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Cover: Close-up view of Morton Gneiss. Credit: Wirestock / iStock / Getty Images Plus. See related article on pages 4–10.

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A glowing red lava flow from Hawai'i, taken from a helicopter. From Wikimedia Commons: Pāhoehoe and Aa flows at Hawaii.jpg. Photo by Brocken Inaglory.

SCIENCE

USA's Oldest Rock? A Simple Question with a Complex Answer

Carol D. Frost, [*,1] Paul A. Mueller,[2] Marion E. Bickford, [†,3] and Robert J. Stern[4]

ABSTRACT

Superlatives—whether tallest, longest, or fastest—are more interesting than averages. This characteristic applies to many aspects of the geosciences, where scales of time and space are beyond human experience. The deepest trench, the highest mountain, and the most expansive desert are much more interesting than average ones. Interest in superlatives also applies to the oldest rocks. In this essay, we show that the oldest rocks in the United States are 3.62–3.45 billion years old (Ga) and are found in three different states. These localities define an east-west–trending belt in the upper midcontinent that stretches ~3000 km from Wyoming through Minnesota and into the Upper Peninsula of Michigan. Complex U-Pb zircon systematics are observed in the oldest rocks from all three areas, complicating efforts to distinguish zircons that crystallized in the magma(s) that made the host rock from xenocrystic zircons incorporated by assimilating older rocks. Within these uncertainties, the oldest rock in the United States is 3.62 Ga (Eoarchean to Paleoarchean), but older, 3.8 Ga zircon-bearing felsic crust existed and may be identified by future investigations.

INTRODUCTION

Most geoscientists are aware that Canada's Acasta Gneiss is considered to be the oldest rock in the world (Bowring and Williams, 1999). Fewer know what is the oldest rock in the United States. In this contribution, we consider three candidates for the United States' oldest rock (Figs. 1 and 2).

Some questions about geologic superlatives are easy to answer, but "what is the oldest rock in the USA?" is not. The 1975 vintage sign in the thumbnail above suggests that the matter is settled, and the oldest rock in the United States, and indeed in the world, is the Morton gneiss in the Minnesota River valley. Clearly, the Morton gneiss is a rock, but as rocks go, it is a mess. A cursory look at this gneiss (Fig. 2B) makes it clear that this rock experienced a complex history involving multiple different events. How does one use radiometric dating to determine the age of a complicated rock like this? Modern geochronology of ancient rocks commonly uses the mineral zircon. However minerals are not rocks but rock constituents, and their ages do not necessarily represent when the rest of the rock formed. Can we determine when different components of a complex gneiss formed?

Figure 1. Basement map of the contiguous United States, showing locations of candidate oldest rocks discussed in this paper (modified from Lund et al., 2015), with Wyoming Province boundaries from Bedrosian and Frost (2022). GLTZ—Great Lakes tectonic zone; MN R.—Minnesota River subprovince.

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†M.E. Bickford passed away during preparation of this paper.

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Figure 2. Field photographs of the candidate oldest rocks. (A) Sacawee gneiss sample 10GR2, a strongly foliated biotite trondhjemite gneiss from the Wyoming Province. Scale is 15 cm. (B) Morton gneiss from a road cut near Morton, Minnesota, in the Minnesota River valley. Pencil for scale. (C) Biotite tonalite Watersmeet gneiss from the core of the Watersmeet dome, northern Michigan. Pencil for scale. Photo credits: Images in A and B are courtesy of C. Frost; image in C is by Paul Brandes (mindat.org; Brandes, pers. comm., December 2024).

This contribution is aimed primarily at the scientifically literate public and students who want to learn more about old rocks and how geoscientists date them. We also made a short video on the topic, which can be found on the University of Texas at Dallas (UTD) Geoscience Studio YouTube channel (https://www.youtube.com/watch?v=-SLCzt89LRc).

EVOLUTION OF GEOCHRONOLOGY

When the sign on page four was erected in 1975, it was justified because some workers argued that the Morton gneiss was formed as much as 3.8 b.y. ago (Goldich and Hedge, 1974). Later research, however, suggests that the oldest igneous components in the Morton gneiss formed closer to 3.5 Ga (Bickford et al., 2006). Clearly, the age of the rock has not changed, but the accepted age changed as geochronology techniques advanced and because different radiometric methods on different minerals lock in different times and conditions. For example, early studies on the Morton and other ancient gneisses measured the K and Ar contents and Ar isotopic compositions in micas and other K-bearing minerals; this allowed Goldich et al. (1956) to estimate an age of ca. 2.4 Ga for the Morton gneiss, which we now know is much too young because these minerals lose radiogenic argon at relatively low temperatures (~300 °C; McDougall and Harrison, 1999). The science of dating rocks advanced rapidly in the last half of the twentieth century, and new techniques based on the decay of ^{87}Rb to ^{87}Sr allowed Goldich et al. (1970) to estimate an age of 3.55 Ga for whole-rock samples. These samples were collected at different spatial scales in attempts to distinguish the ages of individual components using location, color, dimensions of compositional banding, and mineralogy. However, this approach commonly yielded geologically meaningless ages (Field and Råheim, 1979) and has fallen out of use.

Dating zircon grains using U-Pb techniques is now celebrated as the optimal method for determining when igneous rocks formed. The decay of two isotopes of U along independent decay chains to produce different Pb isotopes means that two radiometric "clocks" are ticking in every U-bearing mineral at rates that are optimized for ancient rocks. Zircon ($ZrSiO^{4}$) incorporates U^{+4} ions structurally, but the subsequent decay products do not fit in the crystal structure well. The end products of ^{235}U and ^{238}U decay, the Pb isotopes ^{207}Pb and ^{206}Pb, may leave the crystal in a process referred to as lead (Pb) loss. By comparing the ages obtained from these two chronometers, it is possible to detect processes such as Pb loss that affect age calculations. U-Pb systematics of zircons in Archean gneisses show they almost invariably experienced complex histories, including Pb loss.

Improved laboratory protocols for determining zircon U and Pb contents and Pb isotopic compositions have enabled geochronologists to distinguish individual components of complex, migmatitic rocks such as the Morton gneiss and to determine their ages. The pioneering work of Tom Krogh (1936–2008) in the 1980s transformed zircon geochronology. Previously, the laborious procedure required separating milligram-sized groups of zircon grains followed by dissolution and chemical separation of U and Pb before analysis using a mass spectrometer. Krogh developed procedures in which zircons were distinguished by size, shape, and magnetic susceptibility, and laboratory processes by which U and Pb contents and isotopic compositions of individual grains, including physically abraded grains and parts of grains, could be measured and interpreted (Krogh, 1982a, 1982b; Davis et al., 2003). The most precise ages for ancient zircons still come from the analyses of pure fractions of U and Pb extracted from carefully selected zircon grains or parts of grains, which may have been physically abraded or chemically conditioned prior to analysis. Beginning in 1980, less precise but very useful in situ determinations of U and Pb in zircons using the secondary ion mass spectrometer (SIMS) began to supplement advancing chemical techniques (Compston, 1996). This was followed by other in situ techniques like laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) and multicollector (MC) ICP-MS. U-Pb measurements of microdomains in zircons are now routinely accomplished in situ on single zircons with spot analyses as small as 5 µm (Schaltegger et al., 2015). This size is much smaller than a typical zircon, which is on the order of 100 µm (0.1 mm) long, allowing different ages to be determined in the core versus the rim of a single zircon. It is no wonder that zircon geochronology is called "the queen of geochronology" (Harley and Kelly, 2007).

Regardless of the analytical particulars, U-Pb zircon geochronology remains the best way to determine ages of ancient zircons and by inference their host rocks. This reflects the unmatched physical and chemical robustness of zircon coupled with the sensitivity of the two U-Pb decay schemes.

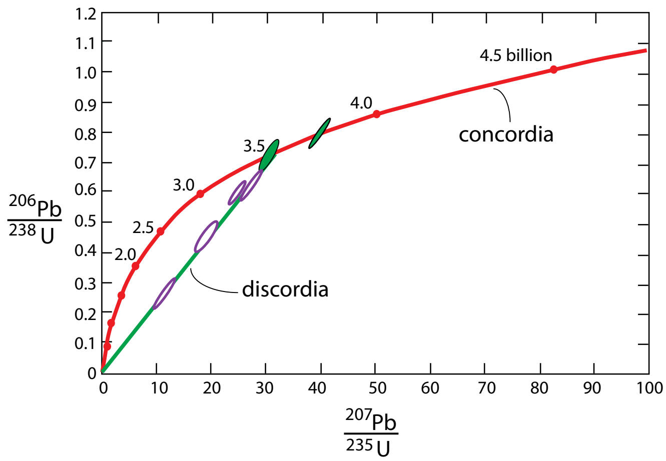


Figure 3. Concordia diagram, with the concordia shown as the red curve. Ages are in billions of years. Samples plotting on the concordia (green ellipses) give the same age in both the $^{238}U/^{206}Pb$ and $^{235}U/^{207}Pb$ decay systems. Arrays of discordant points (open purple ellipses) may form a chord (discordia; green line) that intersects the concordia at the crystallization age. Portions of the concordia diagram are enlarged on plots in Figure 4 to focus on the areas of the analyses.

Individual zircons can survive many cycles of erosion and sedimentation, metamorphism, and partial melting. Nonetheless, not all zircons survive these events intact isotopically: Some events may add uranium, especially to zircon rims, and metamorphism causes Pb loss. The significance of ages revealed by analysis of any zircon by any method must be judged on the basis of concordance.

Concordance in zircon geochronology is when ages calculated in the ^{235}U-^{207}Pb and the ^{238}U-^{206}Pb decay systems are identical within analytical error. These results are typically displayed on concordia diagrams (Fig. 3). The concordia curve represents the locus of all data for which the two U-Pb ages agree. Data that plot on concordia are called concordant ages, while data that fall off the curve are discordant. Discordance can range from essentially 0 to +99% and is most commonly associated with loss of radiogenic Pb from zircons; this is common when rocks were sufficiently heated by younger metamorphism. While U gain produces a mathematically identical result, it is rare. Greater discordance leads to greater age uncertainty. Discordant data are not, however, bad data; they reveal complexities in the history of these zircons, and thus in the rocks that host them. As shown in Figure 3, discordant data may define a discordia, which is a straight line connecting an array of discordant data. In coherent arrays, the intersection of a discordia with concordia can provide critical information. For example, the intersection of a well-constrained discordia with concordia yields a date equivalent to a point on the concordia diagram; these are referred to below as regressed ages. Even concordant zircon ages vary in reliability; tight groups of ages are more reliable than loose groups of ages. Geochronologists use statistical measures of the tightness of the zircon age cluster, particularly the mean square of weighted deviates (MSWD), in their interpretations. An age with a low MSWD is more reliable than one with a high MSWD. Another challenge in interpreting multiple age groupings from old, typically migmatitic, gneisses is to identify younger zircons that formed by metamorphism after the original igneous rock crystallized; these may be recognized by their low Th/U ratios (<0.1).

