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GSA TODAY

THE MEMBERSHIP PUBLICATION OF THE GEOLOGICAL SOCIETY OF AMERICA™

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Forging Paths to Inclusive Geoscience Field Education

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GSA TODAY

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Photo credit: wanderluster / E+ via Getty Images.

Three hikers on a trekking adventure walk on dangerous ridges with deep crevasses and blue water on Lemon Glacier, Juneau Icefield, Juneau, Alaska, USA. See related article on pages 4–5.

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Erratum: The July issue of *GSA Today* mistakenly omitted the name of newly elected Fellow Daniel Jones of New Mexico Tech. Dr. Jones's nominator, Lewis Land, says of him: "Dr. Daniel Jones is a geobiologist who studies the influence of microbial metabolisms on mineralogical and biogeochemical processes, crossing disciplinary boundaries between biology and geosciences. His support and promotion of the work of students and early career geoscientists is helping to build the future of the Geological Society of America."
GSA Today regrets this omission. Congratulations, Dr. Jones!

THE GEOLOGICAL SOCIETY OF AMERICA®

A Virtual Expedition to the Juneau Icefield

Allie Balter-Kennedy,[1, 2, †] Arianna Varuolo-Clarke,[1,2,*, †] Seth Campbell,[2,3] and Alex Eppel[4]

INTRODUCTION

The Juneau Icefield Research Program (JIRP) and Upward Bound (UB) have partnered to offer new field and classroom programming to increase the number of UB participants, many of whom have identities that are underrepresented in the polar sciences, who go on to major in related fields in college. UB is a Department of Education–funded college preparation program for high school students from low-income families where neither parent holds a bachelor's degree. JIRP, operated through the University of Maine, has offered research opportunities and field training on the Juneau Icefield, Alaska, since 1946. Here, we outline a two-week virtual polar science course that complements the UB summer field programs on the Icefield.

Understanding, predicting, and responding to unprecedented climate changes, which are amplified in the polar regions (e.g., Rantanen et al., 2022), requires knowledge from a diverse group of researchers (Medin and Lee, 2012). Yet polar science has historically struggled to support racial, gender, economic, and ability diversity (Hulbe et al., 2010; Carey et al., 2016; Seag et al., 2020). Field experiences can attract students to the polar sciences but can also pose significant barriers to students with minoritized identities (e.g., Demery and Pipkin, 2021; Giles et al., 2020). Innovative programs like Inspiring Girls* Expeditions (e.g., Young et al., 2023) and GeoSPACE (Marshall et al., 2022) are re-envisioning inclusive geoscience field education. Since its inception, JIRP has been a pipeline to careers in the polar sciences; nearly 2,000 students, faculty, and staff have conducted research resulting in ~70 M.S. and Ph.D. dissertations and >1,000 reports and publications. The JIRP-UB partnership leverages the JIRP network and infrastructure to engage a new, diverse generation of polar scientists.

Students from the Washington State University (WSU) UB program, which serves residents of the Colville Reservation and the broader Okanogan County, were set to participate in the inaugural JIRP-UB field course in 2021, but this field experience was delayed due to COVID. To fill this gap, we designed a two-week virtual course titled "A Virtual Expedition to the Juneau Icefield," which we delivered to WSU UB students in the summer of 2021. Authors AVC and ABK, at the time both Ph.D. students at Columbia University in the Department of Earth and Environmental Sciences, designed and instructed the course. AVC, a first-generation college graduate, woman of color, and atmospheric scientist, was an undergraduate student at JIRP in 2015. ABK, a white woman and glacial geologist, served as JIRP research faculty in 2019. Our two-week virtual course used JIRP as a framework and mimicked the arc of a polar science research project, from conception to field expedition to data analysis and communication. We strove to also highlight the many ways to be a polar scientist beyond fieldwork and integrate our personal experiences as scientists.

THE VIRTUAL EXPEDITION

The two-week course was designed so that the second week built off the first, but students could participate in either week without being required to do the other. Throughout the course, we communicated via satellite text with author and JIRP Director SC, who was instructing JIRP's flagship field course during the same time period, so that students could ask questions about research and life on the Icefield.

Week 1: Designing a research project on the Juneau Icefield

In the first week, students developed tools to plan their own scientific expedition to the Juneau Icefield. Week 1 lectures, activities, and homework covered (1) the climate of the Juneau Icefield; (2) an overview of what it is like to live and work on the Icefield; (3) interactions between glaciers and climate; and (4) the basics of glacier mass balance, the sum of yearly ice accumulation and loss on a glacier.

During a climate observations activity, adapted from Doughty (2013), we split students into three breakout rooms, each with 3–4 students, to become "experts" in one of three climate factors: temperature, topography, or glacier distribution. To do so, the students made observations about the global patterns of their climate factor from maps. We then shuffled groups so that each new group contained at least one temperature, one topography, and one glacier expert. In the new groups, students hypothesized about how glaciers and climate interact. For example, one group hypothesized that "mountains have a colder temperature than its [*sic*] surrounding regions which can lead to forming of glaciers."

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CITATION: Balter-Kennedy, A., et al., 2024, A virtual expedition to the Juneau Icefield: GSA Today, v. 34, p. 4–5, https://doi.org/10.1130/GSATG585GW.1.

For the Week 1 final project, students created a plan for a scientific expedition to the Juneau Icefield. After learning about life on the Icefield, students developed a list of personal gear that they would bring on their expedition. The following day, we split students into their expedition groups, in which they picked a research question, wrote a paragraph describing their motivation for the study, and briefly described what measurements they would make in the field. Each group posed a research question; one asked, "How much snow is left after summer?" and the other asked, "What is the most common plant species on rock outcrops at the Juneau Icefield?" For homework, each student wrote one hypothesis for their proposed research project. On the last day of class, the groups presented their proposed research expedition.

Week 2: Making sense of scientific data from the Juneau Icefield

During Week 2, we imagined we had returned from our expedition to the Juneau Icefield with glacier mass balance data to analyze. Several new students joined in Week 2, so we reviewed glacier mass balance concepts and re-ran the climate observations activity. To reduce repetition for returning students, we added a global precipitation map to further emphasize the relationship between glaciers and global-scale climate patterns.

Our final activity was to analyze mass balance data sets from the Taku and Lemon Creek Glaciers, outlet glaciers of the Juneau Icefield that JIRP has monitored since the 1940s and 1950s (McNeil et al., 2020). Students performed the analysis in Google Sheets, following along with one instructor who was sharing their screen. The other instructor monitored the chat and was available to go into a breakout room with any students who were experiencing difficulties. Students produced figures to compare year-to-year variability in mass balance against the long-term trend. They also explored the relationship between glacier melt and warming temperatures by plotting glacier mass balance versus local summer temperature. In doing so, the students reproduced a figure from an article published in the *Journal of Glaciology*. For many, this was their first experience producing a figure from scientific data.

FEEDBACK AND RESOURCES

Survey responses at the end of Week 1 indicated students enjoyed learning about glacier mass balance and designing an expedition, and they looked forward to joining the second week. Post-course feedback from AE and other UB instructors emphasized that the course was effective in building enthusiasm for the polar sciences and engaging students in the scientific process. In 2022 and 2023, ~150 UB students participated in cost-free field programs in Alaska, with additional programs planned for 2024, demonstrating the overall success of the JIRP-UB partnership (Campbell et al., 2024). The curriculum described here serves as one of many classroom resources that JIRP-UB is developing to reach additional students. The curriculum is available at bit.ly/virtual-jirp. We hope other educators will adapt our course to bring the Juneau Icefield to their own classrooms.

ACKNOWLEDGMENTS

We acknowledge the many folks planning and teaching field and classroom programs through the JIRP-UB partnership, supported by NSF RISE Award #2119883 to SC. Our curriculum draws from workshops for UB students in New York City, organized by Dr. Elizabeth Case and co-taught by EC, AVC, and ABK. We thank Meghan Carranza, director of WSU UB Okanogan County, a federal TRIO program funded by the U.S. Department of Education.

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THE GEOLOGICAL SOCIETY OF AMERICA®
CONNECTS 2024
22–25 September
Anaheim, California, USA

LETTER FROM THE GSA ACTING PRESIDENT

Welcome

I'm excited to welcome you to GSA Connects 2024 in Anaheim, California, taking place from 22–25 September. GSA Connects is back in Southern California after a long hiatus, and it's exciting to be in this geologically dynamic corner of the country. It is likely to be hot in Anaheim, so I hope you'll take the time to enjoy the local amenities, such as Disneyland or one of the nearby Pacific beaches.

As always, GSA Connects affords ample opportunity for scientific engagement and networking with colleagues. Themes for Connects 2024 focus on **Water in a Changing World** and **Life Along an Active Margin**, both topics deeply relevant to Southern California, and there will be numerous sessions focused on these themes. But the science at GSA Connects is wide-ranging and there will be symposia and topical sessions spanning all the geoscience disciplines.

The **Exhibit Hall** will be a lively space with our vendors, sponsors, and a few new touches this year. There is a broad slate of field trips including excursions to see the dynamic geology across Southern California and as far away as the Sierra Nevada and Hawai'i. In partnership with Mountain Press, we've crafted a poster-sized geological map of Southern California that highlights exemplary geosites across the region—it's suitable for framing, and I encourage you to snag a copy of this map while you're at Connects.

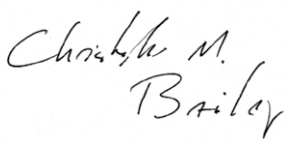
"THIS EXCITING EVENT WILL CELEBRATE THE OUTSTANDING ACHIEVEMENTS OF OUR GSA MEMBERS AND FELLOWS..."

The five Pardee Symposia will cover a wide range of important subjects, from water and wildfires to sustainability and critical minerals—plus, there is a session that discusses insights from 130 years of research in the Turkana Basin of East Africa. This year's Halbouty Distinguished Lecture (Tuesday at 12:15 p.m.) will be delivered by Lawrence Meinert, who will discuss **Limits to Growth—Revisiting Concepts of Natural Resource Scarcity, Supply Chains, and Sustainability.**

On Sunday at noon, we're mixing up the **Presidential Address and Awards Ceremony** to make it upbeat and dynamic. This exciting event will celebrate the outstanding achievements of our GSA members and fellows, from students and early career professionals to senior scientists. My presidential address, titled "Life on an Active Margin: Swimming Pools and Movie Stars," will highlight my connection to Southern California, and who knows—there might even be a movie star or two in attendance! I'd be honored if you took the time to join the GSA community and attend this event. It promises to be memorable and time well spent.

Enjoy GSA Connects 2024 and revel in the Southern California sun.

