edu](mailto:kek1@unm.edu)) with a letter of intent that includes a statement of your research interests, the relevance of your recent work to the themes of the field conference, the subject of a proposed presentation, and your complete contact information. Students and early career professionals may apply for scholarships by adding a paragraph about their need for scholarship support. Participants must commit to attending the full conference. Group size will be limited to 28 participants.

#### Synergistic “Land Session” Meeting

**22–25 September 2019: GSA 2019 Annual Meeting & Exposition** in Phoenix, Arizona, USA. Thompson Field Forum participants are encouraged to attend, present at, and serve as panelists for the GSA theme sessions that immediately follow the trip.



Near Phantom Ranch, Grand Canyon, USA. Photo by Laurie Crossey.

# GSA Science Communication Fellowship Wrap-Up

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*Beth Geiger, 2017–2018 GSA Science Communication Fellow*

In June 2017, I was thrilled and honored to be selected as GSA's first Science Communication Fellow. This was a 10-month, remote position helping GSA spread the word about research published in GSA journals and at meetings.

I'm originally a geologist, but I've worked as a freelance science writer for quite a while. Though I write about everything from clouds to conservation, geology is by far my first love. So I was especially excited about the opportunity to be re-immersed into the latest research and current hot topics in earth science.

A major part of the Fellowship involved writing monthly press releases, to be distributed on the GSA website and on science news hubs such as EurekaAlert. As a science writer, I'm often assigned stories based on press releases that my editors have seen. But with the GSA Fellowship I found myself in a different place, at the very beginning of that process, reviewing and selecting interesting technical papers and then writing the press releases that summarize and publicize them.

It's a fascinating challenge. What research will seem important and/or intriguing to the lay public? Can I explain the science, its context and its implications, clearly enough to catch the eye of the media? (And of course accurately: I am always gratified ... and relieved... when a researcher tells me I explained their work well.) Choosing a paper to promote also meant digging into the backstory to learn if the results resolve a long-standing debate, forge into important new territory, or just add incrementally to previous work.

I soon realized that the power to choose papers for news releases also came with responsibility. After all, my selection and my words could lead to more publicity for a researcher, and perhaps more recognition and funding. In one case, for example, I emailed a British researcher to tell him my press release about his upcoming *Geology* paper had been posted that day. "I know," he emailed right back. "The BBC just called me."

Another significant role of the Science Communication Fellowship was assisting with media-related tasks for the GSA Annual Meeting in Seattle in October 2017. Before the meeting, along with several other writers and GSA staff, I helped choose 20 abstracts out of nearly 5,000 to highlight for the press. Just reading through all those abstracts was dizzying: equal parts exciting geologic journey, "aha" moments, and brain fry. After three or so conference calls, we'd agreed on a mix of abstracts that

had high public interest (think landslides and earthquakes), were geologically groundbreaking, or in a couple cases, were just fun. Here, especially, I think my geology background really helped.

At the Seattle meeting I helped run the onsite newsroom, where journalists could pick up press releases and tip sheets, stash their coats, mingle, and have a quiet place to file stories. I was also able to interface with GSA leadership and attend presentations and social events that gave me an inside view of what is happening in the world of geology.

In addition, I had the pleasure of mentoring four graduate student Science Communication Interns at the 2017 Annual Meeting. Each developed a blog post based on a technical talk of their choosing. Working with them and editing their drafts after the meeting was fun and rewarding. It gave me new insights into the nitty gritty of the writing process and what it really takes to communicate a technical topic in a clear and compelling way.

The GSA Science Communication Fellowship has been a wonderful experience for me. Selecting papers and writing press releases gave me an appreciation for that process, which I've usually only experienced from the other side, and I think made me a better writer. I made great contacts, some new and some renewed, and even met some true legends of geology. And I really enjoyed mentoring and editing aspiring science writers, too.

I hope my work has helped GSA spread the word about how cool and relevant earth science is. I also hope to contribute to GSA's media efforts in the future. For others interested in this or similar opportunities, I would say that excitement about earth science, the willingness to meet particular editorial needs, and some experience writing for lay audiences will go a long way.

GSA staff, particularly my main contacts Justin Samuel and Christa Stratton, were great to work with. I extend a heartfelt thanks to them, and also to Bruce and Karen Clark, who graciously funded the fellowship, for providing me with this terrific opportunity.