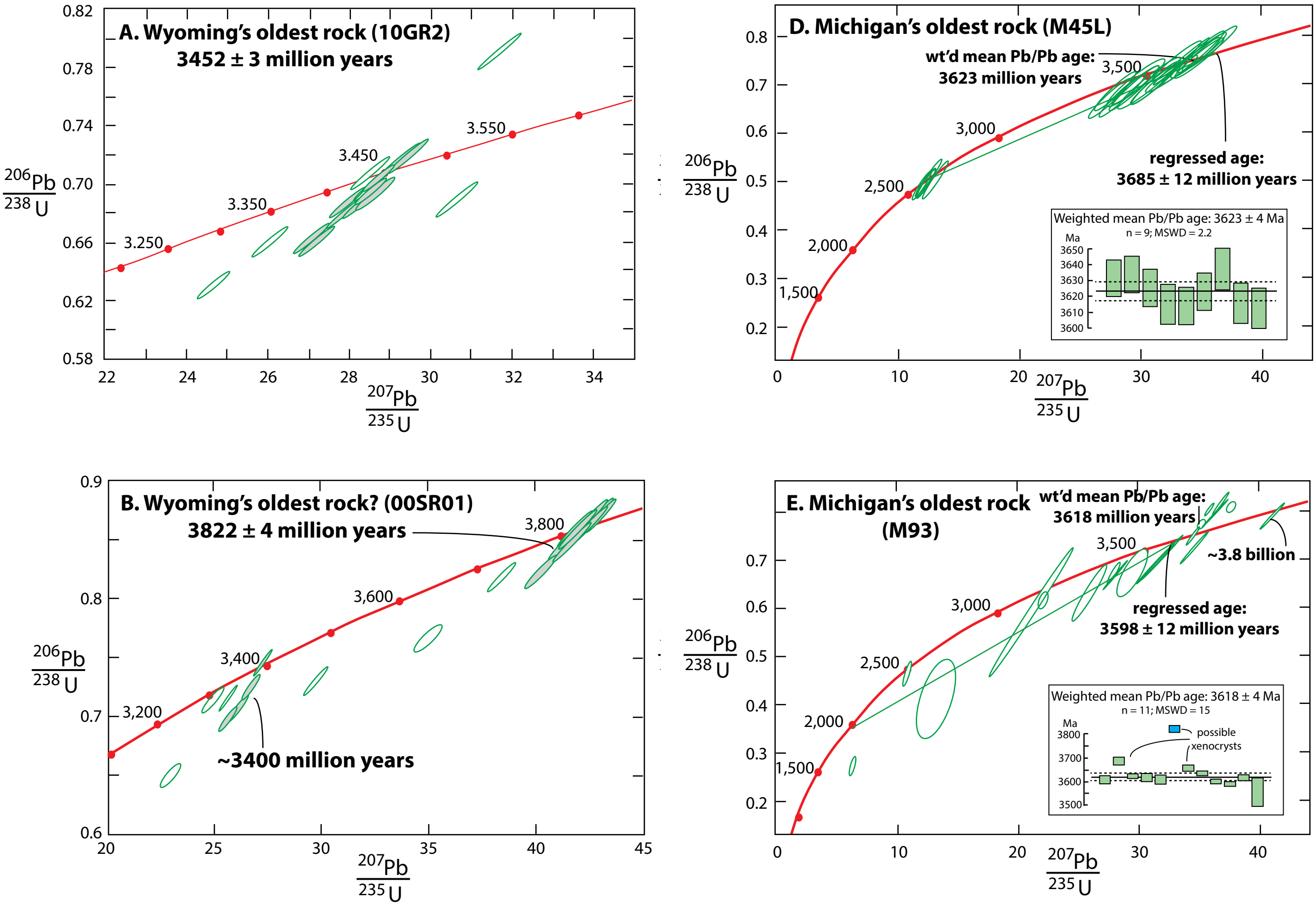
THE CANDIDATES

Our candidates for the oldest U.S. rock are ancient gneisses with complex histories. As one might expect, these candidates do not exist in isolation but are parts of larger entities commonly referred to as age provinces, gneiss complexes, terranes, or cratons. The oldest rocks in the United States are located in the north-central part, where our three candidates are found, in (1) the Archean Wyoming Province (e.g., Condie, 1976); (2) the Minnesota River valley subprovince of the Superior Province of the Canadian Shield (e.g., Goldich et al., 1970); and (3) the Watersmeet gneisses of the Upper Peninsula of Michigan (Peterman et al., 1980). Each of these candidates is a gneiss that was originally an igneous rock.

Wyoming Province

The Wyoming Province contains numerous indications of its antiquity (e.g., Mueller and Frost, 2006; Mogk et al., 2023). The northern part hosts ca. 3.5 Ga Paleoarchean gneiss spectacularly exposed in the rugged Beartooth Mountains and the northern Madison Range of Montana and Wyoming (Mueller et al., 1996, 2014). Detrital zircons as old as 4.0 Ga also are documented from the northern Wyoming Province (Mueller et al., 1992; Mueller and Wooden, 2012). Here, we highlight two samples of the Sacawee orthogneiss of the Granite Mountains in central Wyoming (Frost et al., 2017).

The Sacawee block comprises a narrow belt of Archean crust exposed in central Wyoming (Fig. 1; Frost et al., 2017). It is composed of quartzofeldspathic gneisses and metamorphosed mafic rocks, variably deformed and interlayered on outcrop to map scale. Gneiss protoliths were mainly biotite-bearing trondhjemites, tonalites, and granodiorites (TTG), a group of broadly granitic rocks common in the Archean (Moyen and Martin, 2012). Sacawee block gneisses are intruded to the south by 2.63–2.62 Ga granite of the Wyoming batholith and to the north by ca. 2.65 Ga foliated granite. The oldest date from the Sacawee block comes from U-Pb analyses of zircons from a strongly foliated, but compositionally homogeneous, coarse-grained biotite trondhjemite gneiss (Fig. 2A). U-Pb isotopic data from zircons using SIMS are shown in Figure 4A. A prominent grouping of 12 analyses, close to and within uncertainty of the concordia, yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 3452 ± 3 Ma (where Ma = million years old; MSWD = 1.8), which was interpreted as the intrusive age of the granitic protolith (Frost et al., 2017). Analyses yielding slightly younger ages were interpreted as having lost Pb shortly after intrusion, and a single analysis of an older zircon suggested that this grain must have been "inherited" or entrained as the magma passed through older rocks. Clues to the identity of these older rocks were revealed in a sample of a nearby biotite tonalite gneiss. This rock contained two age populations of zircon, one group at ca.



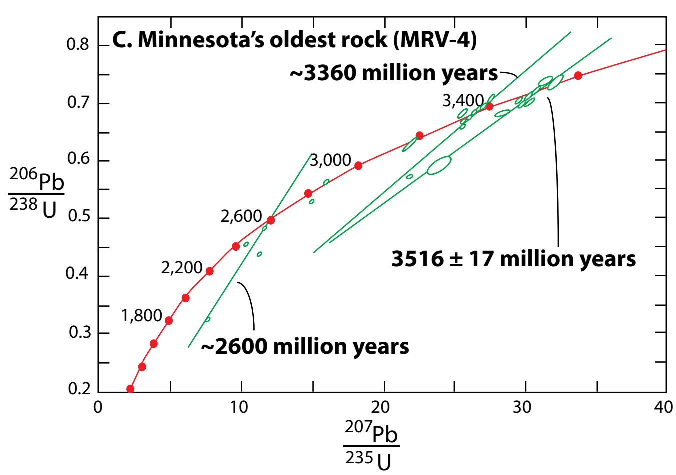


Figure 4. Concordia diagrams of the candidate oldest rocks in the United States. (A) Sacawee gneiss sample 10GR2 from the Wyoming Province. (B) Tonalite gneiss sample 00SR01 from the Wyoming Province, 20 km east of sample 10GR2. Data for both samples from Frost et al. (2017). (C) Morton gneiss sample MRV-4 from the Minnesota River subprovince. Data are from Bickford et al. (2006). (D) Watersmeet gneiss sample M45L. (E) Watersmeet gneiss sample M93 from northern Michigan. Samples of Watersmeet gneiss were collected by Z.E. Peterman and zircon U-Pb analyses were conducted by P.A. Mueller by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS). Analytical methods and data are provided in the Supplemental Material files (see text footnote 5). Many analyses are strongly discordant. Data in part D show the 29 of 60 analyses from M45L are <5% discordant (48%), and data in part E show that 20 of 80 analyses from M93 that are <10% discordant (25%). Insets show weighted mean $^{207}Pb/^{206}Pb$ ages of the oldest concordant analyses. In the case of M93 (Fig. 4E), three analyses (3822 ± 8 Ma, 3764 ± 16 Ma, and 3687 ± 9 Ma) lie outside the error envelopes of the weighted mean ages and are interpreted as xenocrysts derived from yet older crust. The 3822 Ma analysis was not included in the weighted mean age. MSWD—mean square of weighted deviates.

3.4 Ga, which has been interpreted as the crystallization age, and an older group (Fig. 4B). Nine analyses of grains from this older group yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 3822 ± 4 Ma (MSWD = 1.4; Frost et al., 2017). These zircons were interpreted as xenocrysts, and their age was interpreted as indicating that the protolith of the ca. 3.4 Ga gneiss intruded 3.82 Ga Eoarchean crust, although such rocks have yet to be found.

Minnesota River Valley

Like Wyoming Province gneisses, the ancient Morton and Montevideo gneisses of the Minnesota River valley (MRV) are dominantly tonalite, trondhjemite, and granodiorite (Bickford et al., 2006). The Minnesota River terrane is commonly described as a subprovince of the Superior Province, but it is separated from the Neoarchean (2.8–2.5 Ga) granite-greenstone belts that dominate the southern Superior Province by the Great Lakes tectonic zone (Sims et al., 1980). MRV gneisses, particularly the Morton gneiss, have been widely used as a building stone in North America (Lund, 1953, 1956).

The oldest MRV rocks have a complex history, as illustrated by a Morton gneiss sample studied by Bickford et al. (2006). A concordia diagram of SIMS U-Pb data (Fig. 4C) shows one group of zircons with a regressed age of 3516 ± 17 Ma and a second group of essentially concordant grains with a regressed age of 3360 ± 9 Ma. One concordant analysis from a rim around a ca. 3.5 Ga core yielded a concordant $^{207}Pb/^{206}Pb$ age of 3145 ± 2 Ma, apparently reflecting zircon growth during an igneous event associated with the nearby intrusion of mafic magmas (Bickford et al., 2006). A fourth group of analyses, with a regressed age of 2595 ± 4 Ma, was obtained from rims around the 3516 Ma and 3360 Ma zircons, and this group records a Neoarchean event that affected these rocks (Fig. 4C). The zircons in the 3516 Ma group are euhedral and show well-developed oscillatory growth zones, whereas the 3360 Ma grains do not show growth zones. These relationships suggest that the Morton gneiss is an aggregate of older, ca. 3.5 Ga igneous rocks mixed with ca. 3.36 Ga igneous rocks during a deformation event 2.6 b.y. ago, which also formed young rims on the older zircons (Bickford et al., 2006).

Upper Peninsula of Michigan

An Archean gneiss terrane forms the crystalline basement in northern Wisconsin and the Upper Peninsula of Michigan (Fig. 1). Although Archean rocks form the bedrock, exposures are limited. Our candidate for the oldest rock in this terrane is the Watersmeet gneiss, exposed in the center of the 8 × 25 km Watersmeet dome. This is one of several domes that formed during and immediately after the Paleoproterozoic Penokean orogeny (ca. 1870–1830 Ma) that are cored by Archean gneiss folded with and intruded by Proterozoic rocks (Schulz and Cannon, 2007). The Watersmeet dome was deeply buried during the Penokean orogeny and now exposes the deepest crustal level in the orogen. Peterman et al. (1980) discussed the "Gneiss at Watersmeet" and estimated the tonalite gneiss to have a minimum age of 3410 Ma. Further refinement of the ages by Peterman et al. (1980) using LA-ICP-MS on zircons extracted from two of the same samples illustrated the complex history experienced by this ancient gneiss (Figs. 4D and 4E; Table S1 in the Supplemental Material[5]). In one sample of Watersmeet tonalite gneiss, 29 of 60 analyses were <5% discordant. Those 29 analyses defined two age groups of ca. 2.64 and ca. 3.60 Ga (Fig. 4D). U-Pb ages of zircons from a second Watersmeet tonalite gneiss sample displayed substantial discordance with $^{207}Pb/^{206}Pb$ ages from 3.8 Ga to 1.3 Ga (Table S1). This discordance likely reflects Pb loss during five later igneous and metamorphic events as well as Phanerozoic uplift and erosion. Precambrian events included: (1) intrusion of the Neoarchean Carney Lake gneiss (ca. 2750 Ma; Ayuso et al., 2017, 2018); (2) crosscutting leucogranite dikes and intrusion of the ca. 2600 Ma Puritan quartz monzonite (Peterman et al., 1980); (3) strong Penokean deformation ca. 1800 Ma (inferred from Rb-Sr whole-rock and U-Pb zircon analyses); (4) uplift of the Watersmeet dome at 1755 Ma (Peterman et al., 1980; Schneider et al., 1996); and (5) ca. 1110–1070 Ma igneous activity of the Mesoproterozoic Midcontinent Rift (Fairchild et al., 2017). Regression ages for the two aforementioned samples were 3685 ± 12 Ma and 3598 ± 12 Ma (Figs. 4D and 4E). If only the oldest, least discordant analyses are considered, weighted mean $^{207}Pb/^{206}Pb$ ages of 3623 ± 4 Ma and 3618 ± 4 Ma are obtained (see insets on Figs. 4D and 4E). Because discordance likely reflects Pb loss during later events, the least discordant analyses are considered to be the most reliable. However, because of possible early Pb loss, even these ages should be viewed as minimum ages.

Despite the multiphase history of the Watersmeet gneiss, there are indications of even older crust. Three analyses from the tonalite gneiss lie outside the error envelopes of the proposed ages and are viewed as xenocrysts derived from older crust (3822 ± 8 Ma, 3764 ± 16 Ma, and 3687 ± 9 Ma; see inset in Fig. 4E).

A similar history is preserved in the Archean Carney Lake gneiss, exposed east of the Watersmeet gneiss in northern Michigan. Like the Watersmeet gneiss, it contains concordant and discordant zircons that define regression ages of around 1000 Ma, 2750 Ma, and 3750 Ma (Ayuso et al., 2017, 2018). Detrital zircons up to ca. 3.8 Ga have been reported from Paleoproterozoic (Huronian) sedimentary rocks in the region (Craddock et al., 2013), requiring an older source rock. These data suggest that continental crust began to form in what is now the Upper Peninsula of Michigan by around 3.8 Ga, but like the 3.8 Ga crust of the Wyoming Province, the oldest crust was largely subsumed in younger magmas.

DISCUSSION AND CONCLUSIONS

Our interrogation of the oldest rocks in the United States and their zircons unearthed many devilish complexities. Interpretations are easy when multiple zircons give the

[5] Supplemental Material. Text S1. Analytical methods. Table S1. Zircon U-Pb isotopic data for the Watersmeet gneiss. Please visit https://doi.org/10.1130/GSAT.S.28315214 to access the supplemental material; contact editing@geosociety.org with any questions.

same concordant age, but that is not the case for ancient rocks such as these. So many different zircons analyzed from each of the candidates yielded different ages. This age range is of particular concern when (1) analyzed zircons are discordant, requiring a regression age; (2) there are limited geochemical data to help define groups of discordant analyses (such as petrographic and trace-element characteristics or O and/or Hf isotopic data on the grains; e.g., Drabon et al., 2024); and (3) there is no corroborating evidence to allow younger dates to be interpreted based on the ages of "known" events in the region. Answering the apparently simple question of "Which is and where is the oldest rock in the United States?" requires an honest appraisal of various possible interpretations.