Thanks, and see you soon.



Christopher (Chuck) M. Bailey (he/him)
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William & Mary
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Presidential Address and Awards Ceremony

Sunday, 22 September ★ noon–1:30 p.m.
Ballroom A&B, Anaheim Convention Center

Acting President Christopher (Chuck) M. Bailey presents:

Life on an Active Margin: Swimming Pools and Movie Stars

Southern California is a region of both beauty and excess that lies astride an active and sometimes feckless plate boundary. Here more than 20 million inhabitants face a set of geological and environmental challenges, some well-known and dramatic while others are subtle but ever present. This address will include a personal take on the geology of southern California and then pivot to the critical role that geoscience must play in the future.

Join GSA Acting President Christopher Bailey and Emcee Melanie Brant, Executive Director and CEO, for the 2024 awards ceremony! Come support your colleagues as they are recognized as GSA awardees, new GSA Fellows, Division awardees, and more!

You're invited to gather in the Lobby of the Anaheim Convention Center Ballroom at 11:15 a.m. for a special **Pre-Event Reception**, open to everyone. Enjoy complimentary food and beverage before the momentous awards ceremony.

Congratulations to the 2024 President's Medal Recipient

Kathy Jefferson Bancroft is a Paiute-Shoshone community leader and environmental protector from Owens Valley, California, USA. Trained as a biologist and chemist, Kathy has brought attention to decades of water misuse and the consequent environmental degradation due to alkali dust pollution in the Owens Valley. Kathy has worked tirelessly to educate her Tribe, the public, and policymakers to bring about meaningful environmental mitigation in a changing world.

ABOUT THE PRESIDENT'S MEDAL

The President's Medal of the Geological Society of America, commissioned in 2007, will be conferred only on individuals, groups, or entities whose impact has profoundly enhanced the geoscience profession through (A) supporting and contributing to the Society; (B) advancing geosciences, enhancing professional growth, and/or promoting geosciences in service of humankind; or (C) significantly enlarging the range of scientific achievement for the growth of our profession.

Browse the Meeting Program and Build Your Schedule

Download the official GSA Connects 2024 app today.

View Meeting Program on Your Phone's Browser

Information for Presenters

All presenters must be registered to present at GSA Connects 2024 in Anaheim.

All sessions will be held in person at the Anaheim Convention Center (ACC).

POSTER PRESENTERS

- Display boards are provided at no charge, 8-ft-wide by 4-ft-high (244x122 cm) in landscape orientation.
- Posters can be printed on any material, not exceeding size of display board.
- Wi-Fi is available in the poster hall.
- Posters will be displayed from 8 a.m.–5:30 p.m., with presenting authors at their posters from 9–11 a.m. or 3:30–5:30 p.m. Times will be listed in the program.
- Posters must be removed after the session. Leftover posters will be recycled.

ORAL PRESENTERS

- Aim to limit your presentation to about 15 minutes (12 minutes plus 3 minutes for Q&A).
- Visit the Speaker Ready Room at least 24 hours before your presentation to upload your slides.
- All presentation rooms are equipped with PCs with MS Office 2016.
- Prepare presentations in a 16:9 ratio, and use common fonts to ensure compatibility. Note: Keynote software is not supported.
- Run through your presentation in the Speaker Ready Room to check for compatibility and get comfortable with the equipment. Technicians are available for assistance.

Speaker Ready Room
Anaheim Convention Center, Room 210A
Sat., 21 Sept.: 8 a.m.–8 p.m.
Sun.–Tues., 22–24 Sept.: 6:30 a.m.–6:30 p.m.
Wed., 25 Sept.: 6:30 a.m.–1:30 p.m.
Note: No internet service in the Speaker Ready Room.

https://bit.ly/3WhgEx9

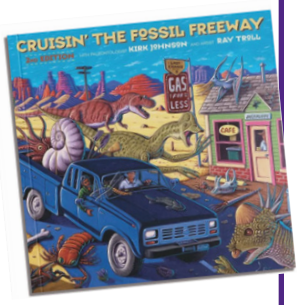
Five Tips for Creating Effective Presentations

1. **Craft Slides for Visual Presentation:** Ensure that slides are specifically designed for visual presentations, not just imported from printed pages or the internet. Redraft analysis graphics into presentation graphics to enhance legibility and communication.
2. **Simplify and Eliminate Clutter:** Follow the KISS principle (Keep It Short and Simple). Remove unnecessary elements such as grid lines, logos, and excessive text. Use simple, telegraphic style for labels and avoid overly complex diagrams.
3. **Maximize Visibility:** Adhere to Gallagher's ratio (10:1) to ensure legibility. Make text and images sufficiently large, using landscape configuration for slides. Ensure all elements are easily readable from the back of a large room.
4. **Use Effective Design Techniques:** Opt for black or dark blue text on a white or pastel background for maximum legibility. Avoid red and green for critical data. Utilize simple fonts and appropriate font sizes (over 40 points for titles is rarely needed).
5. **Test and Practice:** Review and enlarge text and images where possible. Preview slides from the back of the lecture hall to ensure clarity. Practice the presentation to refine both slide transitions and public speaking skills.

Find presentation templates and logos on the Attendee Toolkit page: **https://bit.ly/3WlnCBn**

Lecture: Ray Troll and Kirk Johnson Cruise the Fossil Freeway and Coastline: The Travels of an Artist and a Scientist in the American West
Sun., 22 Sept., 6–7 p.m. Open to everyone.

A Reception and Book Signing with Ray Troll and Kirk Johnson
Sun., 22 Sept., 7–8:30 p.m.
$75 Professionals; $45 Students and Early Career Professionals.



Your ticket includes a copy of their latest book, *Cruisin' the Fossil Freeway* 2nd edition ($30 value). Get your copy personally signed, chat with the authors, and enjoy a Q&A session.
https://bit.ly/4cfWBFA

Beyond the Degree: Making an Impact with Geology

Join Cate Larsen and Ethan Penner, experienced geocommunicators, and Dave Applegate, director of the USGS, for this special session.

Mon., 23 Sept., 8 a.m.–5:30 p.m., with a break from noon to 1:30 p.m., in Ballroom D of the Anaheim Convention Center.

For Students and Early Career Professionals: Get an in-depth look at internships and careers in diverse fields such as consulting, public policy, museums, oil and gas, mining, state surveys, the USGS, and mass media. Gain valuable insights and practical advice on navigating your career path in the geosciences.

For Faculty: What essential skills do your students need to succeed in these careers? Are you adequately preparing them for opportunities beyond academia? Engage in this informative session to discover key competencies and strategies for fostering career readiness in your students.

Celebrating 25+ Years of GSA Mentor Programs: After the session, join us for a special celebration of GSA's mentor programs, featuring our esteemed speaker, Roy Shlemon, who pioneered these programs in 1996.

GSA Connects for Educators

We want to help you inspire the next generation of young geoscientists! GSA Connects 2024 offers professional development opportunities for educators at all levels, including:

- Special sessions such as "Exploring Earth: Integrating Geosciences Across the K–12 Curriculum," endorsed by the National Association of Geoscience Teachers
- Geoscience Education Topical Sessions
- Short courses on topics such as designing effective surveys and communicating science
- A 20% discount on field trips for K–12 teachers

Learn more at **https://bit.ly/3W7BlM4.**

Learn, network, and get into the field with GSA while fulfilling your CEU or PDH requirements.

Whether you're renewing a teaching certification or pursuing a professional license, GSA Connects can help! Earn Continuing Education Units (CEUs) or Professional Development Hours (PDHs) by attending the meeting, short courses, and field trips.

- Up to 3.2 CEU/32 PDH for Connects 2024
- Up to 1.6 CEU/16 PDH for Short Courses
- Up to 3.0 CEU/30 PDH for Field Trips

https://bit.ly/3Wgyt0K

Explore Anaheim through EarthCaching

An EarthCache is a special place that anyone can visit to learn about a unique geoscience feature. Visitors to EarthCache sites can see how our planet has been shaped by geological processes, how we manage Earth's resources, and how scientists gather evidence to learn about the Earth.

To find EarthCache sites near Anaheim, go to www.geocaching.com and enter zip code 92802. You can also search via the GC-code associated with a specific EarthCache. Below you'll find a list of some EarthCache sites in the vicinity of the Anaheim Convention Center, including their GC-codes.

- **El Modena Volcanics (GC3W57A):** Observe evidence of past volcanism right in Orange County.
- **Brea Olinda Natural Oil Seepage (GC59474):** Witness a natural oil seepage like the ones that drew the first oil prospectors to this area.
- **Crystal Cove Columnar Joints (GC6E696):** See columnar joints in outcrops of andesite along the coast in Crystal Cove State Park, a geological playground. A nice variety of EarthCaches can be found in this area.
- **Turtle Rock (GCAABX5):** Visit a limestone outcrop rich in bivalve fossils, nestled in a suburban neighborhood.

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GEOCAREERS

Jumpstart Your Career with GSA

Network, learn about geoscience opportunities, and connect with a mentor. Everyone is welcome to attend GeoCareers events in Ballroom E of the Anaheim Convention Center.

Résumé Review
Sun.–Tues., 22–24 Sept., 10 a.m.–3 p.m.
Get expert advice on how to optomize your résumé.

Drop-in Mentoring
Sun.–Tues., 22–24 Sept., 10 a.m.–3 p.m.
Sign up early on site to secure your 30-minute consultation. Ask about jobs, graduate school, research, or anything else!

Success in Publishing: Navigating the Process
Sun., 22 Sept., 10–11:30 a.m.
Hear from editors about how to prepare and publish papers.

Women In Geology Program
Sun., 22 Sept., 5:30–7 p.m.
A networking session and reception follows, providing time for sharing ideas and getting to know other women geoscientists.

Early Career Professional Coffee
Mon., 23 Sept., 9–10 a.m.
Learn about opportunities from representatives of several non-profits.

Mapping Your Future in Earth Science with Geotechnologies
Mon., 23 Sept., 10–11:30 a.m.
Learn how you can chart your own future with exciting, rapidly evolving 2D and 3D tools.

Networking Reception
Mon., 23 Sept., 11:30 a.m.–1 p.m.
An opportunity for students and early career professionals to network with geoscience professionals.

Geology Club Meet-Up
Mon., 23 Sept., 2–3 p.m.
Chat with other representatives about their activities, goals, and accomplishments.

Post and Review Jobs
Sun.–Wed., 22–25 Sept.
Browse the job board for exclusive geoscience opportunities.