## Geoscience Jobs & Opportunities

Ads (or cancellations) must reach the GSA advertising office no later than the first of the month, one month prior to the issue in which they are to be published. Contact advertising@geosociety.org, +1.800.472.1988 ext. 1053, or +1.303.357.1053. All correspondence must include complete contact information, including e-mail and mailing addresses.  
**Online: [www.geosociety.org/jobs](http://www.geosociety.org/jobs).**

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Apply online at <http://employment.ku.edu/academic/12288br> for the Hydrogeochemist and at <http://employment.ku.edu/academic/12289br> for the Groundwater Hydrologist. For further information contact Geoff Bohling ([geoff@kgs.ku.edu](mailto:geoff@kgs.ku.edu)) or Don Whittemore ([donwhitt@kgs.ku.edu](mailto:donwhitt@kgs.ku.edu)). For further information about other aspects of the position, contact Annette Delaney, HR, at [adelaney@kgs.ku.edu](mailto:adelaney@kgs.ku.edu) or +1-785-864-2152. KU is an EO/AAE, <http://policy.ku.edu/IOA/nondiscrimination>.

#### TWO FACULTY POSITIONS IN PETROLOGY/VOLCANOLOGY AND MINERAL RESOURCES

##### UNIVERSITY OF ALASKA ANCHORAGE

The Department of Geological Sciences at the University of Alaska Anchorage ([www.uaa.alaska.edu/geology/](http://www.uaa.alaska.edu/geology/)) seeks to hire two tenure-track faculty members (open rank), with a start date of August 2019. We aim to expand and complement existing areas of research expertise in the Department which include geochemistry, structural geology, sedimentology, stratigraphy, petroleum geology, geophysics, hydrogeology, and planetary geology. The successful candidates are expected to teach undergraduate and graduate courses to a diverse student body in the B.S. and M.S. programs in geological sciences.

(1) Igneous/Metamorphic Petrology and/or Volcanology: Teaching expectations for this position include igneous & metamorphic petrology, vol-

canology, geological field methods or field camp, advanced petrology, and other courses in support of the Department's teaching needs.

(2) Mineral Resources and/or Economic Geology: We encourage applications from individuals with expertise in one or more of the following areas: economic geology; mining geology; mineral resources in magmatic, hydrothermal, and/or placer deposits; structure and emplacement of ore deposits; or mineral exploration. Teaching expectations for this position include mineralogy, ore deposits, geological field methods or field camp, advanced mineral resources, and other courses in support of the Department's teaching needs.

We seek applicants with a commitment to teaching, research, and partnership building with resource industries and research organizations in Alaska and elsewhere. Successful candidates must develop externally funded research that actively involves graduate and undergraduate students. Both positions require a Ph.D. in geological sciences or a related field at the time of initial appointment, university teaching experience or potential, and demonstration of research experience and future potential. Relevant industry or post-doctoral experience will be considered favorably.

Please submit a cover letter, curriculum vitae, a statement of teaching and research interests that includes how you will involve students in research opportunities, contact information for at least three references, and unofficial academic transcripts to [careers.alaska.edu](http://careers.alaska.edu) for: (1) posting 509521 (petrology or volcanology); or (2) posting 509519 (mineral resources). Review of applications will begin September 24, 2018.

For more information regarding these positions, please contact the department director, Dr. Simon Kattenhorn: [skattenhorn@alaska.edu](mailto:skattenhorn@alaska.edu).

UAA is an AA/EO Employer and Educational Institution. Applicant must be eligible for employment under the immigration Reform and Control Act of 1986 and subsequent amendments. Your application for employment with UAA is subject to public disclosure under the Alaska Public Records Act.

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### Structural Geologist

The Department of Geology at Stephen F. Austin State University invites applications for a tenure-track position at the assistant (or associate) professor level. Applicants must have a doctoral degree in geology or a related field with emphasis on structural geology and field camp, a strong commitment to excellence in teaching and a willingness to direct Master of Science geology students in research. Preference will be given to candidates with structural geology and field camp teaching and/or research experience. Teaching responsibilities for structural geology will include introductory courses, upper-level and graduate courses in the applicant's specialty, and occasional weekend field-trip courses. Teaching responsibilities for field camp will include teaching or co-teaching field methods in the spring semester and co-teaching summer field camp. Other expectations include research, university service and continuing professional development.

To apply and submit required documents, please visit: <http://careers.sfasu.edu/postings/2803>.

Review of applications will begin on September 3, 2018, and will continue until the position is filled. SFA is an equal opportunity employer. This is a security-sensitive position and will be subject to a criminal history check.