So, which is the oldest rock in the United States? Is it the Watersmeet gneiss in Michigan, which contains near-concordant groups of zircons giving ages of 3623 ± 4 and 3618 ± 4 Ma? Or is it the Wyoming Sacawee gneiss that contains 3822 ± 4 Ma zircons? We can't be sure, but based on our analyses, we propose that the Watersmeet gneiss wins the prize for the oldest rock, at >3.6 Ga. The 3822 Ma zircons, interpreted as xenocrysts in the Sacawee gneiss, are important because they tell us about the presence of even older, Eoarchean crust. The Morton gneiss—no longer the oldest rock in the world, or in the United States—nevertheless serves as an outstanding example of how U-Pb zircon data can be used to unravel complex Archean histories from a single sample.

Moving beyond superlatives to science, it is useful to consider the implications of ~3.5-b.y.-old crust in multiple locations across the northern United States. The similar Archean histories between the southern margins of the Superior and Wyoming cratons suggest that these areas once were part of a single crustal block. Archean gneiss in northern Michigan may be part of the Minnesota River subprovince (Sims, 1980; Bickford et al., 2007). Although the Minnesota River subprovince has long been grouped with the Superior Province of Canada, its Archean geologic history has more in common with the Wyoming Province than with adjacent parts of the Superior Province (Schmitz et al., 2018). In fact, it has been proposed that the Wyoming Province lay south of the Minnesota River subprovince until ca. 2.1 Ga, when it rifted away and rotated to its present location farther west (Ernst and Bleeker, 2010). Taken together, the Archean rocks of the Wyoming-Minnesota-Michigan block represent the oldest continental crust in the United States, the nucleus around which the younger rocks of the nation were assembled. That's a superlative worth knowing!

ACKNOWLEDGMENTS

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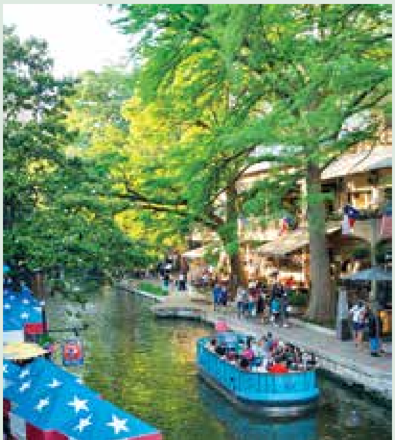
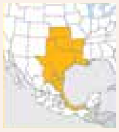


CONNECT GLOBALLY, EXPLORE LOCALLY

WITH GSA SECTION MEETINGS

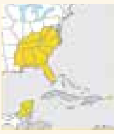


SOUTH-CENTRAL

9–11 MARCH 2025

University of Central
Arkansas Conference Center
CONWAY, ARKANSAS, USA

geosociety.org/sc-mtg

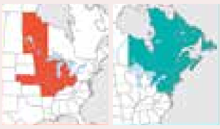


SOUTHEASTERN

19–21 MARCH 2025

Hotel Madison & Shenandoah
Valley Conference Center
HARRISONBURG,VIRGINIA, USA

geosociety.org/se-mtg



JOINT NORTHEASTERN /NORTH-CENTRAL

27–30 MARCH 2025

Bayfront Convention Center
ERIE, PENNSYLVANIA, USA

geosociety.org/ne-mtg

CORDILLERAN

1–4 APRIL 2025

Holiday Inn Sacramento
SACRAMENTO, CALIFORNIA, USA

geosociety.org/cd-mtg

ROCKY MOUNTAIN

18–20 MAY 2025

Utah Valley Convention Center
PROVO, UTAH, USA

geosociety.org/rm-mtg

Important Deadlines

5 MARCH
Cutoff for NE/NC Hotel Registration

10 MARCH
Cutoff for Cordilleran Hotel Registration

13 MARCH
Deadline for Regular Registration - Cordilleran & NE/NC

16 APRIL
Deadline for Early Registration and Student Travel Grant Applications - Rocky Mountain

28 APRIL
Cutoff for Rocky Mountain Hotel Registration

5 MAY
Deadline for Regular Registration - Rocky Mountain

REGISTRATION TYPE*	EARLY	REGULAR	LATE/ONSITE
Professional Member	$225	$425	$450
Professional Non-Member	$265	$465	$490
Professional Senior Member	$150	$245	$270
Early Career Professional Member	$195	$295	$320
Student Member	$95	$110	$130
Student Non-Member	$150	$165	$190
K-12 (Member & Non-Member)	$115	$145	$170
Guest	$75	$95	$120

*For one-day registration, each fee is $50 less. Attendees from lower and middle-income countries (according to the World Bank) will receive 50% off their registration fee, which is automatically applied during the registration process.
For group discounts, contact Jennifer Nocerino, jnocerino@geosociety.org. Cancellations must be received no less than 30 days prior to the meeting. 50 percent of the registration fee will be reimbursed

CHARTING YOUR GEOSCIENCE JOURNEY

Impactful Mentoring Programs at GSA Section Meetings

GSA student members will have the opportunity to discuss career prospects and challenges with applied geoscientists from various sectors.

SOUTH-CENTRAL MEETING	SOUTHEASTERN MEETING	JOINT NORTHEASTERN/ NORTH-CENTRAL MEETING	CORDILLERAN MEETING	ROCKY MOUNTAIN MEETING
9–11 March 2025	19–21 March 2025	27–30 March 2025	1–4 April 2025	18–20 May 2025
University of Central Arkansas Conference Center Conway, Arkansa, USA	Hotel Madison & Shenandoah Valley Conference Center Harrisonburg, Virginia, USA	Bayfront Convention Center Erie, Pennsylvania, USA	Holiday Inn Sacramento Sacramento, California, USA	Utah Valley Convention Center Provo, Utah, USA
Shlemon Mentor Program Monday, 10 March	**Shlemon Mentor Program** Thursday, 20 March	**Shlemon Mentor Program** Friday, 28 March	**Shlemon Mentor Program** Wednesday, 2 April	**Shlemon Mentor Program** Monday, 19 May
Mann Mentor Program Tuesday, 11 March	**Mann Mentor Program** Friday, 21 March	**Mann Mentor Program** Saturday, 29 March	**Mann Mentor Program** Thursday, 3 April	**Mann Mentor Program** Tuesday, 20 May

GeoCareers Workshops at GSA Section Meetings

PART 1

CAREER PLANNING & NETWORKING

Your job-hunting process should begin with career planning, not when you apply for jobs. This workshop, recommended for freshmen, sophomores, and juniors, will help you begin this process and practice your networking skills. The earlier you start your career planning the better!

PART 2

GEOSCIENCE CAREER EXPLORATION

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

PART 3

COVER LETTERS, RÉSUMÉS, AND CVS

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

EARN CEUs

WHEN YOU ATTEND SECTION MEETINGS

Keep your professional license current and stay up-to-date on the latest research in your area of interest.
Continuing Education Units are earned when you attend the 2025 Section Meetings, field trips, and short courses.

LEARN MORE ABOUT CEUS

Help Shape the Future of Geoscience—Serve on a GSA Committee!

Looking for an opportunity to work toward a common goal, give back to GSA, network, or make a difference? We invite you to volunteer (or nominate a fellow GSA member) to serve on a Society committee or as a GSA representative to another organization.

Learn more and access the nomination form at **www.geosociety.org/Committees.** Use the online form to make a self-nomination or nominate a colleague.

View Open Positions: **rock.geosociety.org/forms/viewopenpositions.asp.**

Terms begin 1 July 2026 (unless otherwise indicated).

GSA Headquarters Contact: Darlene Williams, Associate Director of Governance and Awards, +1-303-357-1060, dwilliams@geosociety.org.

Photo Credit: pixelfit/E+ via Getty Images.

Nomination deadline: 15 June

GSA COUNCIL

(3) Councilor (4-year term; E, M); President-elect (3-year term; E, M); Treasurer-elect (1-year term; E, M)

The management of the affairs and the property of the Society shall be the responsibility of the Board, which shall also be known as the Council. The Council shall have the authority, power, and responsibility for the general management, control, and general supervision of the affairs, business, activities, property, and assets of the Society so that the corporate activities are consistent with the stated purposes of the Society and that no act is committed by the Society in contravention of its Articles of Incorporation or Bylaws. Primary duties are to attend and participate actively in all Council meetings, serve as an active member on an average of two GSA committees per year, and inform the GSA Foundation of GSA's ongoing programs and funding priorities. Further information can be found at **www.geosociety.org/GSA/about/Who_We_Are** or **www.geosociety.org/GSA/About/Leadership/GSA/About/LdrResources.aspx.**

ACADEMIC AND APPLIED GEOSCIENCE RELATIONS COMMITTEE

Member-at-Large, Industry (3-year term; E, M)

This committee is charged with strengthening and expanding relations between GSA members in applied and academic geosciences. As such, it proactively coordinates the Society's effort to facilitate greater cooperation between academia, industry, and government geoscientists.

Qualifications: Committee members must work in industry and be committed to developing a better integration of applied and academic science in GSA meetings, publications, short courses, field trips, and education and outreach programs. Members must also be active in one or more GSA Divisions.

Professional Interest: Environmental and Engineering Geology; Hydrogeology; Karst; Quaternary Geology and Geomorphology; Structural Geology and Tectonics; Sedimentary Geology.

ANNUAL PROGRAM COMMITTEE

(2) Member-at-Large (4-year term; B, E, M)

This committee is charged with developing a plan for increasing the quality of the annual and other Society-sponsored meetings in terms of science, education, and outreach; evaluating the technical and scientific programs annually to identify modifications necessary for accomplishing the Society's long-range goals; conducting short- and long-range planning for the Society meetings as a whole; and developing a long-term logistical plan/strategy for the technical programs of all GSA meetings and other Society-sponsored meetings. One member-at-large should have previous meeting experience.

ARTHUR L. DAY MEDAL AWARD

(2) Member-at-Large (3-year term; E, T)

This committee selects candidates for the Arthur L. Day Medal.

Qualifications: Members should have knowledge of those who have made "distinct contributions to geologic knowledge through the application of physics and chemistry to the solution of geologic problems." All the committee's work will be accomplished during the months of February and March. All committee decisions must be made by 1 April.

DIVERSITY IN THE GEOSCIENCES COMMITTEE

(2) Member-at-Large (3-year term; E, M); Member-at-Large, Industry (3-year term; E, M); Member-at-Large, Student (3-year term; E, M)

This committee provides advice and support to GSA Council, raises awareness, and initiates activities and programs that will increase opportunities for diverse groups in the geosciences, particularly in the dimensions of race, ethnicity, gender, and physical abilities. The committee is also charged with stimulating recruitment and promoting positive career development.

Qualifications: Members of this committee must have professional or experiential knowledge of issues relevant to the goals of the committee. GSA strongly encourages nominations of members who are from the communities for which this committee is expected to serve.

DORIS M. CURTIS OUTSTANDING WOMAN IN SCIENCE AWARD COMMITTEE

Member-at-Large, North America and member at large, student (2-year term; E, T); Member-at-Large, International Associated Society (4-year term; E, M)

The purpose of this committee is to generate, receive, and evaluate candidates for the Doris M. Curtis Outstanding Woman in Science Award. The award was established as a means to encourage women in the geosciences. Women are eligible for the first five years following their degree.

Qualifications: Members should have the ability to assess the contributions of those women who have made a major impact in the geosciences based on their Ph.D. work.

EDUCATION COMMITTEE

Informal Science Educator Representative (4-year term; E, M); Graduate Educator Representative (4-year term; E, M)

This committee works with GSA members representing a wide range of education sectors to develop informal, precollege (K–12), undergraduate, and graduate earth science education and outreach objectives and initiatives.

Qualifications: Informal science educator (museums, visitor centers) or graduate educator to provide input, advice, and insight into education initiatives and the quality of earth science education.

> "Nominating a colleague, even (or especially) one you don't know personally, for a GSA award or honor is an especially gratifying experience. For me, recognizing the achievements of others cements the sense of community that nourishes our discipline and is a hallmark of GSA."
>
> —Jim O'Connor, Geologist, U.S. Geological Survey

FLORENCE BASCOM GEOLOGIC MAPPING AWARD COMMITTEE

Member-at-Large (3-year term; E, T); Member-at-Large, Industry (3-year term; E, T); Member-at-Large, Government (3-year term; E, T)

This committee selects candidates for the Florence Bascom Geologic Mapping Award. This award acknowledges contributions in published high-quality geologic mapping that led the recipient to publish significant new scientific or economic-resource discoveries, and to contribute greater understanding of fundamental geologic processes and concepts.

Qualifications: Members should be knowledgeable in the field of mapping.

GEOLOGY AND PUBLIC POLICY COMMITTEE

(2) Member-at-Large (3-year term; E, M); Member-at-Large, Student (3-year term; E, M)

This committee provides advice on public policy matters to GSA Council and leadership by monitoring and assessing international, national, and regional science policy; formulating and recommending position statements; and sponsoring topical white papers. This committee also encourages active engagement in geoscience policy by GSA members.