Respectful and Inclusive Meetings

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SHOW RESPECT
- Keep questions concise and on topic.
- Be considerate, and listen with an open mind.
- Be constructive—critique ideas, not people.
- Avoid saying or doing anything that is or is likely to be perceived as harassment or bullying.

BE INCLUSIVE
- Demonstrate that you welcome a diversity of individuals and their identities.
- Show that you value different perspectives.
- Be mindful of potential biases and avoid comments and behaviors that are likely to make others feel unwelcome or uncomfortable.

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Sun., 22 Sept., 9 a.m.–1 p.m., Anaheim Convention Center Ballroom D. $20; includes lunch.

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- Learn the fundamentals of crafting a winning résumé;
- Discover how to effectively use the USAJOBS database for federal employment applications;
- Engage with mentors from industry, government, and academia; and
- Get answers to career-related questions and valuable advice for preparing for a career in these fields.

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Kansas State University
Louisiana State University, Department of Geology and Geophysics
Missouri State University, Department of Geography, Geology, and Planning
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Oklahoma State University
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University of Arizona, Lowell Institute for Mineral Resources
University of California, Davis, Department of Earth and Planetary Sciences
University of Connecticut, Department of Earth Sciences
University of Florida, Department of Geological Sciences
University of Georgia, Center for Applied Isotope Studies
University of Houston
University of Idaho
University of Kansas
University of Kentucky
University of Michigan
University of Minnesota, Department of Earth and Environmental Sciences
University of Mississippi
University of Missouri
University of Nevada, Las Vegas
University of North Dakota
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University of Oklahoma
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University of Wyoming
Vanderbilt University
Virginia Tech, Department of Geosciences

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Education and Environment
American Geosciences Institute
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EarthScope Consortium
International Association of Sedimentologists
IUGS Deep-time Digital Earth (DDE)
Real World Globes
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Scientific Ocean Drilling
NSF Synchrotron Earth and Environmental Science (SEES)
Western Science Center
Yellowstone Bighorn Research Association (YBRA)

Gems, Mineral Dealers, and Jewelry
IKON Mining & Exploration
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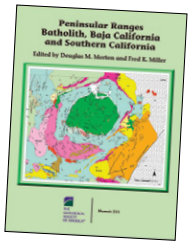
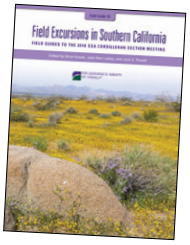
From the Islands to the Mountains: A 2020 View of Geologic Excursions in Southern California
Editors: Richard V. Heermance and Joshua J. Schwartz

This volume includes five geologic field-trip guides in the Los Angeles region, including the active Sierra Madre fault zone, the San Gabriel Mountains, Montecito debris flows, Santa Cruz Island, and Santa Catalina Island.



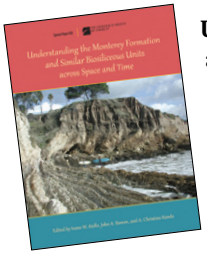
Peninsular Ranges Batholith, Baja California and Southern California
Editors: Douglas M. Morton and Fred K. Miller

The Peninsular Ranges batholith is the southern part of the Cretaceous magmatic arc that extends over 1500 km from northern California to the tip of Baja California. Petrology, geochronology, and regional aspects of individual plutons, as well as evolution of part of the overall batholith are discussed in the 24 chapters.



Field Excursions in Southern California: Field Guides to the 2016 GSA Cordilleran Section Meeting
Editors: Brian Kraatz, Jade Star Lackey, and Joan E. Fryxell

This volume contains six chapters that highlight geological features and processes of southern California and southwestern Nevada, including newly mapped areas in the Mojave Desert, Coyote Mountains, and recently designated Tule Springs Fossil Beds National Monument. (Available as an e-book.)



Understanding the Monterey Formation and Similar Biosiliceous Units across Space and Time
Editors: Ivano W. Aiello, John A. Barron, and A. Christina Ravelo

The Monterey Formation is a Miocene marine unit that occurs extensively in the Coast Ranges and in the continental margins of California. This volume presents a collection of recent studies on the Monterey and other similar biosiliceous deposits that offer modern and updated interpretations of this classic unit and its analogues.

A Geoscientist's Role in Policy

Interested in geoscience policy, but don't know how to get started? Attend one of these sessions to learn about critical societal challenges, and how geoscientists can help shape future policies that impact both the environment and communities.

T26. **The New Role of Geoscience in Archaeological Training and Demand in U.S. Cultural Resource Management (CRM)**
Sunday, 22 Sept., 1:30–5:30 p.m.

T62. **Shaping a Sustainable Future with Geology in the Twenty-First Century: Geology and Society Division Turns 21**
Tuesday, 24 Sept., 1:30–5:30 p.m.

T63. **Geoscience "Ambassador" Programs: Insights on Critical Issues of Power, Dignity, Agency, and Belonging**
Monday, 23 Sept., 8 a.m.–noon

T65. **Intention Is Not Enough: Real-Life Power Imbalances in the History of Geosciences and Possible Futurities**
Tuesday, 24 Sept., 8 a.m.–noon

T78. **Geoscience and Hydrology of Your Public Lands: STEM Internships, Research, Science, Mapping, Resource Management, and Education**
Tuesday, 24 Sept., 8 a.m.–5:30 p.m. (posters); 1:30–5:30 p.m. (session)

Search "Geoscience and Public Policy" as the Discipline Category for even more sessions: **https://bit.ly/3JR7f9W**

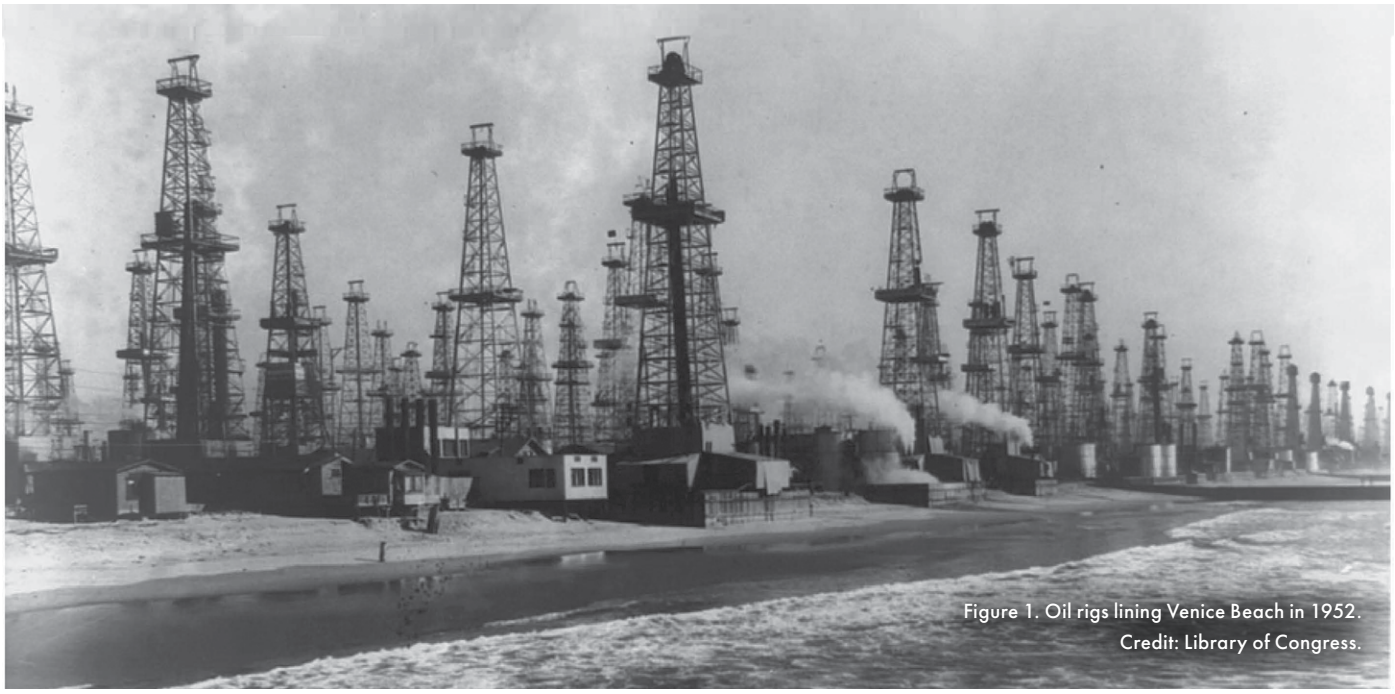


Figure 1. Oil rigs lining Venice Beach in 1952. Credit: Library of Congress.

Los Angeles: A Megacity of 12 Million People Living Over the World's Richest Oil Field

Lon D. Abbott[*,1] and Daniel R. Tormey*[2]

When most people think of giant oil fields, the image that comes to mind is of the Saudi Arabian desert or the West Texas plains, not Beverly Hills or Venice Beach (Fig. 1). But Los Angeles, California, USA, is a megacity built on one of Earth's richest oil and gas deposits; the Los Angeles Basin contains more oil per unit volume of rock than any sedimentary basin on Earth (Biddle, 1991).

The first commercial oil well was drilled in the Los Angeles Basin in 1892, and 300 more wells followed in the next three years. Starting in the 1960s, the surface area of the production sites was greatly reduced by consolidating wells and cleverly disguising them to blend into the urban ecosystem. Today, the basin's 40 oil fields produce ~18 million barrels per year from 5,000 wells. But as 2022 gave way to 2023, in response to growing public health and environmental concerns, both the City and County of Los Angeles banned new drilling. The city also set a 20-year timetable to phase out all existing operations (Johnson and Shamasundar, 2023). *Warren E&P, Inc. v. City of Los Angeles*, No. 23STCP00060 (Cal. Super. Ct. Los Angeles County [2023]) is pending to determine if the city council's actions were legal, but the era of urban oil in LA is waning.

THE MAKING OF A GIANT OIL FIELD: THE MONTEREY FORMATION AND PLATE BOUNDARY TECTONICS

Most organic source material for oil and gas was deposited during the middle-to-late Paleozoic and the middle-to-late Mesozoic. By contrast, the source rock for the Los Angeles Basin petroleum is unusually young. The Miocene, organic-rich Monterey Formation was deposited between ~18–5 Ma in offshore basins at water depths between 500 and 2300 m. These basins formed as California evolved from a subduction to a transform plate margin (Behl, 1999), giving birth to the San Andreas Fault.

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The Monterey Formation is highly siliceous, thanks to the abundance of diatoms that flourished in surface waters fed by nutrient-rich upwelling along the California Current. The basin floors were episodically oxygen deficient, producing petroleum source rocks with high total organic carbon contents up to 23% (Behl, 1999).