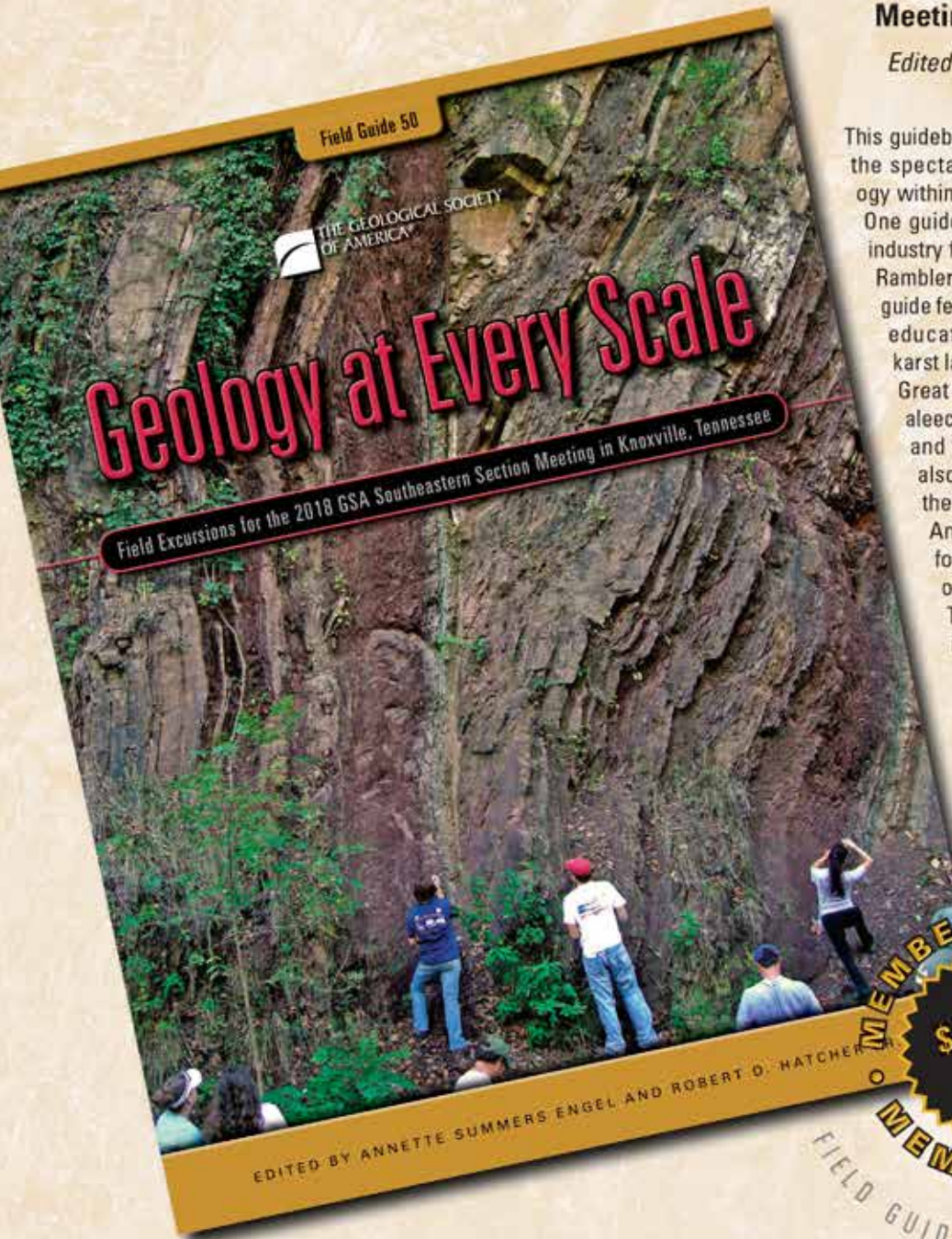


## Geology at Every Scale: Field Excursions for the 2018 GSA Southeastern Section Meeting in Knoxville, Tennessee

*Edited by Annette Summers Engel and Robert D. Hatcher Jr.*

This guidebook contains nine field trips that highlight the spectacular sedimentary and structural geology within, and surrounding, Knoxville, Tennessee. One guide focuses on the East Tennessee marble industry from the vantage point of the Three Rivers Rambler excursion train in Knoxville, and another guide features limestone-centric lessons for STEM educators. Three guides explore the region's karst landscape and geological curiosities in the Great Smoky Mountains National Park and Tuckaleechee Cove, the Flynn Creek impact structure, and the Gray Fossil Site, for which that guide also provides training in nutrient hotspots at the Body Farm—the University of Tennessee Anthropological Research Facility. The last four guides examine regional structural geology and tectonics, including of the Eastern Tennessee seismic zone, the Nashville dome in central Tennessee, and the Blue Ridge and Inner Piedmont belts of the Carolinas and Georgia.