Qualifications: Members should have experience with public policy issues involving the geosciences; the ability to develop, disseminate, and translate information from the geologic sciences into useful forms for the public and for GSA members; and familiarity with appropriate techniques for the dissemination of information.

GSA INTERNATIONAL COMMITTEE

Member-at-Large (4-year term; E, M); Member-at-Large, Outside North America (4-year term; E, M); Member-at-Large, North America (4-year term; E, M); Member-at-Large, Student (2-year term; E, M)

GSA International, GSA's coordination and communication resource, seeks to promote, create, and enhance opportunities for international cooperation related to the scientific, educational, and outreach missions shared by GSA and like-minded professional societies, educational institutions, and government agencies. This committee also builds collaborative relationships with Divisions and Associated Societies in international issues and serves as a channel for member-generated proposals on international themes.

B – Meets in Boulder or elsewhere **E** – Communicates electronically
M – Meets at Connects **T** – Extensive time commitment required during application review period

FELLOWSHIP COMMITTEE

(2) Member-at-Large, Academia (3-year term; E); Member-at-Large, Student (3-year term; E)

This committee serves a vital role in the review of GSA Fellowship Nominations and the selection of the Newly Elected Fellows and makes recommendations for Fellowship to the GSA Council. Committee members should have a well-rounded knowledge of earth and related sciences, including but not limited to publications and geoscience applications.

Qualifications: Committee members should have experience in benefit, recruitment, and retention programs.

MEMBERSHIP COMMITTEE

(2) Member-at-Large (3-year term; E); Member-at-Large, Industry (3-year term; E); Member-at-Large, Student (3-year term; E); Member-at-Large, Early Career Professional (3-year term; E)

This committee contributes to the growth of GSA membership and enhances the member experience with the goal of fostering a membership community as pertinent and global as our science. Committee members should have a broad understanding of the geoscience community, with particular insight into the needs and interests of students and international members.

Qualifications: Committee members should have experience in benefit, recruitment, and retention programs.

NOMINATIONS COMMITTEE

(2) Member-at-Large (3-year term; B, E)

This committee recommends nominees to GSA Council for the positions of GSA Officers and Councilors, committee members, and Society representatives to other permanent groups.

Qualifications: Members must be familiar with a broad range of well-known and highly respected geoscientists.

NORTH AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE

GSA Representative (3-year term; E, M)

This committee develops statements on stratigraphic principles; recommends procedures applicable to classification and nomenclature of stratigraphic and related units; reviews problems in classifying and naming stratigraphic and related units; and formulates expressions of judgment on these matters.

Qualifications: Members must be familiar with the fields of paleontology, biostratigraphy, and stratigraphy. Term commences 1 December 2025.

PENROSE CONFERENCES AND FIELD FORUMS COMMITTEE

Member-at-Large (3-year term; E)

This committee reviews and approves Penrose Conference and Field Forum proposals and recommends and implements guidelines for the success of these meetings.

Qualifications: Committee members must be early career scientists or professionals.

Committee, Section, and Division Volunteers: Council Thanks You!

GSA Council acknowledges the many member-volunteers who, over the years, have contributed to the Society and to our science through involvement in the affairs of GSA. Your time, talent, and expertise help build a solid and lasting Society.

PENROSE MEDAL AWARD COMMITTEE

(2) Member-at-Large (3-year term; E, T)

Members of this committee select candidates for the Penrose Medal Award. Emphasis is placed on "eminent research in pure geology, which marks a major advance in the science of geology."

Qualifications: Members should be familiar with outstanding achievers in the geosciences worthy of consideration for the honor. All of the committee's work will be accomplished during the months of February and March. All committee decisions must be made by 1 April.

PROFESSIONAL DEVELOPMENT COMMITTEE

(2) Member-at-Large (3-year term; E)

This committee directs, advises, and monitors GSA's professional development program; reviews and approves proposals; recommends and implements guideline changes; and monitors the scientific quality of courses offered.

Qualifications: Members must be familiar with professional development programs or have adult education teaching experience.

PUBLICATIONS COMMITTEE

Member-at-Large (4-year term; B, E, M, T); Member-at-Large, Early Career Professional (4-year term; B, E, M, T)

The primary responsibilities of this committee are to nominate candidates for editors when positions become vacant, review the quality and health of each Society publication, and present an annual report to Council that shall include recommendations for changes in page charges, subsidies, or any other publishing matter on which Council must make a decision. To carry out this charge, headquarters will provide the committee with all necessary financial information.

PUBLIC SERVICE AWARD COMMITTEE

Member-at-Large; (3-year term; B, E, M)

The purpose of this committee is to generate, receive, and evaluate candidates for the GSA Public Service Award and the AGI Outstanding Contributions to the Public Understanding of the Geosciences Award. These awards are in recognition of outstanding individual contributions to either public awareness of the earth sciences, or the scientific resolution of earth science problems of significant societal concern.

RESEARCH GRANTS COMMITTEE

(10) Member-at-Large (3-year term; E, T)

The primary function of this committee is to evaluate approximately 800 graduate student research grant applications and award specific grants to chosen recipients, including some named grants supported by funds within the GSA Foundation.

Qualifications: Members may come from any sector (academia, government, industry, etc.) and should have experience in directing research projects and in evaluating research grant applications. GSA strongly encourages nominations of geoscientists from diverse backgrounds and institutions, particularly from minority serving institutions. **Extensive time commitment required 15 Feb.–15 April**; each member reviews approximately 40 applications.

More information: www.geosociety.org/gradgrants

YOUNG SCIENTIST AWARD (DONATH MEDAL) COMMITTEE

(2) Member-at-Large (3-year term; E, T)

Committee members investigate the achievements of young scientists who should be considered for this award and make recommendations to GSA Council.

Qualifications: Members should have knowledge of young scientists with "outstanding achievement(s) in contributing to geologic knowledge through original research which marks a major advance in the earth sciences." All the committee's work will be accomplished during the months of February and March. All committee decisions must be made by 1 April.

> "Nominating your peers for professional society awards is both an egalitarian and intentional act. Honors and awards highlight positive role models and inspire others to strive for excellence. They are also the easiest and most gratifying way to celebrate your colleagues and to promote diversity and level the playing field. When I nominate for an award, I do so with intention. Recognition can enhance awareness of paradigm-shifting ideas and innovative approaches, and it can encourage allocation of funding to a promising area of research or initiative. One way to think about our responsibility to nominate is, 'if you see something, say something.' From personal experience, the impact you will have on the awardee is always immeasurable."
>
> — Julio Betancourt
> Scientist Emeritus, U.S. Geological Survey

GSA Division Awards

CONTINENTAL SCIENTIFIC DRILLING DIVISION

Distinguished Lecturers

Nominations due: 25 March
Submit to: Mike McGlue, michael.mcglue@uky.edu

Three awardees will be outstanding scientists who, through a series of lectures at academic institutions, GSA events, and public talks during the year of the award, highlight the outstanding discoveries and science undertaken through continental drilling.

More information: *https://community.geosociety.org/continentaldrilling/awards/distinguished-lecturer-awards*

Mid-Career Award

Nominations due: 31 March
Submit to: Lisa Park Boush, lisa.park_boush@uconn.edu

The Mid-Career Award is designed to recognize remarkable contributions made by our mid-career members and encourage their continued success. The qualifications for a competitive nominee will be:

1. A mid-career scientist within 11–20 years of receiving the terminal degree.
2. Outstanding contributions to earth and environmental science using continental scientific drilling/coring/subsurface sampling, emphasizing breadth and impact of research, student mentoring successes, and demonstrable efforts at inclusion or community building.
3. Active member of the CSD Division.

More information: *https://community.geosociety.org/continentaldrilling/awards/mid-career-award*

ENERGY GEOLOGY DIVISION

Gilbert H. Cady Award

Nominations due: 1 March
Submit to: Justin Birdwell, jbirdwell@usgs.gov

The Gilbert H. Cady Award, first presented in 1973, recognizes outstanding contributions in the field of coal geology that advance the science both within and outside of North America.

More information: *https://community.geosociety.org/energydivision/awards/cady*

Curtis-Hedberg Award

Nominations due: 31 July
Submit to: Justin Birdwell, jbirdwell@usgs.gov

The Curtis-Hedberg Award will be considered annually in accordance with the bylaws of the Society. The award will be made for outstanding contributions in the field of petroleum geology.

More information: *https://community.geosociety.org/energydivision/awards/curtishedberg*

ENVIRONMENTAL AND ENGINEERING GEOLOGY DIVISION

Distinguished Practice Award

Nominations due: 31 March
Submit to: Ann Youberg, ayouberg@arizona.edu

The Distinguished Practice Award recognizes outstanding individuals for their continuing contributions to the technical and/or professional stature of environmental and/or engineering geology. A nominee need not be a member of the EEGD, but must have made a major contribution to environmental and/or engineering geology in North America. Each nomination must be accompanied by a written citation.

More information: *https://community.geosociety.org/eegdivision/awards/new-item3*

Meritorious Service Award

Nominations due: 31 March
Submit to: Ann Youberg, ayouberg@arizona.edu

The Meritorious Service Awards are for outstanding service to the Environmental and Engineering Geology Division and only Division members are eligible. Each nomination must be accompanied by a brief written statement indicating the outstanding service provided by the nominee.

More information: *https://community.geosociety.org/eegdivision/awards/new-item4*

GEOARCHAEOLOGY DIVISION

Claude C. Albritton, Jr. Award

Nominations due: 30 April
Submit to: gsa.agd@gmail.com

Under the auspices of the Geoarchaeology Division, family, friends, and close associates of Claude C. Albritton, Jr. have formed a memorial fund in his honor through the GSA Foundation. The Albritton award fund provides scholarships and fellowships for graduate students in the earth sciences or archaeology for research. Recipients of the award are students who have (1) an interest in achieving a master's degree or Ph.D. in earth sciences or archaeology; (2) an interest in applying earth science methods to archaeological research; and (3) an interest in a career in teaching and academic research. Awards in the amount of US$650 are given in support of thesis or dissertation research, with emphasis on the field and/or laboratory aspects of the research.

More information: *https://community.geosociety.org/geoarchdivision/awards/student/albritton*

Richard Hay Student Paper/Poster Award

Nominations due: 30 August
Submit to: sa.agd@gmail.com

At the 2006 Annual Meeting in Philadelphia, Pennsylvania, USA, the Geoarchaeology Division's management board elected to rename the student travel award for a distinguished scientist in archaeological geology. After consulting with his family, the award was officially named the Richard Hay Student Paper/Poster Award. Hay was a longstanding member of the Division and had a long and distinguished career in sedimentary geology, mineralogy, and archaeological geology. He is particularly well known for his work on the Olduvai Gorge and Laetoli Hominid-bearing sites and was awarded the Division's Rip Rapp Award in 2000. The Division is proud to have our student travel award bear his name. The award is a travel grant for a student (undergraduate or graduate) presenting a paper or poster at GSA Connects. The grant is competitive and will be awarded based on the evaluation of the scientific merit of the research topic and the clarity of an expanded abstract for the paper or poster prepared by a student for presentation in the Division's technical session at the meeting.

More information: *https://community.geosociety.org/geoarch-division/awards/student/hay*

GEOLOGY AND SOCIETY DIVISION

E-an Zen Fund for Geoscience Outreach Grant

Nominations due: 10 July
Submit to: Lily Jackson, Lily.Jackson@uwyo.edu

This is a grant opportunity for Geology and Society Division members interested in developing innovative methods to bring geoscience knowledge to public audiences. Two grants of US$1,500 each will be awarded to fund projects designed by the applicants to communicate geoscience information to a lay audience with the goal of increasing the understanding of geoscience and its impact on society among nongeoscientists and decision-makers. Applicants may apply as individuals or as groups, depending on the best fit for their project design. While the grant application requirements are intentionally broad to encourage creative thinking and innovation, review of applications will emphasize the potential for impacting communities that traditionally have not had significant exposure to the geosciences.

More information: *https://community.geosociety.org/gsocdivision/news/zenfund*

GEOSCIENCE EDUCATION DIVISION

Biggs Earth Science Teaching Award

Nominations due: 1 March
Submit to: https://forms.gle/ydhYGCdTERY6X5KK8

The Biggs Award recognizes innovative and effective teaching in college-level earth science. Earth science instructors and faculty members from any academic institution engaged in undergraduate education who have been teaching full time for 10 years or fewer are eligible (part-time teaching is not counted in this requirement). Both peer- and self-nominations will be accepted. This award, administered by the GSA Foundation, is made possible by support from the Donald and Carolyn Biggs Fund, the GSA History and Philosophy of Geology Division, and GSA's Education and Outreach Program. An additional travel reimbursement is also available to the recipient to enable him or her to attend the award presentation at GSA Connects.

More information: *https://community.geosociety.org/gedivision/awards/biggsaward*

GEOSCIENCE EDUCATION DIVISION

History and Philosophy of Geology Student Award

Nominations due: 9 August
Submit to: Christopher Hill, chill2@boisestate.edu

The History and Philosophy of Geology Division provides a student award in the amount of US$1,000 for a paper to be given at GSA Connects. Awards may also be given for second place. The award, established in 2004, is made possible by a bequest from the estate of Mary C. Rabbitt. Oral presentations are preferred. Faculty advisors may be listed as second author, but not as the lead author of the paper. The proposed paper may be (1) a paper in the history or philosophy of geology; (2) a literature review of ideas for a technical work or thesis/dissertation; or (3) some imaginative aspect of the history or philosophy of geology we have not thought of before. Students should submit an abstract of their proposed talk and a 1,500–2,000-word prospectus for consideration. The Awards Committee will assist the winner(s) with review of abstracts facilitating presentation according to GSA standards.
Currently enrolled undergraduates and graduate students are eligible, as are students who received their degrees at the end of the fall or spring terms immediately preceding GSA Connects. The award is open to all students regardless of discipline, provided the proposed paper is related to the history or philosophy of a geological idea/person. Monies for the award are administered by the GSA Foundation.