Plio-Pleistocene shortening produced rapid subsidence in the Los Angeles Basin and uplift of adjacent areas, which shed sediments that rapidly buried the Monterey Formation to several kilometers' depth, into the "oil window"—the temperature and pressure regime where liquid petroleum and natural gas is formed and partially liberated from its host rock. That tectonism also produced en-echelon anticlines that formed structural traps for the petroleum, although some of it leaked onto land and into the sea through faults and fractures.

THE LA BREA TAR PITS: A PLEISTOCENE TIME CAPSULE

Oil was seeping to the surface at the future location of Los Angeles by the Pleistocene at the famous La Brea Tar Pits. Starting 60,000 years ago and continuing for thousands of years, sticky "tar" entrapped animals and entombed surrounding vegetation, fossilizing them in asphalt. This unusual fossilization process preserves collagen, cellulose, and other biological materials so exquisitely that scientists can analyze biogeochemical signatures that are usually unattainable (IUGS, 2022). The Tar Pits lie within Wilshire Boulevard's "Miracle Mile," a contemporary creative center and a historic district that epitomizes LA's rise as an engine of commerce.

More than four million fossil plants, invertebrates, and vertebrates have been recovered since the first excavation in 1875. Marquee fossils include saber-toothed cats, giant sloths, dire wolves, mammoths, and mastodons (Fig. 2). Whole ecosystems were entombed together, providing scientists unprecedented windows into Pleistocene ecosystem dynamics, species adaptation and extinction, and the impact of Earth processes like climate change on biological dynamics (IUGS, 2022).

The seminal importance of this, the planet's richest Pleistocene fossil site, has earned the tar pits international recognition. In 1951, they were designated the type locality defining the Rancholabrean North American Land Mammal Age; in 1963, they were named a U.S. National Natural Landmark; and in 2022, the International Union of Geological Sciences (IUGS) named them one of its first 100 "Geological Heritage Sites," a list of especially significant geological locations around the world (IUGS, 2022).

WHOLE ECOSYSTEMS WERE ENTOMBED TOGETHER, PROVIDING SCIENTISTS UNPRECEDENTED WINDOWS INTO PLEISTOCENE ECOSYSTEM DYNAMICS, SPECIES ADAPTATION AND EXTINCTION, AND THE IMPACT OF EARTH PROCESSES LIKE CLIMATE CHANGE ON BIOLOGICAL DYNAMICS.

Hollywood production centers and sound stages overlook the tar pits, which have featured in numerous movies and TV shows. In 2018, José Roberto Villaseñor, an interpreter for the Natural History Museum of Los Angeles, compiled a list of 89 popular culture references to the tar pits. He noted that these references are, unfortunately, rife with scientific misconceptions. They commonly use the tar pits for comic effect, such as Homer Simpson's 1994 entrapment, or as the source of impending disaster, most famously as the site of a volcano that devastates Los Angeles in the 1997 movie *Volcano* (Villaseñor, 2018). The recent science fiction TV series *La Brea* (2021–2024) portrayed the tar pits as a portal for time travel.

HUMAN USES OF PETROLEUM AND BIRTH OF THE LOS ANGELES OIL INDUSTRY

The area's petroleum has been a valuable resource to humans ever since they migrated to what would become Los Angeles. The Indigenous Tongva and Chumash peoples used asphalt as waterproof caulking for boats and containers and to set broken bones (Witt, 2022). A 1769 Spanish expedition noted its value for caulking ships and the flavor it imparted to creek water. When Edward Doheny arrived in Los Angeles in the 1890s, he saw locals burning the asphalt as fuel, which inspired him to drill LA's first commercial oil well. Doheny went on to riches and infamy as an oil baron who inspired a scathing portrayal in Upton Sinclair's 1927 book *Oil!*, which was loosely adapted into the acclaimed 2007 movie *There Will Be Blood* (Tormey and Middaugh, 2014; Witt, 2022).

LA's oil industry was born when the area was largely rural. The city's

Figure 2. A fossil of the iconic saber-toothed tiger (*Smilodon californicus*), recovered from the La Brea tar pits. Credit: James St. John/Creative Commons.

economic growth during the first half of the twentieth century was fueled largely by the oil industry; wells were common sites on beaches and in the backyards of homes (Fig. 1). Massive oil strikes in the 1920s at Wilmington, Huntington Beach, and Inglewood—fields that together contain over 2.4 billion barrels of oil and more than 2.2 × 10^{12} cubic ft of natural gas—supercharged the industry (Biddle, 1991). At that time Los Angeles supplied a quarter of the world's oil (Witt, 2022). That oil legacy was such a point of pride that through the 1960s California's license plates were black and gold to symbolize the state's twin natural resource pillars: oil and gold (Tormey and Middaugh, 2014). But by the 1960s Los Angeles was in the midst of an aerospace, manufacturing, and entertainment boom—all land-hungry new economic engines for the area. The city accommodated the new growth along with ongoing resource extraction by developing rich new offshore oil and gas fields and by infrastructure consolidation at onshore ones.

CAMOUFLAGING OIL INFRASTRUCTURE

In the late 1960s, the City of Los Angeles stipulated that all drilling must be consolidated into a few drilling "islands," whose infrastructure must be compatible with the community in which it is located; it can't be unsightly, loud, or generate dust, odor, or harmful substances (Tormey and Middaugh, 2014). The result is that many contemporary Angelenos and tourists drive by concealed nests of oil wells every day without realizing it (Fig. 3).

These urban drill sites are literally hiding in plain sight. None are more than an acre in size, and most are less than half an acre. They use submersible pumps, allowing a 20–60-well oil field to line up the well heads within oil cellars and to access the subsurface pool by slant and horizontal drilling. There is one dedicated workover rig that is difficult to hide without a multistory disguise. For example, within one commercial district, there is what looks like a seven-story office building covering the field; it is a shell painted to merge with the surrounding offices, but without windows. Another rig is camouflaged to resemble the bell tower of a synagogue; this site won a design award from the City of Los Angeles. Adjacent to the running track at Beverly Hills High School, the oil developer reached out to the community for ideas on how to disguise the workover rig, and the Flower Tower was born (Fig. 3). Each side of the disguise was painted by the community to represent the four seasons. With time, Angelenos came to know the structure simply as the Flower Tower, with little memory that a drill rig lay within.

Figure 3. The "Flower Tower" used to conceal an oil rig on the Beverly Hills High School campus. The floral pattern was designed by two artists who were school alums and painted by terminally ill children who were being treated in local hospitals (Tormey and Middaugh, 2014). This photo was taken during repair of the rig, which is visible behind the Flower Tower. Both the rig and its Flower Tower camouflage were dismantled in 2020. Credit: EricF2000 via Flickr.

DECLINING PUBLIC SUPPORT FOR URBAN DRILLING

Despite efforts by the city and petroleum producers to minimize the impact of oil operations, public concern about industrial mishaps and the long-term health effects of living next to active drill sites has progressively grown (Johnson and Shamasundar, 2023), amplified by national concerns about hydraulic fracturing (which is not conducted in the Los Angeles Basin) and several high-profile disasters over the years. One was the 1963 failure of the Baldwin Hills Dam, which triggered a flood that destroyed 277 homes and killed five people. The dam was adjacent to the Inglewood oil field, and public suspicions abounded that petroleum extraction had caused ground disturbances that triggered the dam's collapse. Although a later study by the California Department of Water Resources concluded that was not the case, not everyone was convinced (Tormey and Middaugh, 2014).

Then, in 1969, a blowout at Union Oil's offshore platform Alpha spilled three million gallons of oil into the Santa Barbara channel. The oil killed fish, marine invertebrates, seals, dolphins, and seabirds. National public outrage was intense; the Santa Barbara oil spill was seminal to the establishment of the current national environmental regulation regime, including passage of the National Environmental Policy Act (NEPA) in 1969 and establishment of the Environmental Protection Agency (EPA) in 1970 (Clarke and Hemphill, 2002). The next disaster to erode public confidence occurred in 1985, when methane filled the basement of a clothing store above the Salt Lake oil field near the La Brea Tar Pits. The ensuing fire injured 23 people and prompted the Los Angeles City Council to adopt new methane monitoring and venting regulations (Tormey and Middaugh, 2014).

THE APPROACHING END OF LOS ANGELES DRILLING RISKS THE DISAPPEARANCE OF THIS MULTILAYERED HISTORY FROM OUR COLLECTIVE MEMORY.

Then, in 2003, Erin Brockovich (made famous by a Hollywood movie depicting her successful 1993 lawsuit against Pacific Gas and Electric) filed a class action lawsuit alleging that emissions from the oil wells on the Beverly Hills High School campus (Fig. 3) were responsible for elevated cancer rates in the school's teachers and alumni. However, several studies concluded that emissions were well below California health guideline limits, and the suit was dismissed. Still, concerns about the health effects of drilling persisted. In 2010, the Los Angeles City Attorney

filed a lawsuit against a Las Cienegas oil field operator because of persistent neighborhood complaints of noxious odors, headaches, nosebleeds, and asthma. The operator reached a settlement requiring the implementation of environmental improvements (Tormey and Middaugh, 2014). Those health worries, coupled with growing concern about climate change, have turned the tide of Los Angeles public opinion from the pride of the black and gold license plates to rejection of continuing operations, ultimately resulting in the 2022–2023 city and county decisions to stop issuing new drilling licenses.

The story of Los Angeles oil and gas has evolved. It includes early elation about an economic bonanza, patriotism regarding the resource's importance for winning World War II, pride in the combination of technological innovation and artistic creativity that enabled the area to grow while still maintaining oil and gas development at hidden urban drill sites, and concern about both adverse health effects and climate change. Like a thought-provoking Hollywood movie, there are layers of meaning that are open to different interpretations. Just as the camouflaging of workover rigs has caused many Angelenos to be unaware that they live atop a giant oil field, the approaching end of Los Angeles drilling risks the disappearance of this multilayered history from our collective memory. This is where geoheritage steps in to celebrate, remember, and teach from this story.

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Introduction to the Series

Thomas (Tim) F. Shipley and Basil Tikoff

In the essay series "Places that Reveal the Geological Mind," we are going to explore what goes on in a mind at the cutting edge of disciplinary practice and when first learning geology. We have selected a series of places on Earth that reveal both geological processes and the mental processes that extract knowledge from rocks. Thomas (Tim) Shipley, a professor of cognitive science, has now been working with geologists and geoscience educators for over two decades. Funding from the NSF-sponsored Spatial Intelligence and Learning Center catalyzed leaving his familiar cognitive science community behind to try to understand how another scientific community thinks. Basil Tikoff, a professor of geology, has been a willing collaborator in the effort to link cognitive science and geology. The appeal, originally, was to understand spatial learning in a field that requires high levels of spatial thinking. It became apparent that understanding how one knows the natural world revealed aspects of spatial thinking that were not recognized by the cognitive science community. This series is the product of their ongoing collaboration.