FLD050, 209 p., ISBN 9780813700502  
list price \$60.00 | **member price \$42.00**



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## Women in Geology—A Rich History For Tomorrow’s Geoscientists

The geosciences have a rich history full of remarkable geologists, and many of GSA’s programs and awards were founded to honor and celebrate these individuals’ legacies. Yet, there are many voices that have been lost from—or worse, written out of—our history. The lives and contributions of women to our science are being more fully recovered, documented, and equally celebrated, so that their experiences may help inform and inspire current and future geoscientists.

*Anomalies—Pioneering Women in Petroleum Geology: 1917–2017*, by Robbie Gries, president of the Geological Society of America, examines the lives of these remarkable women as scientists, entrepreneurs, and philanthropists. Initially setting out “to preserve our stories—mainly thinking about we women who made our 1970s debut into the ‘no woman’s land’ of the oil patch,” Robbie’s book grew to encompass a broader history.

The main objective for this book was to uncover the history of women in the science and business of petroleum geology, to appreciate their lives, their struggles, their successes, and their failures. Robbie notes, “I wanted to better appreciate the building blocks they provided to our generation and future generations.”

Through her research, including informative and inspiring interactions with the relatives and descendants of many of these early pioneers, Robbie shares with us their stories so that “young people who fall in love with geology, as these women did, will enjoy knowing of their adventures, adversities, successes, and inspirational effect.”

The ability to share one’s experience and wisdom with the next generation lies at the heart of a GSA program at our annual meeting—the Women in Geology Career Pathways Reception and Mentor Roundtables. Speakers from various employment sectors share their experience of being a woman in geology, touching on some of the positives as well as challenges they have faced through the years. Afterward, female mentors are available at round tables to meet with students and early career professionals in small groups to discuss these topics in more depth. Participants are encouraged to ask questions and network with their peers.

Speaking of her own experience in the Career Pathways Reception, Robbie tells us, “It is always uplifting to talk to the young women at the GSA receptions, to see their faces light up with our tales and experiences, to think we might be an inspiration too.” The impact these mentors can have on students is profound. One participant told us in their program evaluation, “As a grad student that is contemplating starting a family and striving for a work-life balance, I found the stories and tips very useful. You were all very inspiring!”

Join us in ensuring that the experiences and stories of women in the geosciences will be preserved and shared. Your support allows us to continue mentor programs where future geoscientists can be inspired by this important information. Contact Clifton Cullen at +1-303-357-1007 or [ccullen@geosociety.org](mailto:ccullen@geosociety.org) to learn more.



Robbie Gries speaking at the 2018 GSA Women in Geology Career Pathway Reception.



Participants have the opportunity to ask questions and talk about their experiences during the mentor roundtables.

## Using place-based, community-inspired research to broaden participation in the geosciences

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### INTRODUCTION

There is no question that the geoscience community needs to be more diverse. The National Center for Science and Engineering Statistics (NCSES, 2017) reports over 80% of college and graduate degrees earned by U.S. citizens in the geosciences are awarded to Caucasians. The geoscience community has recognized this discrepancy. The National Science Foundation Directorate for Geosciences continues to make diversity a top priority and emphasizes broadening participation efforts through funding curriculum, instruction, and research opportunities designed to engage students from underrepresented populations.

Much research has been done on geoscience curricula and instruction that engage a broader audience (e.g., Kober, 2015; Singer et al., 2012). Others describe research experiences that have successfully engaged underrepresented students (e.g., Dalbotten et al., 2014; Haacker, 2015; Huntoon et al., 2015). These publications describe elements of Research Experience for Undergraduates (REU) models that prove successful in engaging and retaining students from underrepresented groups. We present another model for engaging underrepresented students—the REU site on Sustainable Land and Water Resources (SLAWR)—that is unique for its emphasis on recruiting Native American students and for its emphasis on place and community. For our model, “place” encompasses both the physical landscape related to the research sites and the human connections to those places. Under our approach, research topics are identified through systematic collaboration with communities tied to these places.

### THE RESEARCH MODEL

The REU-SLAWR research sites are located on tribal lands and in urban environments where underrepresented students live and work. Students are advised by a team of researchers from the Confederated Salish and Kootenai Tribes, the Fond du Lac Band of Lake Superior Chippewa (FDL), Salish Kootenai College (SKC), the National Center for Earth-Surface Dynamics (NCED), and the University of Minnesota Twin Cities and Duluth (UMN/UMD). Projects are developed in collaboration with tribes’ resource management divisions.