More information: *https://community.geosociety.org/histphildiv/awards/student*

LAST CALL FOR NOMINATIONS!

John C. Frye Environmental Geology Award

Nominations due: 31 March
Submit to: awards@geosociety.org

In cooperation with the Association of American State Geologists and supported by endowment income from the GSA Foundation's John C. Frye Memorial Fund, GSA makes an annual award for the best paper on environmental geology published either by GSA or by a state geological survey.

2024 Awardee: Guthrie, G.M., Hastert, G.A., and Puckett, M.H., 2022, An Aquifer Recharge Potential Model for Alabama: Geological Survey of Alabama Bulletin 192, 49 p.

More information: *https://www.geosociety.org/GSA/About/awards/GSA/Awards/Frye.aspx*

GSA FOUNDATION
AASG Association of American State Geologists

KARST DIVISION

Karst Division Meritorious Contribution Award

Nominations due: 31 March
Submit to: awards.gsakarst@gmail.com;
CC: Sierra Heimel, heimelsierra@gmail.com

This award is granted to the author of a published paper or body of work of distinction that has significantly influenced the intellectual direction of karst or broadly enhanced the knowledge of the discipline. If you are submitting a self-nomination, please include a letter of recommendation from a karst professional that can attest to your qualifications. Nominees do not need to be Karst Division members to be eligible for these awards, but it does add merit to the nomination.

More information: *https://community.geosociety.org/karstdivision/awards/new-item*

Karst Division Early Career Award

Nominations due: 31 March
Submit to: awards.gsakarst@gmail.com;
CC: Sierra Heimel, heimelsierra@gmail.com

This award is presented to a distinguished scientist (35 or younger throughout the year in which the award is to be presented, or within 5 years of their highest degree or diploma) for outstanding achievement in contributing to the karst profession through original research and service, and for the demonstrated potential for continued excellence throughout their career. If you are submitting a self-nomination, please include a letter of recommendation from a karst professional that can attest to your qualifications. Nominees do not need to be Karst Division members to be eligible for these awards, but it does add merit to the nomination.

More information: *https://community.geosociety.org/karstdivision/awards/new-item*

Karst Division Distinguished Service Award

Nominations due: 31 March
Submit to: awards.gsakarst@gmail.com;
CC: Sierra Heimel, heimelsierra@gmail.com

This highly esteemed award is given in recognition of distinguished personal service to the karst profession and to the Karst Division. If you are submitting a self-nomination, please include a letter of recommendation from a karst professional that can attest to your qualifications. Nominees do not need to be Karst Division members to be eligible for these awards, but it does add merit to the nomination.

More information: *https://community.geosociety.org/karstdivision/awards/new-item*

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

MGPV Distinguished Geological Career Award

Nominations due: 31 March
Submit to: J. Alex Speer, jaspeer@minsocam.org

The MGPV Distinguished Geological Career Award will go to an individual who, throughout his/her career, has made distinguished contributions in one or more of the following fields of research: mineralogy, geochemistry, petrology, or volcanology, with emphasis on multidisciplinary, field-based contributions. Nominees need not be citizens or residents of the United States, and membership in The Geological Society of America is not required. The award will not be given posthumously.

More information: *https://community.geosociety.org/mgpvdivision/awards/dgca*

Early Geological Career Award

Nominations due: 31 March
Submit to: J. Alex Speer, jaspeer@minsocam.org

This award will go to an individual near the beginning of his/her professional career who has made distinguished contributions in one or more of the following fields of research: mineralogy, geochemistry, petrology, or volcanology, with emphasis on multidisciplinary, field-based contributions. Nominations are restricted to those who are within eight years past the award of their final degree. Extensions of up to two years will be made for nominees who have taken career breaks for family reasons or caused by serious illness. Nominees need not be citizens or residents of the United States, and membership in The Geological Society of America is not a requirement. The award will not be given posthumously.

More information: *https://community.geosociety.org/mgpvdivision/awards/earlycareer*

PLANETARY GEOLOGY DIVISION

Pete Mouginis-Mark Prize in Planetary Volcanology

Nominations due: 6 August
Submit to: Lauren Jozwiak, lauren.jozwiak@jhuapl.edu

The Pete Mouginis-Mark Prize in Planetary Volcanology recognizes outstanding undergraduate and graduate student presentations in planetary volcanology (talks or posters) at GSA Connects. Planetary volcanology, for the purpose of this prize, is defined as research into volcanoes and volcanic processes on the planets (Mercury, Venus, Mars, Moon), asteroids, or the moons of the outer planets. Volcano studies may include the geomorphology and tectonics of summit craters, the lava flows on their flanks, and the deformation of the flanks. Volcanic processes may include numerical modeling of eruptions, as well as petrologic studies of samples from known volcanic areas of the Moon, Mars, or asteroids. Remote sensing (spectral, radar, gravity) of volcanoes and their products is also appropriate.

More information: *https://community.geosociety.org/pgd/awards/mouginis-mark-prize*

Eugene and Carolyn Shoemaker Impact Cratering Award

Nominations due: 15 August
Submit to: https://www.lpi.usra.edu/Awards/shoemaker/

The Shoemaker Award is for undergraduate or graduate students, of any nationality, working in any country, in the disciplines of geology, geophysics, geochemistry, astronomy, or biology. The award, which will include US$2,500, is to be applied to the study of impact craters, either on Earth or on the other solid bodies in the solar system. Areas of study may include but shall not necessarily be limited to: impact cratering processes; the bodies (asteroidal or cometary) that make the impacts; or the geological, chemical, or biological results of impact cratering.

More information: *https://community.geosociety.org/pgd/awards/shoemaker*

Ronald Greeley Award for Distinguished Service

Nominations due: 15 August
Submit to: Jennifer Piatek, piatekjel@ccsu.edu

In 2011, the Planetary Geology Division (PGD) established the Ronald Greeley Award for Distinguished Service. This award may be given to those members of the PGD, and those outside of the Division and GSA, who have rendered exceptional service to the PGD for a multi-year period. The award is not open to currently serving members of the management board but may be awarded to past members of the management board who have provided exceptional service to the PGD after their term on the management board has ended. Nominations for the award, which should include a description of what the nominee has given to the PGD community, may be made by any PGD member to the management board.

More information: *https://community.geosociety.org/pgd/awards/greeley*

QUATERNARY GEOLOGY AND GEOMORPHOLOGY DIVISION

Farouk El-Baz Award for Desert Research

Nominations due: 1 April
Submit to: Karen Gran, kgran@d.umn.edu

The Farouk El-Baz Award for Desert Research rewards excellence in desert geomorphology research worldwide. It is intended to stimulate research in desert environments by recognizing an individual whose research has significantly advanced the understanding of the Quaternary geology and geomorphology of deserts. Although the award primarily recognizes achievement in desert research, the funds that accompany it may be used for further research. The award is normally given to one person but may be shared by two people if the recognized research was the result of a co-equal partnership. Any scientist from any country may be nominated. Because the award recognizes research excellence, self-nomination is not permitted. Neither nominators nor nominees need be GSA members. Nominations should include (1) a statement of the significance of the nominee's research; (2) a curriculum vitae; (3) letters of support; and (4) copies of no more than five of the nominee's most significant publications related to desert research. Please submit electronically unless hardcopy previously approved. Monies for the award are derived from the annual interest income of the Farouk El-Baz Fund, administered by the GSA Foundation.

More information: *https://community.geosociety.org/qggdivision/awards/el-baz*

Distinguished Career Award

Nominations due: 1 April
Submit to: Lisa Ely, lisa.ely@cwu.edu

The Distinguished Career Award is presented annually to a Quaternary geologist or geomorphologist who has demonstrated excellence in their contributions to science. Because the award recognizes research excellence, self-nomination is not permitted. Neither nominators nor nominees need be GSA members.
Nominations should include: (1) a brief biographical sketch; (2) a statement of no more than 200 words describing the candidate's scientific contributions to Quaternary geology and geomorphology; (3) a selected bibliography of no more than 20 titles; and (4) a nomination letter; and (5) optional additional letters from colleagues supporting the nomination. Please submit electronically unless hardcopy previously approved.

More information: *https://community.geosociety.org/qggdivision/awards/distinguished-career*

SEDIMENTARY GEOLOGY DIVISION

Sedimentary Geology Division and Structural Geology and Tectonics Division Joint Award: Stephen E. Laubach Structural Diagenesis Research Award

Nominations due: 1 May
Submit to: https://community.geosociety.org/sedimentarygeologydiv/awards/stephen-e-laubach

The Stephen E. Laubach Structural Diagenesis Research Award promotes research combining structural geology and diagenesis and curriculum development in structural diagenesis. This award addresses the rapidly growing recognition that fracturing, cement precipitation and dissolution, evolving rock mechanical properties, and other structural diagenetic processes can govern recovery of resources and sequestration of material in deeply buried, diagenetically altered and fractured sedimentary rocks. The award highlights the growing need to break down disciplinary boundaries between structural geology and sedimentary petrology, exemplified by the work of Dr. Stephen Laubach and colleagues. The award alternates between being awarded by the Sedimentary Geology Division on odd-numbered years, and the Structural Geology and Tectonics Division on even-numbered years, reflecting the focus of the award on this cycle. Graduate students, postgraduate, and faculty-level researchers are eligible. For questions, contact Joel Saylor (jsaylor@eoas.ubc.ca).

More information: *https://community.geosociety.org/sedimentarygeologydiv/awards/stephen-e-laubach*

SOILS AND SOIL PROCESSES DIVISION

Distinguished Service Award

Nominations due: 1 August
Submit to: Steven Driese, Steven_Driese@baylor.edu

The Distinguished Service Award recognizes individuals who have contributed significantly to the advancement of the Division either through service as an officer, service as a chair or member of a committee (or committees), or any other service-related activities (e.g., sponsorship of symposia or topical sessions, field trips, workshops, etc.) that draw positive attention to the research aims and activities of the Division. It includes lifetime membership in the Division.

More information: *https://community.geosociety.org/soilsdivision/awards/soils-and-soil-processes-division-distinguished-service-award*

Peter W. Birkeland Distinguished Career Award

Nominations due: 15 March
Submit to: Steven Driese, Steven_Driese@baylor.edu

The Peter W. Birkeland Distinguished Career Award recognizes individuals who have made outstanding contributions to the general field of soil or paleosol (buried or fossilized soil) science. Dr. Birkeland's main area of research was soil geomorphology, and his steady stream of publications, often with his students, demonstrated the application of pedology to address landform and landscape evolution.

More information: *https://community.geosociety.org/soilsdivision/awards/peter-w-birkeland-distinguished-career-award*

STRUCTURAL GEOLOGY AND TECTONICS DIVISION

Career Contribution Award

Nominations due: 1 March
Submit to: Mary Hubbard, mary.hubbard@montana.edu

This award is for an individual who throughout his/her career has made numerous distinguished contributions that have clearly advanced the science of structural geology or tectonics. Nominees need not be citizens or residents of the United States, and membership in the Geological Society of America is not required. Nominations should include the following information: (1) name of nominee, present institutional affiliation, and address; (2) summary statement of nominee's major career contributions to the science of structural geology and tectonics; (3) selected key published works of the nominee; and (4) name and address of nominator.

More information: *https://community.geosociety.org/sgt/awards/careercontribution*

Outstanding Publication Award

Nominations due: 1 March
Submit to: Phil Resor, presor@weslyan.edu

This award is given annually for a published work (paper, book, or map) of exceptional distinction that clearly advances the science of structural geology or tectonics. Nominations should include: (1) a full citation; (2) nomination (as short as a paragraph; letters or reviews may also be included); and (3) the name and address of the nominator.

More information: *https://community.geosociety.org/sgt/awards/outstandingpublication*

ON 10 DECEMBER 2024, then-acting president Chuck Bailey signed an MOU with ProGEO in the 1878 Grille at the Cosmos Club in Washington, D.C. Behind the group is an 1897 portrait of John Wesley Powell, founder of the Cosmos Club and second Director (1881-–1894) of the U.S. Geological Survey. An auspicious location!

GSA Student Memberships Are a Great Value!

A GSA student membership is now $25 and includes unlimited Scientific Division memberships.

Student members can volunteer at Section Meetings to receive free meeting registration, apply for student travel grants to cover their travel to the meeting, and take advantage of robust GeoCareers programming to assist them in the next step of their career. Take the next step in your career—join GSA!

www.geosociety.org/members

Become a GSA Campus Representative!