WHY—AND WHAT—PLACES REVEAL

> *We have just travelled 1300 km in a day and a half to spend an hour or so looking at a shallow bay. We four sat for an hour contemplating a collection of dark mounds of bacteria and sediment, while a trickle of tourists walked by, paused for a few moments, and then moved on. After an hour of sitting, looking, and thinking, we left. It was 1300 km back to where we needed to go. At the time, I remember thinking this experience was somehow important … despite not really having a clear idea of what had just happened.*
>
> *I can think of no psychologically notable person, place, or thing that I would want to see so much that I would be willing to spend a day and a half in a car to get there, spend a few hours looking and then get back in the car for the day and half trip back! Neither Freud's study, nor any other trace of an important event in the history of psychology, has the power to call me across a continent.*
>
> —from Tim Shipley's notes on a field trip to Shark Bay, Australia, 2015

The brief travelogue remarking on the distance travelled to see stromatolites may not strike a geologist as unusual or particularly notable, as the need to visit rocks in faraway places is familiar and fundamental to the practice of geology. That need does not have any analogue in psychology or in most other disciplines. Psychologists, for example, could be sitting anywhere when they look at and think about their data. Tim found the experience bewildering because he had no sense of the geologists' motives: why did they need to be here and what were they thinking here? This led him to think about (1) what information a mind can assimilate in a place to be used to understand the past and (2) how geological regularities in specific places change the minds of the observers, both as individuals and as a community. The "aha" moment of the trip was the realization that how geologists think necessarily included consideration of the places in the world that are deeply tied to that thinking.

The field of geology is predicated on the relationship between place and meaning. Because of this relationship, Shark Bay, Australia, calls to geologists. The known properties of present-day stromatolites are the key to the fossil stromatolites, and the fossil stromatolites are critical to an appreciation of the mind-bending longevity of life on Earth. Siccar Point, Scotland, similarly calls to geologists; the angular unconformity there tells us about the enormity of geological time, just as it informed James Hutton and John Playfair. And, because of those individuals, Siccar Point is the place where humans figured it out (Hutton) and managed to communicate it to others (Playfair). The evidence and insight that specific places provide comes from the way the human mind creates meaning, and that meaning is developed through how the mind works. Thus, places can reveal thinking. In this context, specific places are important for some combination of three reasons: They are where something got figured out, they provided critical pieces of a puzzle that allows us to determine Earth history, and they tell us something particularly clearly about Earth processes.

OVERVIEW OF THE SERIES

Over the course of twelve essays, we will take the reader to places around the world. Some places are well known, such as those featured in the top 100 International Union of Geological Sciences (IUGS) geological heritage sites (Hilario et al., 2022), and others less so. In each essay, we discuss how the science of the locale reveals something of the way the mind understands the geology, focusing on one aspect of how the mind works as currently understood by cognitive science.

We begin at **Lake Bonneville, Utah,** where variations in the elevation of abandoned lake shorelines challenge the mind for an explanation, and G.K. Gilbert advances the method of multiple working hypotheses as a way to avoid cognitive bias. We draw cognitive insights on how geologists use their minds from his 1886 scientific report.

Our second essay is about **Shark Bay,** a locale associated with the earliest visible fossil evidence of life, to consider one of the mind's most powerful tools: using analogies to reason about the unknown from the known.

In the third essay, we use the angular unconformity at **Siccar Point** to illustrate the use of mental models. Geologists have an extensive library of mental models of the things

Stromatolites at Shark Bay, Australia.

THE OVERARCHING THESIS OF THE ESSAY SERIES IS THAT BY EXPLORING THE ROLE OF THE MIND AS IT DEEPLY GRAPPLES WITH THE NATURAL WORLD, WE MAY LEARN MORE ABOUT BOTH.

they have seen, and these are the working parts of the scientific mind needed to reason from traces of past events. From individual experiences, generalized models are formed. These mental models are capable of recognizing geologically important features despite their manifestly diverse forms.

We return to G.K. Gilbert and Utah in the fourth essay about the **Henry Mountains,** to discuss how new mental models—such as the idea for a laccolith—are developed.

In essays five and six, about the **Channeled Scablands** of eastern **Washington** and the **Grand Canyon of Arizona,** we consider the mental processes that animate mental simulations of geological processes and how such runnable models might change with new data.

In the next three essays, we discuss the nature of perception and knowing, how we know what is around us in the world, including the cognitive processes that make perception work. We start with an essay on noticing and how the mind unconsciously fills in gaps when objects and events are incomplete, discussing Mesozoic terrane motion and specifically the **Cretaceous Mt. Stuart batholith.** We move on to an essay on the **Burgess Shale, British Columbia, Canada,** about the importance of seeing and thinking in three dimensions. We end this theme discussing the distinction between perceiving and knowing, and how instruments extend human senses, using the observation of CO_2 on **Mauna Loa, Hawai'i.**

The planned final triplet of essays takes a broader perspective on the science. The tenth essay, about the **Sage Hen Flat** pluton in **California**, discusses trust and new ways to communicate uncertainty that allow multiple minds to share information. The next essay, about the **Falkland Islands,** makes a case that the mind works best when it can engage in both goal-directed exploration and play. Our final essay is about the **Massif Central in France.** We use the controversy about plutonism vs. neptunism—which was resolved at this locale—to discuss the importance of multiple minds working on a problem together. This type of collaborative work reflects an important aspect of the way humans think, which is at odds with common conceptions such as the idea that the mind is like a computer. That is, the way in which we think about the mind influences how it gets used.

The overarching thesis of the essay series is that by exploring the role of the mind as it deeply grapples with the natural world, we may learn more about both.

LETTING DISCIPLINES MERGE

Why bring together disciplines whose subject matter seems as distant as their respective buildings on most college campuses? First, a good scientist wants to manage risk. Knowing the limitations of the mind can help adjust practice to reduce the risk of mental errors. For example, cognitive biases often impede advances in theory. In the first essay, we address this topic directly, **discussing geological and cognitive approaches to avoiding bias,** why these approaches work, and why intuitively appealing alternative approaches do not work (Soll et al., 2015). While this practical advice may appear to have an "eat your vegetables" quality, it is grounded in evidence-based findings to motivate the readers to reflect on their current practices, both as individuals and as a community. Second, **a good scientist wants to maximize opportunities.** Understanding the strengths of the mind and how complex reasoning works can increase the likelihood of creative insights. For example, analogical thinking is central to reasoning about the past. In our second essay, we discuss how analogical thinking can be promoted at all levels, from the first encounters with geology to practitioners working on complex problems (Gentner et al., 2001). Realizing the full potential for opportunities afforded by linking geology and cognitive science requires "handshaking protocols" that allow translations of concepts between the cognitive and geological sciences; however, cognitive theories are impoverished in addressing the complexity of how geologists think about the world (Resnick and Shipley, 2013). Third, the fundamental reason for writing these essays—and why we hope they will be read—is that in the

aggregate they **make a case for a powerful approach to knowing the world.** We are proposing a way of thinking that embraces the reciprocity between how the world shapes the mind and how the mind shapes our understanding of the world. Once you start seeing the role of the mind in geology you will not be able to unsee it, just as a geologist cannot unsee abandoned shorelines or U-shaped valleys.

WE ARE PROPOSING A WAY OF THINKING THAT EMBRACES THE RECIPROCITY BETWEEN HOW THE WORLD SHAPES THE MIND AND HOW THE MIND SHAPES OUR UNDERSTANDING OF THE WORLD.

View of Emerald Lake from Burgess Pass in Yoho National Park, British Columbia, Canada.

By encompassing Earth and mind together, we can begin to do science in a holistic way. When we build bridges between the natural and social sciences, a new science can and likely will develop. That new science field—neither cognitive science nor geological science—allows us to break unseen barriers and see new opportunities. We illustrate this claim here using the example of uncertainty in field observations (e.g., Tikoff et al., 2023). A field scientist's uncertainties about their observations are valuable data for the community, because they will enhance trust in shared data, increase participation by those unable to visit the field site to assess data quality, and aggregate knowing so a community can appropriately weigh and use collective data to improve theories. Uncertainty might be recorded in a field notebook, but recording and sharing that uncertainty is not part of disciplinary practice so that valuable data is lost to the vagaries of memory. Why? Likely because the contents of the mind were not seen as within the purview of a natural scientist.

Because the essays address geoscientists' thinking at a given time and how it evolved, they bear some resemblance to a "history of science" analysis, but they diverge in important ways. First, the essays focus on the alignment of a place and the workings of a mind that understands the geology of the place. Second, we use the specific examples to make broader points about how our minds make sense of the world, often unconsciously. Due to the focus, many details about the geology of the specific location and the cognitive science cannot be included. To make up for this admitted shortcoming, we provide suggestions for further reading.

Finally, a word about the writing process for these essays. Some essays began by selecting a cognitive process and then identifying a destination that could serve as a sort of type locale for that thinking. Other essays started by selecting a location, then working through the cognitive story it told. In either case, Basil would write the geology summary and Tim would contribute follow-up writing about the cognitive science. After that, the free-for-all of writing and revision leaves it hard to unmix the ideas to confidently identify who had the preponderance of input on any particular essay. To accommodate the linguistic necessity of author orders, the essays alternate who is listed as first author. Finally, for each essay, we include one sentence loglines to summarize the main point for both the geology and the cognitive science.

The series, overall, makes the case that better science will arise from more closely attending to the processes of the world and the processes of the mind. We hope you will find this dual Earth and mind-studying-Earth perspective both interesting and useful.