The REU is rooted in an interdisciplinary team-oriented approach that emphasizes quantitative and predictive methods, indigenous research methodologies, and traditional ecological knowledge. Leaders incorporate a full-day seminar on indigenous research and community-based participatory research (CBPR) for students and mentors during orientation to help the students make connections between their research and local communities’ needs and interests. Projects typically focus on native species and habitat restoration to enhance biodiversity and support cultural values. Student projects at Fond du Lac have focused on wild rice, a plant that is culturally significant to the Ojibwe. Research projects have examined the impact of sulfides and sulfates on plant health. Data about these relationships provide tribal and non-tribal officials with information about mining impacts in Minnesota. Team SPAW (Salish and Pend D’Oreille Aboriginal Watershed) projects include habitat characterization of culturally significant blue camas and wild huckleberries. These characterizations include study of soils, plant communities, pollinators, macro-invertebrates, reptiles, amphibians, birds, and

mammals including bears and bats, water quality, invasive species, and other land and water resource issues. Team Stream has focused on issues of sediment transport related to stream restoration and debris flow prediction using state of the art facilities at UMN’s St. Anthony Falls Laboratory (SAFL) for computational modeling development. In 2017, Team Stream partnered with FDL to develop a project focused on Spirit Island, an island in Spirit Lake, which is an estuary of the St. Louis River that drains into Lake Superior, newly acquired by FDL in 2016. It is one of the most culturally significant sacred sites for the Ojibwe people. The tribe is concerned about the continued existence of the island because of shoreline erosion and changes to current patterns in the Lake Superior Estuary. Researchers at SAFL have been working on a computer model of the problem. A new project using complementary physical modeling was developed in conjunction with this research.

Teams in Montana and at FDL who work directly on projects of cultural significance present their research to governing boards of the tribes. For example, in 2017 both our wild rice team (Team Zaaga’igan) (whose research outcome showed that sulfates do impact wild rice growth) and the Spirit Island team (Team Spirit) worked on projects that were developed with FDL Resource Management. The students presented their results to resource managers from Minnesota and Wisconsin at the Great Lakes Indian Fish and Wildlife Commission Voigt Taskforce meeting. Furthermore, nine of 14 students from the 2017 REU went on to present at national conferences in the months following the REU. Dissemination of research



Table 1. Demographic data collected from REU\* participants from 2012–2017

	No. students (%)	Age range (avg.)	>25 years old (%)	Parents (%)	No. of students who consider place important (%)
All REU participants	98	18–54 (26)	31 (32%)	26 (27%)	49 (50%)
Native American REU participants	41 (42% of total)	19–54 (29)	25 (61% of Native students)	22 (54% of Native students)	27 (66% of Native students)

\*REU—Research Experience for Undergraduates.

findings occurs at different levels—locally to tribal governments as well as nationally.

### SUCCESS OF THE SLAWR MODEL AND LESSONS LEARNED

Data collected from participants (Table 1) highlight the importance of place and community for Native American participants. When project evaluators asked students if the location of the REU site influenced participation in the summer program, about half said “yes,” which was not necessarily surprising. What was surprising were responses that students provided to the open-ended question of *why* place mattered. A thematic content analysis of all responses from Native American students revealed that the majority listed family responsibilities (36%) and being close to home (28%) as reasons they selected and applied for the REU-SLAWR. Others noted interest in the unique landscape of the area (14%), the place-based nature of the research projects (14%), and working in Native communities (8%) as factors that played into their decision to apply. In comparison, non-Native students who indicated that place was important identified the landscape/geography and field-based research topics as reasons why they applied to the REU, with far fewer noting family responsibilities or proximity to their home as reasons they decided to participate.

These responses to the importance of location were different than expected, but understandable given that the Native American REU-SLAWR students were, on average, slightly older and made up the majority of the participants with children (85%). The data from participants suggest that physical proximity of the REU site to their homes helped facilitate Native student participation by allowing participants to meet their family obligations while also gaining research experience. That research topics were locally relevant was also an important draw as participants were aware that their research findings would directly impact their home communities in which the research was conducted.