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https://www.geosociety.org/CampusReps

Apply Now: Section Undergraduate Research Grants

Deadline: 10 April

Are you an undergraduate geoscience student with a research project in mind? Our Section Undergraduate Research Grants provide funding to support original research, helping you explore new ideas and advance your studies. In 2024, we proudly awarded grants to 12 outstanding students—now it's your turn! Don't miss this opportunity to bring your research to life and connect with a growing community of future geoscience leaders. Find your Section and apply today!

https://www.geosociety.org/GSA/GSA/grants/sectionResearch.aspx

"It was such an incredible opportunity to experience science 'in the field' rather than in a classroom. I got to see that there is so much that goes into field work both before and after the field season is over. Seeing a project from start to finish, working with data that I helped collect is truly a wonderful experience and made me feel like I was contributing to a project larger than myself."

—Kathleen Grube, Gustavus Adolphus College

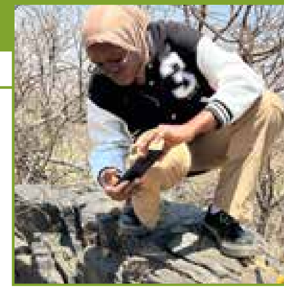
"The GSA Section Undergraduate Research Grant made studying seagrass beds in North Carolina possible for my student, Olivia Key. Her honor thesis would not have been publishable without the support of GSA."

—Antonio Rodriguez, Professor and Associate Chair of Academic Affairs, University of North Carolina at Chapel Hill

ANNE SHEPHERD
Field Camp: St. Andrews University

FARID SAID MOHAMMED
Field Camp: Curtin University Malaysia

KYLIE WILSON
Field Camp: Idaho State University



RODIAT AMUSAN
Field Camp: Dordabis Iron Project

Apply for a J. David Lowell Field Camp Scholarship

Deadline: 9 April

GSA and the GSA Foundation are pleased to announce that J. David Lowell Field Camp Scholarships will be available to undergraduate geology students for the summer of 2025. These scholarships will provide students with US$2,000 each to attend the field camp of their choice. Applications are reviewed based on diversity, economic/financial need, and merit.

Learn more at **https://bit.ly/JDavidLowell** | Questions? Contact Rebecca Taormina, **rtaormina@geosociety.org**

GSA FOUNDATION | BRUNTON

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- Gauge your offer's competitiveness with our offer analyzer
- Access in-depth, localized salary insights
- Ace your interviews with professional coaching

Get started using the ultimate resource for geology jobs at **careers.geosociety.org.**

Exploring the Geology of the Coyote Mountains: A Transformative GSA/Chevron Field Trip Experience

Christian Adejoh

As a recipient of a GSA/Chevron Field Trip Award, I had the privilege of participating in an unforgettable field trip to the Coyote Mountains in the Salton Trough, Southern California, USA. Held in conjunction with GSA Connects 2024 in Anaheim, California, this trip was a remarkable blend of rigorous geological study and collaborative exploration, led by two exceptional geologists, George J. Morgan and J.R. Morgan.

The primary goal of the trip was to propose a new model for the Mesozoic deformation of the Coyote Mountains, followed by an analysis of the interplay between Cenozoic sedimentation and Basin and Range tectonics. Using field maps and road logs, we mapped outcrops to refine the stratigraphy and positions of key geological features previously documented in the literature. It was an exciting opportunity to contribute to the ongoing re-evaluation of the region's tectonic and depositional history.

The rugged terrain of the Coyote Mountains presented both challenges and inspiration. The desert heat was intense, but it did not deter our group from meticulously mapping outcrops and analyzing stratigraphic relationships. One of the highlights of the trip was being introduced to the depositional environments, stratigraphy, and ages of the common rock units in the region—many of which were dated by one of our field leaders, J.R. Morgan. Observing and interpreting these features in their natural setting deepened my appreciation for the geologic history of Southern California and the processes that have shaped it.

This field trip significantly advanced my geoscience knowledge, enhancing my skills in field mapping, structural analysis, and sedimentological interpretation. Working closely with both colleagues and mentors fostered an environment of collaboration and learning, where I gained insights not only into the tectonic history of the Coyote Mountains but also into broader methodologies of modern geological fieldwork.


Rickbramhall / Wikimedia Commons.


Piriya Photography / Getty Images.

Beyond the academic rigor, the trip was filled with memorable experiences. We visited the Imperial Valley Desert Museum in Ocotillo, where we explored fascinating indigenous and historical artifacts that provided cultural context to the region. The camaraderie among participants, along with the delicious meals and shared moments of fun, made the trip both intellectually and personally enriching.

This experience has profoundly shaped my growth as a geoscientist. It reinforced the importance of combining modern field techniques with a collaborative spirit to produce meaningful geological insights. I am particularly inspired by the ongoing mapping efforts and the potential for our contributions to enhance the understanding of the region's tectonic evolution.

I am deeply grateful to Chevron and GSA for making this opportunity possible. Programs like this not only equip young geoscientists with essential skills but also inspire a lifelong passion for unraveling Earth's history. This field trip has been a transformative experience, and I look forward to applying the knowledge and skills I gained to future research and professional endeavors.

Hawai'i's Dynamic Volcanoes: A Firsthand Look at Recent Eruptions

Mateo Ospino

Kevin Thrash / Getty Images.

I want to sincerely thank The Geological Society of America and Chevron for giving me the chance to join the field trip "The Changing Landscape on Hawaiʻi Island" as part of GSA Connects 2024. This experience gave me a better understanding of volcanic activity and how it affects the land and the people who live there.

The trip began with an introduction at Moku Ola (Coconut Island) in Hilo, where we discussed the island's history with tsunamis and the community's resilience. From there, we visited Hawaiʻi Volcanoes National Park, starting at the Visitor Center and Volcano House with views of the Kīlauea Caldera. Standing at Uēkahuna Bluff, we learned about the post-2018 eruptions and the role of the Hawaiʻian Volcano Observatory (HVO) in monitoring volcanic activity.

One of the most impactful parts of the trip was hiking along the old Crater Rim Drive, where we observed Keanakāko'i Crater, the 1974 lava flows, and the dramatic 2018 caldera collapse. Exploring areas like Kulanaokuaiki Campground and the Koa'e fault system highlighted the region's active faulting and fissures, while the short hike to Mauna Ulu's 1969 fissures brought the island's more recent volcanic history to life.

On the second day, we traveled to the Lower East Rift Zone, starting at Pāhoa to view the 2014 lava flows and continuing to Leilani Estates, one of the hardest-hit areas during the 2018 eruption. Seeing the cone of Ahu'ailā'au and the lava flows at Pohoiki Bay illustrated the scale of change in the area. We also visited the Lava Tree State Monument and hiked along the 2018 lava channel near Puna Geothermal Ventures (PGV), which emphasized the intersection of volcanic activity and human infrastructure.

The final day took us to Mauna Loa's eruption sites from 2022. Hiking the Kaulana Manu Nature Trail and Pu'u Huluhulu offered views of the new lava flows and kīpuka—islands of older land surrounded by newer lava. Standing at the 9,000-foot elevation point on Observatory Road and witnessing the extent of the 2022 flows underscored the enormity of Mauna Loa's eruptions.

Photo: Anton Petrus / Getty Images.

This field trip was an unforgettable experience that deepened my passion for geology and volcanology. It reinforced the importance of continuous volcanic monitoring and community preparedness. I'm truly grateful for this opportunity to learn directly from the land and from experts in the field.

Figure 1. The research facility used by Keeling on Moana Loa, Hawai'i. From the U.S. National Oceanographic and Atmospheric Administration.

Mauna Loa, Hawai'i, and Human Perception

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

Geology logline: *CO_2 monitoring on Moana Loa, Hawai'i, suggested significant increases of CO_2 in Earth's atmosphere with implications for global warming starting in 1965.*

Cognitive science logline: *How we talk about the human senses is not how we actually perceive with our senses. Understanding the underlying processes can help when considering the relative strengths of human collected data (self-correcting, visceral) and instrumentally collected data (quantitative, high sensitivity).*

Charles David Keeling went to Mauna Loa in the late 1950s to measure, as precisely as possible, the amount of carbon dioxide in the atmosphere. Keeling's training as a chemist allowed him to devise an instrument and a workflow that could measure carbon dioxide to within 0.2 ppm. The instrument was set up on Mauna Loa as part of the International Geophysical Year (1957–1958). Roger Revelle provided this description: "Keeling's a peculiar guy. He wants to measure CO_2 in his belly... And he wants to do it with the greatest precision and the greatest accuracy he possibly can" (Weart, 2003, p. 42). Instruments have measured CO_2 continuously from 1958 until 2022 on Mauna Loa (Fig. 1), when lava from an eruption closed the road, and the instruments were moved to Mauna Kea on the same island of Hawai'i.

The result of Keeling's measurements is widely known (Fig. 2). The rising level of atmospheric CO_2 is clear despite seasonal variability, which is large relative to a year's rise. Starting in ca. 1960 (e.g., Keeling, 1960), the overall upward trend was noticed by an increasing number of people, and its implications were publicly discussed as early as 1965 (e.g., President's Science Advisory Committee, 1965). The Keeling curve has unambiguously influenced both the geological and nongeological mind: Humans are a planetary-scale force to be reckoned with. Given the significant implications of increased CO_2 for humanity, it would be reasonable to wonder why action has been so slow. The answer is complicated and unambiguously political (e.g., Oreskes and Conway, 2010; Rich, 2018), but it is also partly a result of the nature of human perception.

In this essay, we are going to address aspects of human

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perception, which is a central topic in cognitive science. We ask the readers for their collective perseverance with the promise of a payoff in the next five essays. In cognitive science, perception is defined as the gathering of information about the world around us, including both the use of familiar human senses and instruments built to extend those senses. Effectively, perception is about understanding objects and events, but in a way that is integrated into what that understanding allows us to do and feel.

How one thinks about perception (i.e., one's mental model of how perception works) may unconsciously influence how one thinks about data in the context of an observational science. We utilize an approach to perception that focuses on the relationship between the perceiver and the environment that they are perceiving. In the cognitive science literature, this is known as an "ecological" approach because of the equal importance placed on understanding the cognitive processes of the perceiver, information in the environment, and their interaction. We contrast this approach with two alternative models, one that focuses on the perceiver and the other that focuses on the environment. The perceiver-focused model claims that all perception is learned, as was the predominant view of American psychologists until the early 1960s (e.g., Hull, 1943). In this case, one might worry that observational data are the product of a theory, with no basis in the reality of the environment. That is, a community consensus could be a hallucination. Such a view is one end member of perceptual accuracy and trust. The environment-focused model, total trust, claims that humans accurately perceive the world. In this end member, scientists simply go out and record the world the way it is. We make the case that neither end member is correct. A central theme of this essay is that perception is best conceived as a process that can correct errors, through obtaining additional information from the world when a perceptual error is made.

Three significant issues arise when one takes the approach that human perception guides observations and inferences in science. First, humans do not have conscious access to how they are perceiving the world (Idea 1). Second, perception is coupled with cognition (e.g., memory, runnable mental models, spatial or mathematical analyses) to make sense of the world (Idea 2). Third, visceral responses to perception, which motivate action, are generally coupled to cognition (Idea 3).

IDEA 1: HUMANS DO NOT HAVE CONSCIOUS ACCESS TO HOW THEY ARE PERCEIVING THE WORLD

We begin with the question: Why do humans perceive? *The answer is because human perception is needed for action.* Perception provides the ability to respond to threats or opportunities.

Because we are adapted for action, we experience the things in the world, but human perception does not provide us with the details of how our senses are stimulated. In fact, human perception is distinctly different from how we talk about it. Although we talk of feeling vibrations or seeing light, humans do neither. Rather, we feel and see **objects**; we see and hear **events**. If you pick up a pencil, close your eyes, and explore the desk in front of you, you feel the objects of the world. What you are detecting is the vibrations of the pencil against the skin of your fingers. Before conscious awareness occurs, the mind has correlated those vibrations to feeling an object.

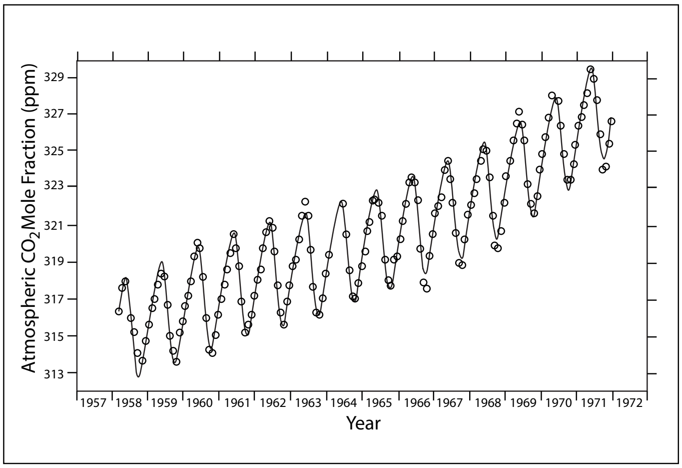

Figure 2. The Keeling curve as redrawn from Keeling et al. (1976). There is both an annual cyclicity, caused by plant growth in the Northern Hemisphere, and an upward increase, caused by human emissions of CO_2.

With vision, our brain perceives objects because photons stimulate our retina. But, the eye is not a photometer and does not report precise wavelength or luminance. We do not directly sense what is on the retina. Instead, our minds focus on the ***pattern*** of light on our retina because there is generally a consistent relationship between those patterns and what is out in the world. The important point is that we do not have access to the raw data that impinge on our senses (e.g., nasal mucosa, ear drum, or retina).