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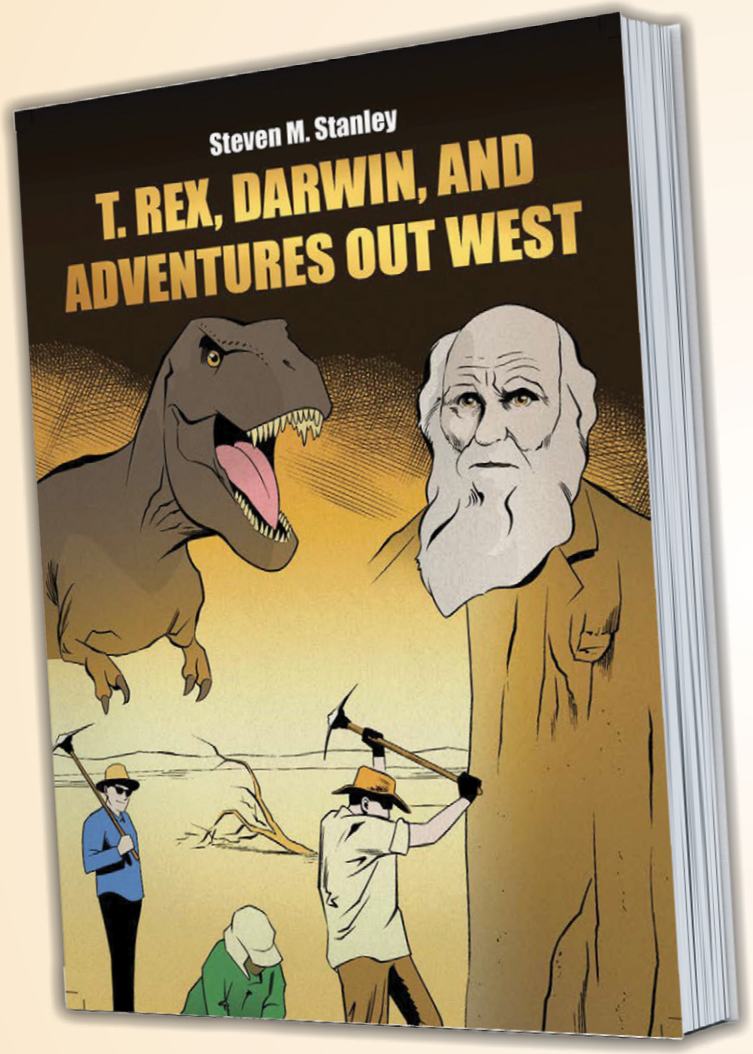
T. REX, DARWIN, AND ADVENTURES OUT WEST



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A group of bright college students who call themselves "The Melange" are ready for adventure. Led by their inspirational professor, they embark on a journey Out West. From a close encounter with *T. rex* that leads to a mystery, the novel is a whirlwind of drama, elation, tragedy, and humor. You'll be left pondering whether dinosaurs were really warm-blooded, the origins of storytelling, and the curious conundrum of why dogs come in so many varieties while cats all look alike.

About the Author:
Steve Stanley has authored many scientific journal articles and has written several books. He's the only paleontologist to have received GSA's Penrose Medal in the past 30 years.

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Figure 1. Shorelines from Lake Bonneville exposed on Antelope Island, Utah. The highest shoreline (Bonneville shoreline) is from the high lake level that occurred ~17,500 years ago (Oviatt, 2020).

Lake Bonneville Shorelines, Utah, and the Role of the Mind in the Practice of Geology

Thomas F. Shipley[1] and Basil Tikoff *,[2]

Geology logline: *G.K. Gilbert developed the use of multiple working hypotheses when determining the cause of the differential elevation of shorelines at Lake Bonneville, providing a tacit recognition of the role of the mind.*

Cognitive science logline: *There are aspects of doing science to which we do not have conscious access, and being aware of one's mind in the practice of geology can improve outcomes and reduce bias.*

The shorelines of Lake Bonneville are a prominent feature of the eastern part of the Basin and Range Province (Fig. 1). The shorelines that record different lake levels are well preserved on mountains. A lake level can change for two primary reasons. First, the climate can change and there can be more or less water flowing into the basin than evaporating out of it. Second, the lake can erode a drainage divide and start spilling into an adjacent basin. The latter happened to Lake Bonneville when it reached its highest level and catastrophically drained into southern Idaho through Red Rock Pass. When this happened, the lake level is estimated to have dropped ~110 m in a flood lasting about a year (O'Conner, 1993).

The Lake Bonneville shorelines are also the backdrop for one of the most historically important scientific publications that both recognizes the role of the mind and provides a practical approach to support the mind in the practice of geology. It was written by geologist G.K. (Grove Karl) Gilbert, a scientist who lived over 100 years ago but is still known and revered by geological practitioners for his insights. It was in his 1886 presidential address to the Geological Society of America that G.K. Gilbert proposed his method of multiple working hypotheses, using the existence and subsequent differential uplift of the Lake Bonneville shorelines (Fig. 1) as his case study. Rather than following one hypothesis and working to advance it, Gilbert suggested identifying multiple hypotheses and collecting data that could support any of them. He articulated a new way of doing science that reduced the risk of focusing on a single hypothesis. Chamberlin (1897) popularized multiple working hypotheses and often gets the credit, but Gilbert (1886) first developed and applied the method.

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Gilbert (1886) is one of the clearest papers about the value of thinking about geological thinking ever published. We begin our essay series here because the concept of multiple working hypotheses is known to most geologists, and it highlights the value of being aware of one's thinking in the practice of geology. It is perhaps the first, and certainly the best-known, publication that raises the broader questions: "What is the geologist's mind doing as they practice geology, and how does the Earth influence that mind?" In this essay, we offer a cognitive scientific context for Gilbert's work and reflect on the potential for this approach to advance both cognitive science and geology.

IN THIS ESSAY, WE OFFER A COGNITIVE SCIENTIFIC CONTEXT FOR GILBERT'S WORK AND REFLECT ON THE POTENTIAL FOR THIS APPROACH TO ADVANCE BOTH COGNITIVE SCIENCE AND GEOLOGY.

G.K. Gilbert, like other practitioners of his time, recognized that shorelines occurred in internally drained lake basins and recorded past high-water levels.[3] The Lake Bonneville shorelines (Figs. 1 and 2) were an example of this pattern. However, he made a critical observation, not obvious to the casual viewer, that the shorelines are not perfectly horizontal. One could walk a single shoreline and it would rise 10 m over a distance of 100 km.

Note that the "observation" of a shoreline illustrates an implicit character of human, and thus scientific, reasoning. Geological observation is the balance of accumulated evidence for (and against) a claim about a property of the world: It is not, strictly speaking, a property of the world that is visible to everyone. What is the evidence for a shoreline? First, the shoreline is revealed by a break in slope, with a shallow slope above a steep slope. Second, the break in slope is more-or-less continuous. In the case of shorelines, "more-or-less" means that some portions can be subsequently eroded away and a geologist mentally ignores this type of complication. Third, the shoreline must be, for all intents and purposes, horizontal. It took Tim a long time, but he finally convinced Basil: Most of what Basil calls "observations" are really low-level interpretations—inferences—with which almost all geologists agree.

It is important to dwell on Gilbert's observation that the shorelines were not horizontal, because violations of expectations are important starting points in science. If these features are shorelines, they should all be level. That is, there is a prediction—horizontality—that is embedded in the inference that these features are shorelines. It could be that the inference is wrong, but there is no evidence that Gilbert seriously entertained this option. He focused on the alternative, that a previously unrecognized process had changed the shorelines after they formed. Gilbert figured out something important about the way the world works, and he did it by identifying an unexpected pattern in the world. There is a spatial regularity to where the shorelines are not flat, as can be seen in Gilbert's map of the elevation of the highest and most prominent shoreline (Fig. 3). A simple correlation is evident once mapped: The elevation of the top-most shoreline is highest where Lake Bonneville was deepest.

Patterns in the world commonly have multiple causes, and determining a single explanation for any observed pattern can require additional data. Keeping multiple hypotheses in mind helps motivate and guide the collection of that additional data. Each hypothesis is a high-level interpretation, which we refer to as a model, as it is an explanation for how the phenomenon could occur. Gilbert realized that if you only have one model for the data, you will both focus only on data that confirm that idea and ignore data that are incompatible with it. This phenomenon is an example of what is now called *cognitive bias* and is well-documented in the cognitive science literature (Tversky and Kahneman, 1974; Soll et al., 2015). The use of multiple and competing models tends to reduce bias and keep you open to making new observations that may cast doubt on a specific model. Gilbert recognized—and made a case for attending to—the role of the mind in the practice of geology.

Gilbert, using the Lake Bonneville shorelines as an example for his new method, came up with multiple models that could explain the data. Although

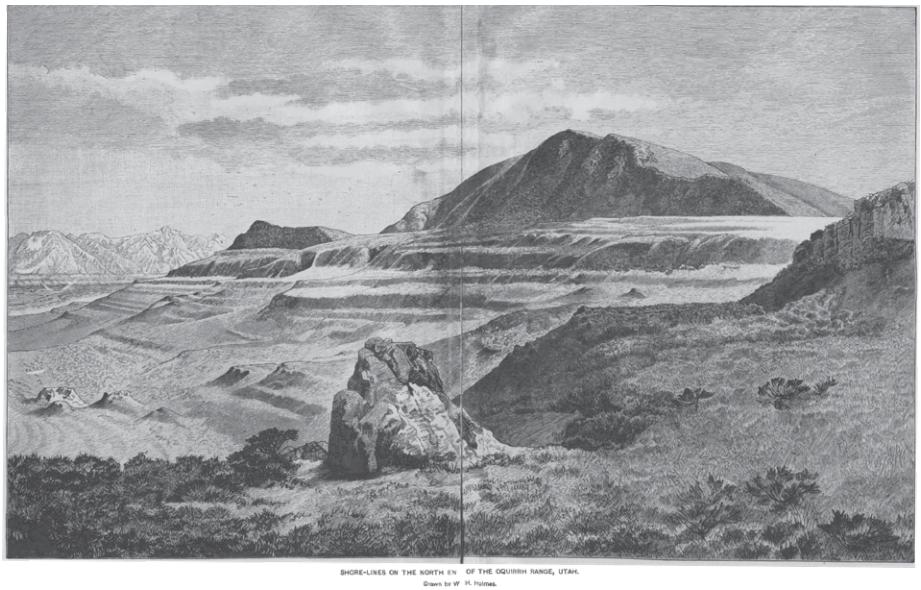

Figure 2. Field sketch of shorelines on the north end of the Oquirrh mountains, likely drawn in the 1870s. This figure is the frontispiece from Gilbert's USGS monograph (Gilbert, 1890).

[3] Shaler (1868) published a paper about shoreline modification, indicating that workers were generally aware of these geomorphic features. Further, Shaler considers the vertical movement of shorelines resulting from large-scale folding and modified geothermal gradients. Gilbert had a copy of this work in his files, which we recently obtained.