As the project evolved, student feedback helped REU leaders appreciate how

important and interrelated place, community, and family were for Native American students in particular. In interviews, students noted that while it was difficult to balance family responsibilities with the responsibilities required of the REU, accommodations for family made it possible to participate in the project when they would not have otherwise been able. Leaders also responded to student feedback indicating needed clarity on how or why their projects were community-based because planning occurred before the students arrived onsite. In response, the leaders made the connections with the projects and local communities more explicit and included more CBPR material as part of orientation.

### NEXT STEPS

The REU-SLAWR completed its sixth season and continues to refine its model to best support the needs of the diverse students who participate each year. In addition to annual project evaluation, the project leaders are planning to conduct a longitudinal analysis of student data collected since the start of the REU to identify the most influential model elements that recruit, support, and retain students from underrepresented groups in the geosciences. These essential elements can be used as a model for other REUs who wish to broaden participation in the geosciences.

The REU-SLAWR is developing new approaches to undergraduate research that focus on place-based projects that are relevant to students and their communities. A few of the things that the REU-SLAWR does to support diversity in the program include: (1) ensure that students have a paycheck the day they arrive; (2) encourage students to let the leaders know if they have any cultural events (e.g., powwow) or other issues and make allowance for these things; (3) value and incorporate traditional knowledge and cultural information and encourage students to share it; and (4) put students on teams and emphasize teamwork over individual success.

The REU-SLAWR offers a new paradigm for undergraduate research that incorporates

place-based and community-based participatory research, and all mentors and participants are trained in this approach. The hope is that this experience will prepare Native Americans to fill resource management positions and prepare the next generation of researchers in best practices for doing research on tribal lands.

### ACKNOWLEDGMENTS

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## Rapid 3-D analysis of rockfalls

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### INTRODUCTION

On the afternoon of 27 Sept. 2017, thousands of visitors to Yosemite National Park were enjoying scenic attractions in Yosemite Valley. Dozens of rock climbers were scaling El Capitan, a 900-m-tall granitic cliff famous for its challenging climbing routes. Suddenly, at 13:51 Pacific Standard Time (PST), a rock slab detached from 230 m up the southeast face of El Capitan. Tragically, rock debris struck two rock climbers walking along the base of the cliff, killing one and seriously injuring the other. Over the next three hours, as the park's search and rescue team worked to extract the climbers, six more rockfalls originating from the new scar pummeled the base of the cliff. The following afternoon at 14:21 PST, a much larger rockfall occurred from the same location. A massive slab fell from just above the previous day's rockfalls, fragmenting on impact and generating an enormous dust cloud (Fig. 1). A rock fragment struck a vehicle, puncturing the sunroof and injuring the driver, prompting temporary closure of the main road exiting Yosemite Valley. To manage these challenging events, the National Park Service (NPS) had a critical, immediate need for quantitative information regarding the sequence of events and the potential for additional rockfalls.

### BASELINE DATA COLLECTION

Rockfalls are common in Yosemite Valley, with up to 80 events documented each year (Stock et al., 2013). Rockfalls are the dominant erosional process in Yosemite, key to shaping this iconic landscape but also, with 4–5 million visitors to the park each year, posing significant risk (Stock and Collins, 2014). With more than 50 km<sup>2</sup> of rockfall-prone cliffs in Yosemite Valley alone, it is difficult to anticipate when and where the next rockfall will occur. Accordingly, we have spent the past

decade collecting baseline remote sensing data of the cliffs, including gigapixel imagery, infrared thermal imagery, and high-resolution terrestrial laser scanning (TLS) data. These data allow us to track rockfall activity, quantitatively document events, and evaluate rockfall susceptibility (e.g., Stock et al., 2017; Matasci et al., 2018). El Capitan has been a particular focus, with five TLS acquisitions since Oct. 2010. We also generated a “historical” 3D model using Structure-from-Motion (SfM) photogrammetry techniques (Westoby et al., 2012; Guerin et al., 2017); derived from black-and-white photographs taken from a helicopter ca. 1976, this SfM model shows El Capitan as it looked more than 40 years ago (Stock et al., 2017). All of these baseline data proved critical for

rapidly analyzing the rockfalls that occurred in Sept. 2017.