To further understand vision, it is necessary to recognize that any object "structures" the light that is reflected from it. What do we mean by this? Objects and light interact so that there are systematic patterns in the light reflected by objects; we use those patterns to see objects. For example, the light from a smoothly curving object has a continuous gradient within the visible bounds of the object. In contrast, an object with distinct sides (e.g., an object with a dihedral edge) will likely have a discontinuity in the reflected light corresponding to the discontinuity in surface orientation. Thus, an object *structures* light everywhere in the environment, so that from any perspective from which you view the object, the distinction between a smoothly curving surface and a corner will be evident.

A challenge we faced writing this essay was using *structure* as a verb, when it is a common noun in geology. The usage comes from psychologist Gibson (1979), who advocated an approach to perception that focused on detecting information relevant to a perceiver. We adopted Gibson's term to convey the important idea that an object in the world causes regularities in the patterns of smell, sound, and light (e.g., the concept of "structured light"), and that these regularities are sufficient to accurately perceive objects. Highlighting the pattern recognition process is intended to bring an awareness of a human's lack of conscious access to perceptual processes. That lack of awareness may be the source of the incorrect intuition that perceiving objects is easy and can be done directly by the senses.

It is the regularities in how light is structured—not its absolute values—that allow humans to accurately perceive the world. To see color, the mind compares the spectral distribution coming from multiple objects. Since all objects in a scene are generally illuminated by the same source, the pattern of wavelengths that is common across the scene is likely attributable to the light source. That common spectral profile can then be discounted from each object's reflectance profile to recover the object's true color. Here is how you know that it is the structure that matters, not the wavelength of a photon: A visual field that is totally uniform, and therefore unstructured, will appear gray regardless of the wavelength (Hochberg et al., 1951; Cohen, 1958). The Hochberg et al. (1951) study, for example, used ping-pong–sized half spheres that were placed over the eyes and an outside light source that produced long-wavelength light (e.g., that clearly looks red to an observer outside the experiment). That totally uniform field of long-wavelength light appeared gray to the subject. However, when the experimenter cast a shadow, from their finger, on the ping-pong half spheres, it provided some structure to the light (contrast), and the shadow was seen to be surrounded by a red field.

Although human sensors detect light, we do not perceive sensor stimulation. That is, there is no reliable relationship between individual sensor activity and what we see out in the world. Rather, a sensor's signal is only meaningful in relation to other signals.

To illustrate the need to use structure to perceive objects, consider how we see lava to be red and glowing in daylight (Fig. 3). The photons from the lava are neither red nor glowing. Rather, the photons are either reflected sunlight or emitted by the rock, but they are all just photons of predominantly long wavelength in the visible spectrum. For an illuminated scene, the returning wavelengths are influenced by both the reflective properties of the object *and* the spectrum of the light falling on the object. The mind solves the problem of disambiguating the reflective properties of an object from the wavelengths that illuminate that object by taking advantage of the regularities of the pattern of light across a scene (Gilchrist et al., 1999). How did we see the lava as glowing—appearing to give off light—if not from those emitted photons directly? The answer is by way of comparison, rather than by sensing it directly. Things appear to glow when the amount of light coming from their surface exceeds the ratio of highest (white) to least (black) reflective surfaces, so an object giving off 60 times more light than the darkest objects will appear to glow (Gilchrist et al., 1999). Because we have no conscious access to any of this processing of information, and perception is correct so much of the time, it is easy to feel that there is no underlying cognitive process associated with our senses. Consequently, we *feel* that we know exactly what is in the world; unfortunately, that is not true.

All human perception comes from sensory input that is structured by the world, not just vision. Objects and events structure the soundscape of our world; objects and events structure chemical gradients in the "smellscape" of our world. As with vision, the mind does not have conscious access to the sources that stimulate human (e.g., auditory, olfactory) sensors. Objects and events are the content of perceptual experiences because we need to know about them in order to act. The implication is that the way we talk about perception (e.g., seeing light) is not how we perceive (e.g., seeing objects).

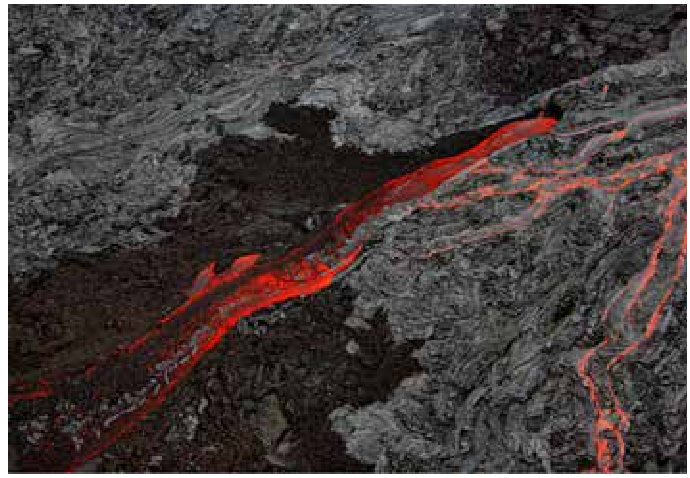

Figure 3. A glowing red lava flow from Hawai'i, taken from a helicopter. From Wikimedia Commons: Pāhoehoe and Aa flows at Hawaii.jpg. Photo by Brocken Inaglory.

IDEA 2: PERCEPTION IS COUPLED WITH COGNITION TO MAKE SENSE OF THE WORLD

The insight that perception must be coupled with cognition to make sense of the world was made by psychologist Ulrich Neisser (1976). Neisser accepted perception as a starting point and argued that optimal interactions are informed by both the information from the world and by what we already know about the world. Moreover, what humans know about the world comes from a variety of sources in one's past experiences, as recorded in memory. He advocated for a way of thinking about the mind that integrated perception and memory in a cycle in which understanding of the world changed over time.

Figure 4 illustrates the cycle of perception as proposed by Neisser. Structured information is perceived, leading to an initial interpretation of the world. That interpretation is informed by memory and necessarily leads to expectations about what else would be in the world, if one continued to move, explore, and gather further structured information. The interpretation effectively becomes a mental model of the world that could be added to with additional information or replaced when incoming information violated an expectation. Mental models—including runnable mental models—guide what one looks for in the world.

Neisser proposed this cycle to replace an approach to perception as input into a chain of processing that resulted in recognition. Such a linear system is ripe for errors resulting from expectations. In response, Neisser proposed a cycle where expectations lead to actions, such as reaching for an object or moving eyes to look at an object. The actions have expected sensory consequences, and the potential to violate those expectations gives perception the capacity to self-correct.

Note that what is meant by "recognition" is a determination of whether the object has been seen before. One can, of course, see new things. In this case, however, the part of the cycle labeled recognition would register the object or event as "unfamiliar." Because the cycle is continuous, the distinction between input and output blurs. That is, perception can lead to action, and action leads to new information to perceive.

If this cycle is a good model for how the mind works, what are the implications? We may make errors, but we correct them because perception is not static. New information may change how knowledge influences processing and recognition, and hence changes our perception. Put simply, perceptual correction comes from the world in the form of new information.

Because perception involves cognition and memory, it will necessarily differ among individuals and across cultures. As we noted in Tikoff and Shipley (2025), people lump memories into categories. Perceptual categories often reflect regularities of the world. There are many such regularities in objects and events. Different regularities may be emphasized by different cultures, which in turn influences how they lump and split object and event categories. Examples of differing categories include phonemes (the units of speech sounds, such as "ba" and "pa") and colors (Winawer et al., 2007). These categorical differences have been argued to reflect differences in communication needs among cultures (Regier et al., 2016). Thus, individual differences in memory may guide actions to pick up different aspects of objects and events. In the same way, expertise may guide the categorization of information that affords finer splitting in the area of expertise.

APPLICATION OF NEISSER'S CYCLE TO GEOLOGY

This perceptual process is a close analogy to the practice of science, a point made explicitly by Shipley and Tikoff (2016). In science, expectations may influence models, but eventually observations can correct erroneous models. The cycle of perception (Fig. 4) allows structured information in the world to be detected by a finely tuned system to allow optimal interactions with the world. Science attempts to determine and characterize patterns in the natural world and, by doing so, understand the underlying processes that resulted in those patterns. The meaning of those patterns, however, requires more than perception: It requires cog-

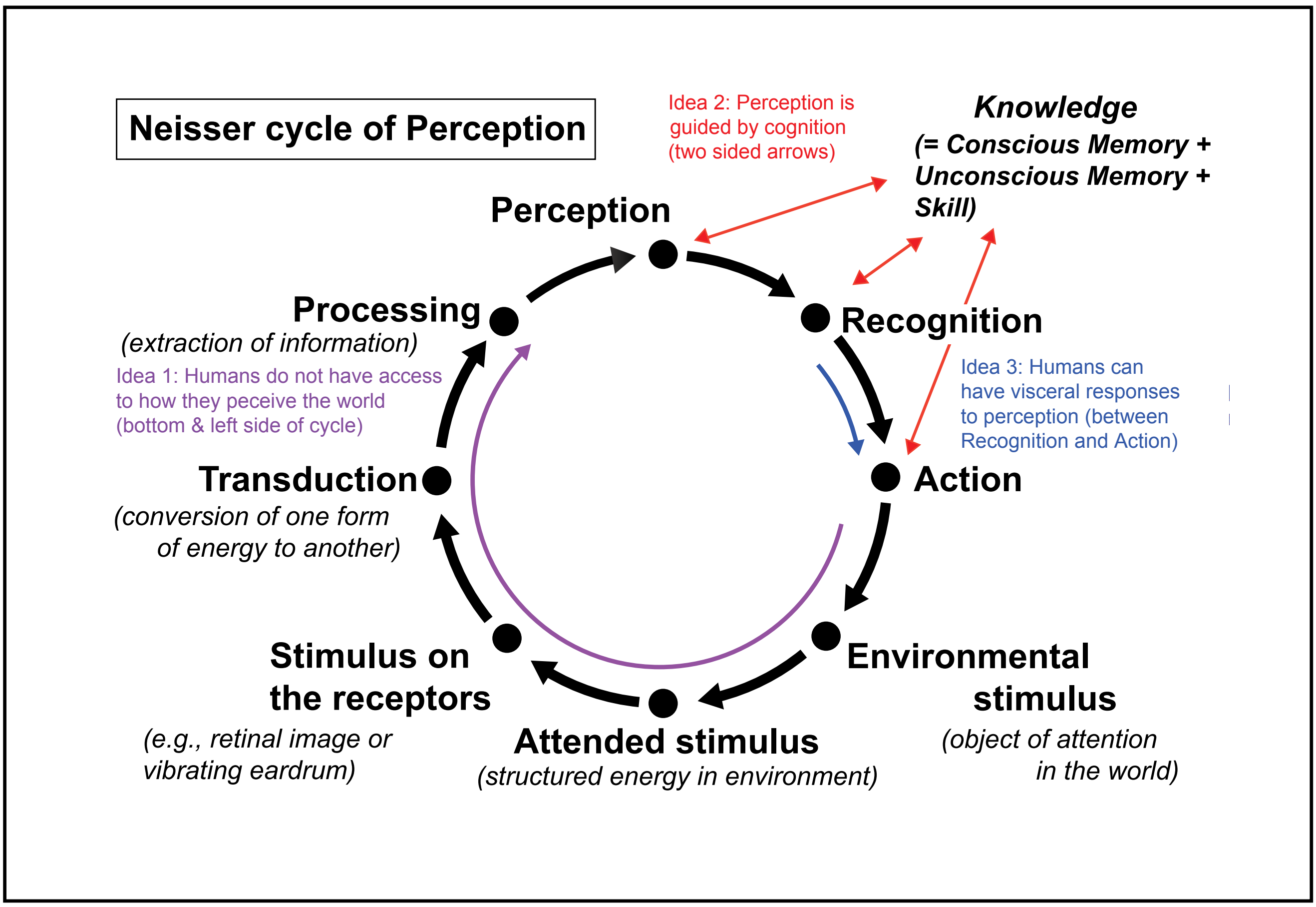

Figure 4. The ongoing cycle of perception proposed by psychologist Ulrich Neisser, as shown by the black arrows. The bottom and left-hand side of the cycle are largely unavailable to consciousness (Idea 1). Perception, Recognition, and Action are all informed by what we already know about the world (knowledge), and this relationship is shown by double-sided arrows (Idea 2). Visceral responses are a part of the perception cycle (Idea 3). Perception guides action, which allows us to explore the world and to correct perceptual errors. Figure is modified from Neisser (1976).

nition. For the purposes of practicing geology, that cognition requires some combination of: (1) memory (Shipley and Tikoff, 2025); (2) ability to utilize a runnable mental model (Tikoff and Shipley, 2025); and/or (3) ability to visualize (see upcoming essay on the Burgess shale in the June 2025 issue of *GSA Today*).

We continue the analogy between the ecological approach to perception—with its unconscious pattern processing—and a scientist making observations. The fact that a geologist can make sense of an outcrop indicates that the patterns and the processes are not arbitrary. Knowing what is out in the world and why it is important (e.g., the meaning of something in the world) can come from the regularities between geological patterns and processes. This claim may seem counterintuitive, but it arises from the nonarbitrary nature of how the world structures information. For example, imagine standing on top of a cliff. How could we know the meaning of a cliff if not by memory? The optics at the cliff's edge tell us there is no further support for a foot, and thus taking a step would be a bad idea. Thus, both mental models (from a theoretical view) and the world itself, as picked up by perception (from an empirical view), provide meaning. *Information in the world allows mental models to improve over time*

The take-home message is that scientific observations based on perception tend to be correct because the world itself acts to correct both perception and scientific inferences. Another level of uncertainty is added with using instruments, where interpretation mediates action.