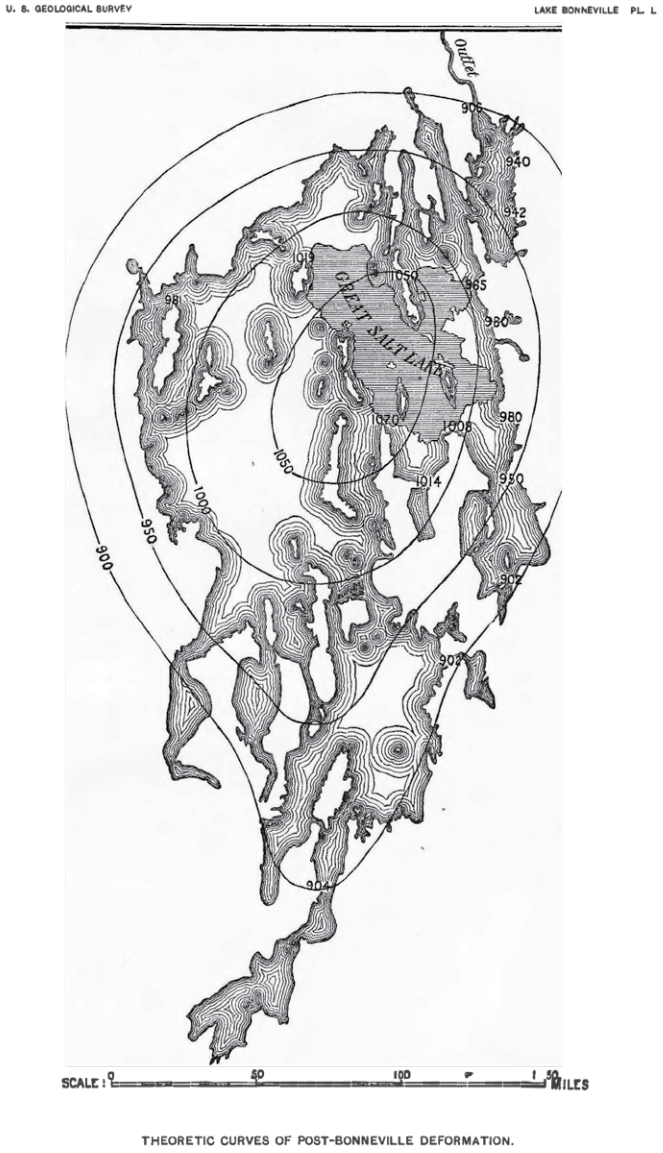

Figure 3. Map of Lake Bonneville and recent extent of the Great Salt Lake. The contour lines indicate hypothetical magnitude of post-Bonneville uplift, extrapolated from a few known points. The contours are feet above 1880s lake level. This figure is plate 50 from Gilbert's USGS monograph (Gilbert, 1890).

Gilbert did not attribute any of the models to other geologists, some models for variation in ocean shoreline elevations were proposed by Shaler (1868). He addressed, but ultimately dismissed the possibility that the shoreline uplift is a result of either gentle folding or active faulting, because neither of these explanations is consistent with the correlation between depth of the lake and amount of uplift. He then proposed three more options. First, the removal of water could cause the Earth's crust to rise in elevation proportional to the thickness of the water (a process called isostasy, although that word is not used by Gilbert). That is a huge conceptual leap, because it requires that the Earth—the prime example of stability for many people—is not stable. As Gilbert (1890) wrote, "To imagine the result it is necessary to divest the mind of the ideas of brittleness and great strength ordinarily associated with granite and other massive rocks" (p. 382). Second, the removal of water could cause changes in the gravity field and thus the geoid. Third, the removal of water could cause thermal expansion of the underlying rock. He ultimately settled on isostasy as the best of the options. So, Gilbert figured out that the Earth is capable of changing shape, "massive rocks" moving upward and downward in response to vertical loads, such as the addition or removal of water in large lakes. Equally important, however, he figured out how scientists can avoid biasing—and thereby fooling—themselves.

Gilbert was not just advocating for a new way of doing science; he was also making an observation about doing geology that allows inferences about what is going on within the mind. Gilbert identified, articulated, and proposed solutions for one of the mind's limits that are particularly important for expert practice. He did this when psychology was in its intellectual infancy and well before cognitive science had a name for the problem. The value of attending to the mind, with its known strengths and weaknesses, can be hard to see. The problem is that the mind's errors are not immediately apparent to the mind. To make a geological analogy, the non-horizontal nature of the shorelines are not immediately apparent either. The limits of human perception make it hard to see they are not horizontal, and thus hard to accept they may be tilted. Like the mind observing itself doing science, it is hard to see when it is going astray. Accepting the non-horizontality of the shorelines allowed Gilbert to recognize the important tale that Lake Bonneville was telling both about the world and the mind. This is doing science while being aware of human cognition.

In short, a scientist cannot count on noticing that they are making an error. The consequence, articulated well by J.S. Mill, is that "...while everyone well knows himself to be fallible, very few think it necessary to take precaution against their own fallibility..." (Mill, 1859, p. 32). The use of multiple working hypotheses is a safeguard against one's own fallibility. Attending to the mind is an insurance policy against risks in reasoning that could delay progress in science.

However, safeguards need to be in place to be effective. Geologists are familiar with the advice to construct multiple working hypotheses, yet may not do so every time they are in the field. Thinking through all possible explanations for observed patterns takes significant intellectual resources and is impractical for well-established inferences, such as, "that's a shoreline." Multiple hypotheses become relevant for models where there is a lack of community agreement and bias can influence practice.

Please allow us a one-paragraph digression to illustrate the crucial point that a mind cannot determine when it is making errors. When the continental drift hypothesis was first introduced (Wegener, 1915), consider whether you would have been an early adopter of this mobilist idea. Both authors agree, we think we would have been early adopters of mobilism. Even a cursory consideration of the historical facts, however, shows just how wrong our confidence is. The proportion of the scientific community that were early adopters was tiny and in all likelihood we would have been fixists. The earliest versions of a mobile Earth were widely rejected for decades,

by the overwhelming majority of the geological community. Thinking that one would be an early adopter of continental drift occurs because one knows the right answer. One knows how all of the facts fit neatly together, which allows the correct answer to readily come to mind. The ease of thinking the idea—here, that the continents can move relative to each other—causes us to believe we would have also easily believed the idea when we first encountered it. But humans cannot accurately predict what we would think if we did not know something (Fischhoff, 1975).

Focusing on any single hypothesis similarly allows all the consistent facts to come readily to mind, which makes the hypothesis feel like a right answer. The bias of being inclined to believe the things that come most easily to mind is a trap. The mind will thereafter focus on a favored hypothesis to the exclusion of other potential hypotheses, and people are unlikely to recognize the uncertainty in that hypothesis. Moreover, non-conforming data will be overlooked, not collected, and/or not reported. There are effective ways to avoid this trap. One approach does not work, however: Mentally commanding yourself to not be trapped (Soll et al., 2015). One approach that does work, however, is to avoid commitment to a single hypothesis, and to design a mental workflow to allow or evaluate alternative accounts.

THE THESIS OF THIS ESSAY IS THAT THERE ARE ASPECTS OF DOING SCIENCE TO WHICH WE DO NOT HAVE CONSCIOUS ACCESS. SOME KEY MENTAL PROCESSES FOR SCIENCE REQUIRE MENTAL PROCESSES, SUCH AS RECALLING THE RELEVANT FACTS AND EVALUATING THEIR CONSISTENCY WITH A NEW OR OLD HYPOTHESES, THAT ARE COLLECTIVELY UNDERSTOOD TO REQUIRE MEMORY.

To illustrate the power of minor changes to workflow, consider this example of interpreting seismic reflection profiles: Clare Bond and colleagues (Macrae et al., 2016) documented improved performance if individuals were required to explicitly articulate the temporal ordering of events when multiple interpretations are possible. Although Bond and colleagues did not explicitly ask for multiple hypotheses, the act of articulating the logic of temporal ordering was sufficient to avoid errors that arose because the wrong answer came to mind first. Even the best-intentioned expert participants could not feel their mind making the error of thinking that what came to mind easily was a right answer. Absent knowing an error is being made, we need methods that reduce the chances of making errors.

Why should we follow Gilbert's direction, whether to employ multiple working hypotheses or other techniques, to be aware of and support the mind's practice of geology? The thesis of this essay is that there are aspects of doing science to which we do not have conscious access. Some key mental processes for science require mental processes, such as recalling the relevant facts and evaluating their consistency with a new or old hypotheses, that are collectively understood to require memory. We evaluate hypotheses and theories by how well memories cohere into a viable account of the world. These mental processes are simultaneously a discovery engine that advances science and an error engine that hinders science. By recognizing the mind's limits, we can see the value of Gilbert's guidance and ultimately the importance of knowing some fundamentals of cognitive science while practicing science.

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Earth Science Week 2024: Earth Science Everywhere

Lindsay Mossa, Lauren Brase, Sequoyah McGee, and Ed Robeck

Since 1998, the American Geosciences Institute (AGI) has organized Earth Science Week (ESW) to raise awareness about and increase engagement in earth science among teachers, students, and the general public. ESW 2024 will be held from 13–19 October and will celebrate the theme "Earth Science Everywhere." This celebration encourages the recognition that earth science involves interactions between all of Earth's systems across the globe and permeates all parts of our lives, from the materials we use to the air we breathe.

The ESW Toolkit is developed annually by AGI and its partners to provide earth science resources, such as activities, posters, and online interactives, for use in formal and informal educational settings. The Geological Society of America (GSA) is one of many Earth Science Week sponsors that provide funding, enabling the development of high-quality educational materials, particularly the annual Geologic Map Day (GMD) Poster. The 2024 GMD poster showcases the 2020 unified geologic map of the Moon on the front, and a set of geologic maps and satellite images on the back that feature specific impact craters on both the Moon and Earth.

In addition to being a sponsor, GSA is also an ESW partner that actively participates in the creation of educational resources. This year, an activity in the ESW calendar was developed by GSA to highlight the theme of "Earth Science Everywhere" by having students participate in EarthCaching in their local area. EarthCaching is a type of geocaching that has participants use GPS devices to explore areas they might not otherwise visit to learn about unique geologic features and Earth's natural history. All activities in the calendar are linked with the Next Generation Science Standards and so could be used in any educational setting, but GSA's EarthCaching activity is especially well-suited for informal learning. EarthCaching can be done worldwide by students, families, or anyone interested in exploring geologic and other natural features.

Activities and resources can be found on the 2024 Earth Science Week website. **www.earthsciweek.org/resources/2024/**

AGI encourages members of GSA to get involved in Earth Science Week by hosting and/or attending ESW events in addition to promoting it online. Hosting an EarthCaching event or creating your own EarthCache could be an easy way to celebrate Earth Science Week. Interactive, in-person events are a way to educate the public about the importance of studying the earth sciences, in addition to disseminating the educational resources that GSA has to offer. We also highly encourage classroom visits so that students can see the work that geoscientists do, which can inspire students to pursue additional educational opportunities or careers related to the geosciences.