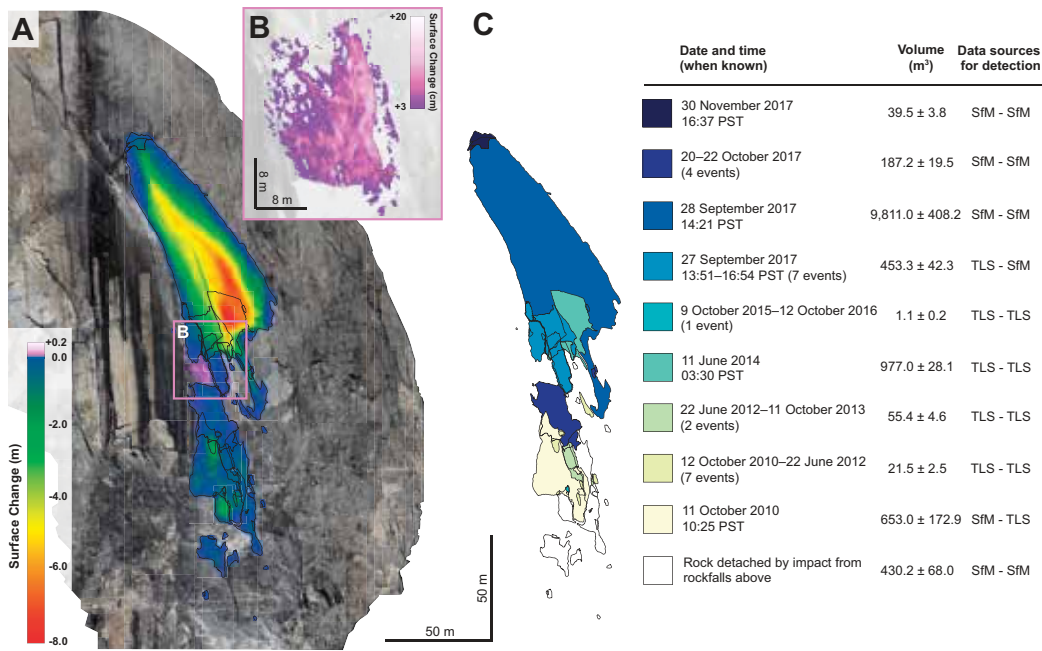
### RAPID ANALYSIS OF THE EL CAPITAN ROCKFALLS

Within three hours of the initial rockfall on 27 Sept., we acquired photographs of the cliff from a helicopter. We built a SfM point-cloud model from these photographs, aligned it with earlier TLS data, and performed a point-to-mesh comparison (e.g., Guerin et al., 2017). The resulting difference map yields precise locations, dimensions, and volumes for the rockfalls (Fig. 2). The cumulative volume of all rockfalls on 27 Sept. was  $453.3 \pm 42.3$  m<sup>3</sup>, with the first event being the largest at  $290.0 \pm 27.8$  m<sup>3</sup>. We repeated this process the following day



**Figure 1.** A 9,811 m<sup>3</sup> rockfall from the southeast face of El Capitan at 14:21 PST on 28 Sept. 2017. Photo by Przemek Pawilkowski.





**Figure 2. Spatial and temporal progression of rockfalls from the southeast face of El Capitan between Oct. 2010 and Nov. 2017. (A) Structure-from-Motion (SfM) model with color overlay showing the spatial progression of rockfalls, derived by comparing SfM models against earlier terrestrial laser scanning data (TLS). Negative surface change represents rockfall thicknesses; positive surface change, shown in (B), represents outward displacement of a rock sheet by up to 20 cm. (C) Temporal progression of rockfalls occurring between Oct. 2010 and Nov. 2017.**

after the larger 28 Sept. rockfall, comparing the new SfM model against data collected the previous day (Fig. 2). The 28 Sept. rockfall was 120 m tall, 45 m wide, and up to 8 m thick, with a total volume of  $9,811.0 \pm 408.2 \text{ m}^3$ . The impact of the collapsed slab on the cliff below dislodged another  $430.2 \pm 68.0 \text{ m}^3$ . Thus, the 28 Sept. rockfall was 23 times larger than the rockfalls that occurred the previous day. Within 24 hours, the NPS was able to disseminate this information to the public via press releases and social media.

Importantly, the data also informed NPS decisions regarding public safety. Structural assessments of discontinuities and plausible future rockfall volumes, enabled by the 3D data, indicated low potential for an imminent rockfall that could reach the road, allowing the road to be reopened. Comparing the volumetric data with historical events (Stock et al., 2013) puts these rockfalls in perspective: the 28 Sept. rockfall was the 29th largest rockfall occurring in Yosemite since 1857, and has a return period of ~6 years.

After the immediate crisis had passed, subsequent analyses offered further insights into the longer-term evolution of the cliff. This area of El Capitan became active in Oct. 2010 (the first activity since at least 1976), with rockfalls occurring sporadically over the next several years, culminating in the large rockfalls on 27–28 Sept. 2017 (Fig. 2C). Subsequently, several smaller rocks fell in Oct. and Nov. 2017. Typical of progressive exfoliation-type failures (Stock et al., 2012), the rockfalls generally propagated upward from the location of the first event. The

rockfalls mostly consisted of rock sheets tens of meters tall and wide but usually <1 m thick (Fig. 2A); more widely spaced regional joints influenced detachment of the larger-volume rockfalls. Finally, whereas differencing of SfM and TLS models typically yields negative surface change indicative of material loss, models generated after the Oct. 2017 rockfalls revealed an area of positive surface change. Here, a rock sheet 23 m tall, 14 m wide, and tens of cm thick rotated outward up to 20 cm along a vertical hinge line on its western side (Fig. 2B). The sheet is bounded on three sides by rockfall scars, and likely displaced during or immediately after the 22 Oct. 2017 rockfall. This geometry, combined with a simplified fracture mechanics analysis, indicates that the sheet should detach with another 20% of fracturing along the partially attached side. Although the 3-D data do not allow us to predict exactly when this will occur, they do define the precise location and volume of this future rockfall.

Our analysis of the El Capitan rockfalls demonstrates the utility of SfM for quickly generating 3-D cliff models that quantify rockfalls, and reinforces the value of having baseline data in place prior to a critical event. The ability to rapidly collect, analyze, and disseminate rockfall data in near-real time represents a significant stride forward in informing land managers and the public about this potent natural process.

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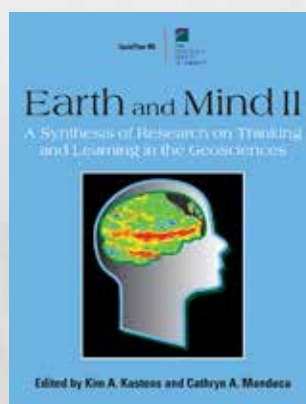
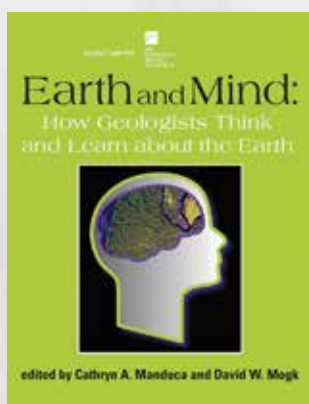
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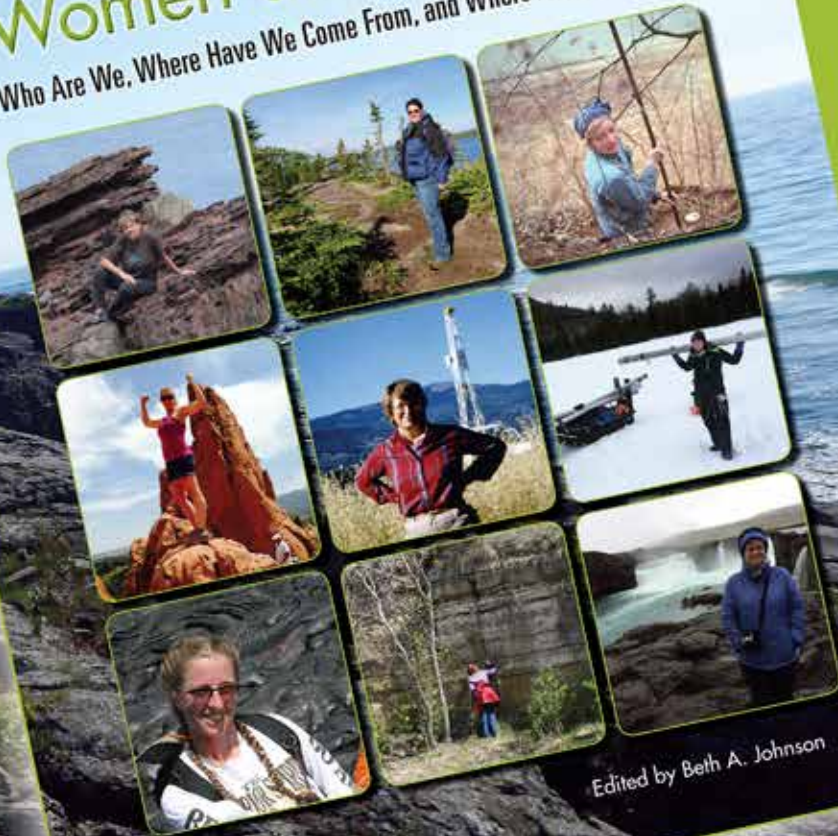
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