Figure 1. (A) One of hundreds of geocaches in and around Annapolis, Maryland, USA. Hidden at each location is a box or other item containing a log of visitors and sometimes a challenge to complete at the site. (B) An EarthCache at Thomas Point Park where visitors can learn about the imported zebra shist that protects the shoreline and the retired lighthouse that is now a NOAA monitoring station on the Chesapeake Bay. Credit: L. Mossa, AGI.

The success of ESW is highly dependent on the efforts of our partners, including GSA. For more information about Earth Science Week, related educational materials, and for tips on hosting ESW events, please visit www.earthsciweek.org or e-mail info@earthsciweek.org.

EARTH SCIENCE WEEK

All About EarthCaching!

Dig deeper into EarthCache and set up an account, read the guidelines, buy merchandise, or support the program. Learn more: **https://bit.ly/3zXstkN**

Eclogites in Space and Time: Bridging the Micro to Planetary Scales

Figure 1. Sonoma Coast State Beach, Sonoma County, California. Photograph by Tatsuki Tsujimori.

19–23 June 2025

Doubletree Inn, Rohnert Park, California, USA

- **Application Deadline:** 15 November 2024
- **Acceptance Notices:** 15 January 2025
- **Registration and Abstracts Deadline:** 15 February 2025

Apply at: **https://forms.gle/ji2HSWaGRgWET3n89**

Learn more: **www.geosociety.org/penrose**

DESCRIPTION

The multidisciplinary study of eclogites from micro to planetary scales over the past 50 years has significantly advanced our understanding of plate tectonics. Eclogites are both the recorders and drivers of planetary-scale tectonics, and their formation is involved in such diverse processes as the geochemical exchange between Earth's surface and deep interior, intermediate-depth seismicity, and continental growth, collision, and evolution.

OBJECTIVES

The objective of this Penrose Conference is to bring together the international eclogite community and scientists working on subduction-zone processes to discuss recent advances in diverse fields (e.g., geodynamics, geochemistry, experimental petrology, and geochronology); catalyze breakthroughs in our understanding of subduction-zone processes; and chart future research on eclogites in space and time.

This Penrose Conference will represent the 15th International Eclogite Conference (IEC15) and will be the first time U.S.-based scientists host the international eclogite community at a dedicated conference.

CONFERENCE FORMAT

The conference format will include oral presentations, poster presentations, breakout discussions, and mentoring opportunities for early career scientists. Attendees will be expected to observe the GSA Code of Ethics & Professional Conduct throughout the meeting.

The venue is close to some of the classic localities of the Franciscan Complex, which we will visit during two syn-conference field excursions. Learn more about the venue online.

THEMATIC SESSIONS

Eclogites, Micro to Macro Scales

What processes do eclogites and eclogite-facies rock reveal at different scales? How do new insights from micro-scale observations on high-pressure and ultrahigh-pressure (HP–UHP) metamorphic rocks better constrain and inform subduction-zone processes? This thematic session will explore the state of knowledge regarding bridging the scales in eclogite research.

Advances in Methods: Thermobarometry and Geo/Thermochronology

Mineral assemblages preserved in HP–UHP metamorphic rocks challenge the assumption that equilibrium was attained during prograde, peak, and retrograde conditions. This thematic session will explore advances in thermobarometry and geo/thermochronologic techniques used to determine the pressure-temperature-time-deformation (*P-T-t-D*) histories of eclogite and related rocks.

The Role of Eclogite in Geodynamics

This thematic session will explore how *P-T-t* paths and deformation histories of eclogites (and related rocks) can be used to improve our understanding of paleogeothermal gradients, and thus the thermal evolution of our planet. It will include how seismic tomography can be integrated with observations from exhumed rocks to constrain the role of eclogites in Earth's geodynamic evolution.

The Franciscan and HP–UHP Rocks of the Circum-Pacific Realm

The Franciscan Complex of California is among the first natural laboratories for the study of subduction zones and subduction processes. This session will focus on how the Franciscan Complex and other HP–UHP terranes in the circum-Pacific realm formed and survived exhumation to Earth's surface. This thematic session will also explore how HP–UHP exhumation mechanisms differ between long-lived and transient subduction zones.

Rheology of the Subduction Interface: Deformation and Earthquake Processes

Can exhumed analogs in the subduction-related metamorphic rock record be used to constrain the rheology of the slab–mantle interface? How does the process of serpentinization affect fore-arc deformation and fluid transport in the mantle wedge? This thematic session will explore the rheology of the subduction interface as preserved in both the seismicity of active subduction zones and the geologic evolution of exhumed HP-UHP terranes.

Fluids, Melts, and Geochemical (Re)cycling in Subduction Zones

What are the roles of fluids and melts in the geochemical cycling in subduction zones? This thematic session will explore how observations on HP–UHP metamorphic rocks can constrain the sources, pressures, and volumes of fluids in subduction zones.

APPLICATIONS

GSA and the meeting conveners are committed to fostering diversity, equity, inclusion, and belonging in the geoscience community. For this meeting, we welcome and encourage applications from all groups including those currently underrepresented within the earth science community. The conference will be limited to approximately 100 participants, and each participant will be expected to attend the full duration of the conference.

As part of the application, you will be asked to prepare a brief statement of your interests and the relevance of your work to the conference themes (300 words maximum), as well as a tentative title for a proposed presentation. Every participant will be expected to present at the conference. Applicants will be notified regarding attendance and presentation format (oral or poster) by 15 January 2025. Conference participants will be asked to submit full abstracts for presentations at the time of registration.

COST

Participants will be expected to pay for travel expenses to the venue. All participants will be expected to make their travel arrangements to arrive at the venue by the evening of 18 June. The registration fee will cover five nights of lodging, meals, transportation for field trips, and facility usage. We anticipate the allocation of some funds to partially support the registration costs of some early career and student participants.

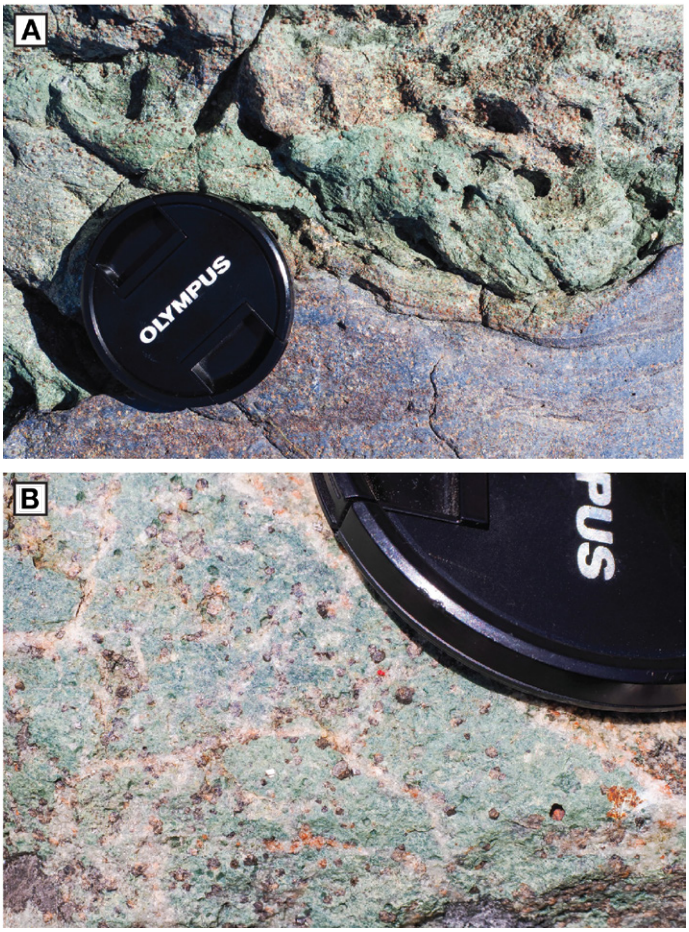

Figure 2. Field pictures of localities to visit during the syn-conference field trips. (A) Jenner and (B) Ring Mountain eclogites. Photographs by Tatsuki Tsujimori.

CONVENERS

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GEOLOGY THROUGH THE LENS

Folds in the Fjord

Brilliantly white iceberg contrasts with recumbently folded red, tan, and black Devonian sandstones and shales exposed in a fjord wall in the Scoresby Sund region of east Greenland.

Credit: Dana Johnston is an emeritus professor in the Department of Earth Sciences at the University of Oregon.

Want your photo to be featured in *GSA Today*? Email submissions to gsatoday@geosociety.org.

Guiding the Future of Geoscience with Brunton

GSA Connects 2024 is just around the corner, and the staff and Board of Trustees of the Geological Society of America Foundation (GSAF) look forward to seeing you in Anaheim! This year's event promises to be an excellent opportunity for us to connect with you and discuss how GSAF, your trusted partner, can continue to support future generations of geoscientists.

One of our Foundation trustees, Lauren Heerschap, will be at Connects, fulfilling her dual role as a trustee and vendor. Lauren is the first ever female co-owner and CEO of Brunton, a company with headquarters and manufacturing facilities in Riverton, Wyoming, USA. Brunton, a brand familiar to virtually all geologists, has been producing essential field equipment like compasses and pocket transits for over 130 years.

Lauren and her husband David bought Brunton in late 2021, and under Lauren's direction, Brunton has thrived. Lauren's commitment to students and their professional growth is noteworthy; Brunton's philanthropic spirit shines through its donation of engraved transits to all students who complete participation in field camps supported by the J. David Lowell Field Camp Scholarship Fund. GSAF proudly promotes the learning and professional growth of students through this scholarship fund, as well as more than 120 additional funds stewarded by the Foundation.

The field camp scholarship fund was established through the generosity of Dr. J. David Lowell, a renowned field-based mineral exploration geologist. Students who attend a field camp supported by the J. David Lowell Fund gain not only a critical understanding of excellence in field studies but also an essential piece of personal field gear in the engraved Brunton transit. We thank Brunton, under Lauren's leadership, for their unwavering support of student learning.

Visit Brunton's booth in the Exhibit Hall to meet Lauren and explore their products, and don't forget to check out the other vendors who support GSA! While you're in the Exhibit Hall, please stop by the GSA Foundation booth. We look forward to seeing you there.

Here is a complete list of GSA Foundation trustees, all of whom are very dedicated volunteers and longtime GSA members. More information about the trustees can be found on our website at https://gsa-foundation.org/trustees/.

Two recent J. David Lowell Field Camp Scholars using their Brunton compass in the field.

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