THE NATURE OF PERCEPTION: REALITY DERIVED FROM INSTRUMENTS

For this essay about detecting CO_2, the relevant senses are olfactory and taste. These two combined senses are referred to as "chemosenses" in the cognitive science literature. Organisms from bacteria to humans use chemosenses to collect information about the presence and amount of a wide range of molecules, from complex polypeptide pheromones to simple CO_2. Human chemosenses are narrow and dull relative to some animals, but they do provide information about the prevalence of some molecules in our environment that matter to us. However, humans cannot detect CO_2 below lethal concentrations of ~15%

The use of instrumentally derived data provides a useful contrast to data derived from human senses. On Mauna Loa, Keeling effectively extended our chemosenses using a workflow that was both like and unlike the processes that animals use to gather information from the chemicals around us. How did Keeling and colleagues make the measurements? The air was sampled every few minutes throughout the day, interspersed with regular intervals of testing a reference standard with known levels of CO_2 to maintain calibration. Keeling recorded data only when readings over 6 hours were stable, and this procedure filtered out the small local burps of volcanic carbon dioxide.

Keeling's protocol and instrumentation provided more accurate data than could human senses. Even if humans could detect CO_2 at nonlethal levels, our capacity to maintain consistency of any perceived intensity is limited. Human perception is optimized for the breadth of stimuli, not the precision along any dimension or narrow range of stimuli. Human capacity to detect a change in any stimulus, also known as "just noticeable difference," is typically on the order 1%–5%. As an example, a good bank teller can tell when a 50-penny roll of coins is a single coin short. Keeling prioritized precision using a standard to maintain calibration to be as stable as possible over time, noting differences of ~0.025% (Harris, 2010).

Years of experimentation have shown us good methods for using instruments so that they will give continuously reliable results. Scientists know that instruments are capable of both drift (variable over time error) and bias (constant error). As a result, scientists have put in place protocols to correct and/or limit these effects. Central features of these protocols are calibration (testing the instrument against some standard) and duplication (using multiple instruments to see if the same answer is obtained).

Humans' organic detectors are no more immune to the potential for drift and bias than are inorganic detectors. Human senses have no analog to calibration, as we do not pause hourly to calibrate the retina with a referent light source. Why not? First, as noted in Idea 1, we rarely care about the absolute values of light or sound. The valuable information almost always exists at the level of relationships among properties. Thus, the mind uses relationships, such as ratios, which are less vulnerable to drift in the absolute magnitude of a sensor's output. For example, when smelling, we notice changes in odorant level and not odorants that remain constant, which explains why we generally do not smell ourselves (whew). Second, the human senses likely take advantage of statistical predictability in the world to keep the sensors tuned (Barlow, 1990). Third, as described above, the base function of perception is to support action. Calibration will occur when action errors are made. A classic psychology experiment illustrates the capacity to adapt to the introduction of a calibration error. Humans wearing prisms that shift the optical directions of objects (as if the muscles of the eye needed calibration) will recalibrate their perceptual-motor system in minutes to accurately reach for objects (Welch, 1986).

IDEA 3: VISCERAL RESPONSES TO PERCEPTION ARE GENERALLY COUPLED TO COGNITION, WHICH MOTIVATE ACTION

Up to this point in the essay, we have discussed basic perceptual processes without consideration of emotion. However, humans have emotions, and emotions affect perception, and vice versa.

There are few things humans are born with an aversion to (bitter tastes associated with toxic plants and optical cliffs make the short list). Many of our emotional responses that inform the meaning of objects and events must be learned from direct experience and community. How do humans have visceral reactions to a scene of death or destruction? Of many possible examples, consider the image of a shell-shocked Syrian boy. Famous images of suffering during conflicts captured something about the human realities of each conflict and were taken as emblematic of those conflicts. This is the power of a visceral reaction to perception, but why do specific images capture attention? They likely arrived at a time where people's mental models understood sufficient aspects of the broader conflict. This understanding, combined with that one image, allowed a viewer to infer the suffering of many people.

In a similar way, Keeling's work in Hawai'i became emblematic of worldwide atmospheric CO_2 concentrations. Why Hawai'i? The careful selection of a sampling site high on Mauna Loa was intended to minimize proximal sources and collect air that was as directly representative of the atmosphere as possible. The Hawai'ian islands are small landmasses in a large ocean. Moreover, there is a persistent atmospheric inversion in Hawai'i at ~2000 m. By sampling above the inversion layer on Mauna Loa, Keeling and collaborators could avoid picking up local influences, including carbon dioxide sources (e.g., bacteria in soil) or sinks (plants). Surrounded by basalt and nothing but a large ocean upwind, it is hard to imagine a much better place to sample and make a case that observed CO_2 levels represent a global average.

A single observation of CO_2 on Mauna Loa allows inferences to be made about the world because it was made at the right place from which to extend from the specific to the general. We are admittedly simplifying the story somewhat, as atmospheric CO_2 was measured by Keeling in a few places that gave the same result (Keeling, 1960). Aside from the placement in Hawai'i, why is a data set from a single place or a single picture so compelling? The Neisser cycle, involving observation and cognition, underlies the notion that human perception can be efficient. Humans, for instance, do not focus visual processing on all the points of the interior of objects, but rather at the edges of objects. A single observation, for example, to determine color, taken at the edge of the object can be extrapolated toward the entire interior of an object. Thus, observations over time, but at a point in space, provide the structured information that allows efficient estimation of the changes in a spatially distant world.

What Keeling's curve lacks for most viewers, however, is the visceral impact of the photograph mentioned above. The information in the Keeling curve does not speak to all humans directly. Only experts, who both can analyze the percentage change of CO_2 and have mental models that connect CO_2 to heat retention, can look at the Keeling curve and feel the danger. That is, one needs the right training to have the appropriate cognition to understand the signal. Moreover, the Keeling curve lacks the visceral nature that would apply to a threat detected by perception alone, such as a large object coming directly at you. Unlike perception of other aspects of the world, there are not multiple opportunities to learn to adapt our behavior to errors in the reading of the Keeling curve.

Thus, while there are formal similarities between directly perceiving the world and knowledge mediated by a built instrument, they will likely differ in the universality of their visceral impact. Pungent smells are universally unpleasant and result in quick action to remove them. Contrast that with the response to CO_2 data collected by Keeling. Even in the 1960s, the trend of increasing CO_2 in the atmosphere was clear (see full report by Keeling et al., 1976). By 1979, models of the role of increasing CO_2 were sufficiently clear that estimates of global warming made then are within the range of current observations. For experts, the meaning and thus implications for actions were clear. There were many options in a series of forking paths that we could have chosen (e.g., Rich, 2018); we are in our current situation because of those choices. The gift that Charles David Keeling gave humanity was an early warning and time to deal with the issue. That we did not, as a society, have the will to enact changes to counteract the trend leads to humanity's contrition and scientists' weariness.

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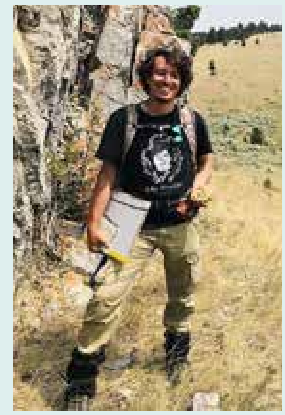
How GSA Foundation Support Transforms Careers: Voices from Our Community

At the GSA Foundation, we understand how easy it is to get caught up in daily tasks and lose sight of the bigger picture behind our work. To reconnect with our mission, we asked some GSA members to share how the Foundation has benefited them. Here are just a few of their stories.

Kenley Eisenmenger, an undergraduate student at the University of Virginia College at Wise, reflected on her experience attending GSA Connects 2024 in Anaheim, California. Her ability to travel across the country to present the results of her study on karst and caves was made possible by a grant from GSA's On To the Future Program. She shared, "I was able to present some of my research on caves and karst and also got to meet my incredible mentor…thanks to GSA." Kenley's story is just one of many examples of how our generous donors enable students to participate in important meetings and advance their research as well as their connections with other scientists.

Steven Semken, a lifetime member, GSA Fellow, and professor at Arizona State University, began his career at a small, under-resourced college. He emphasized the crucial role GSAF played in his journey, stating, "GSAF was absolutely instrumental in helping me secure resources such as books and scientific materials." Steven's experience underscores the support we provide to educators striving to make a difference in their students' lives.



Fieldwork is a cornerstone of geology, and Max Richter, an undergraduate student, experienced this firsthand thanks to a scholarship from the GSA J. David Lowell Field Camp Scholarship Program. Reflecting on his time at field camp, he noted, "The sites we visited were a twisted knot of folds and fractures…disentangling these knots demanded a multifaceted level of thinking that no individual course could possibly develop. Thank you for your support; this scholarship made my attendance possible and changed my life as a geoscientist."

Feedback like this brings a smile to our faces and reinforces the importance of the work we do. We are grateful to our donors for their support, which enables us to continue making a meaningful impact in the lives of students and professionals in the geoscience community.

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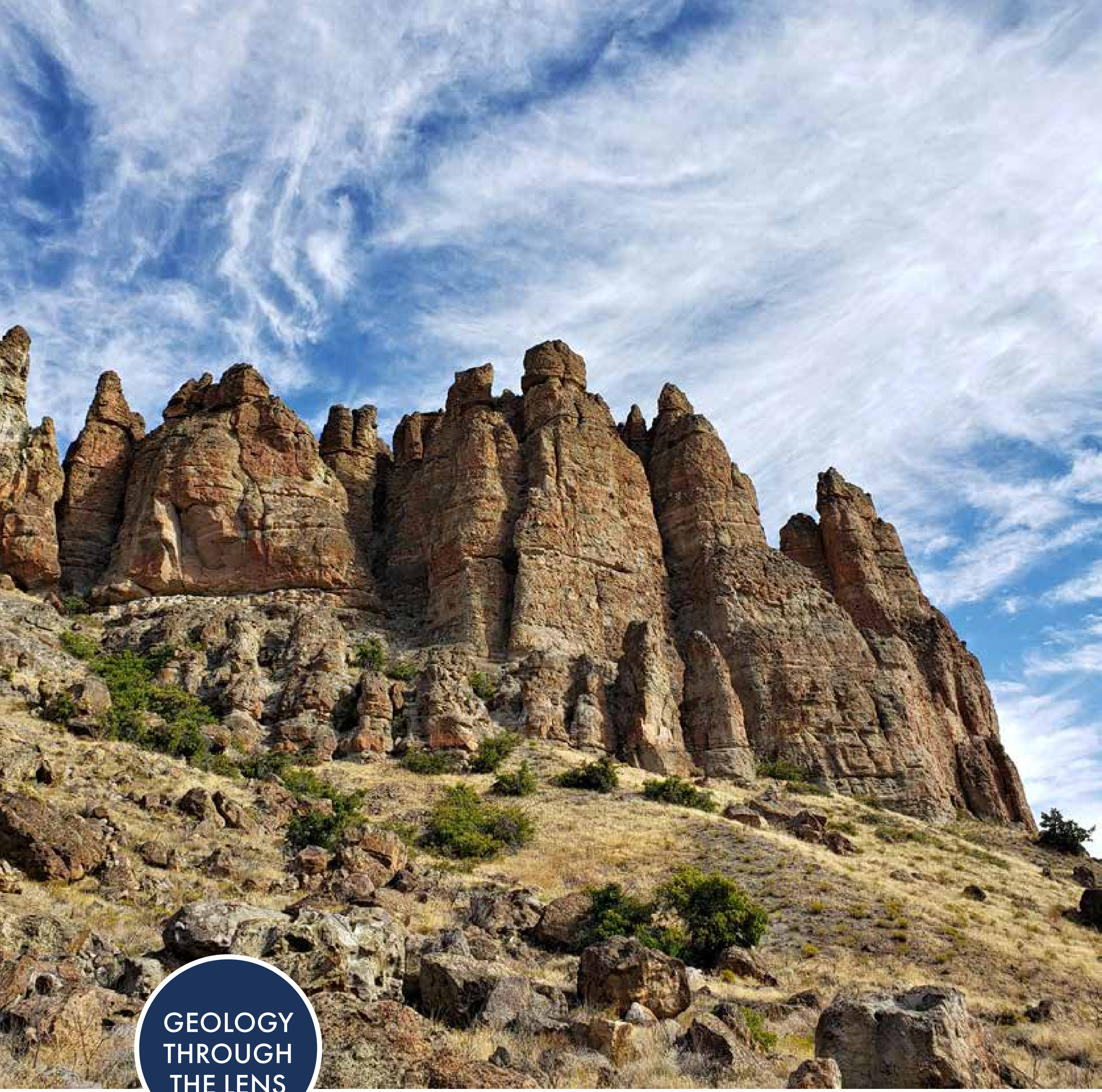

GEOLOGY THROUGH THE LENS

Clarno's Volcanic Towers

The Clarno Palisades at the John Day Fossil Beds National Monument, Oregon, USA.

Credit: Bill Henley is a geology student from Marysville, Washington, USA.

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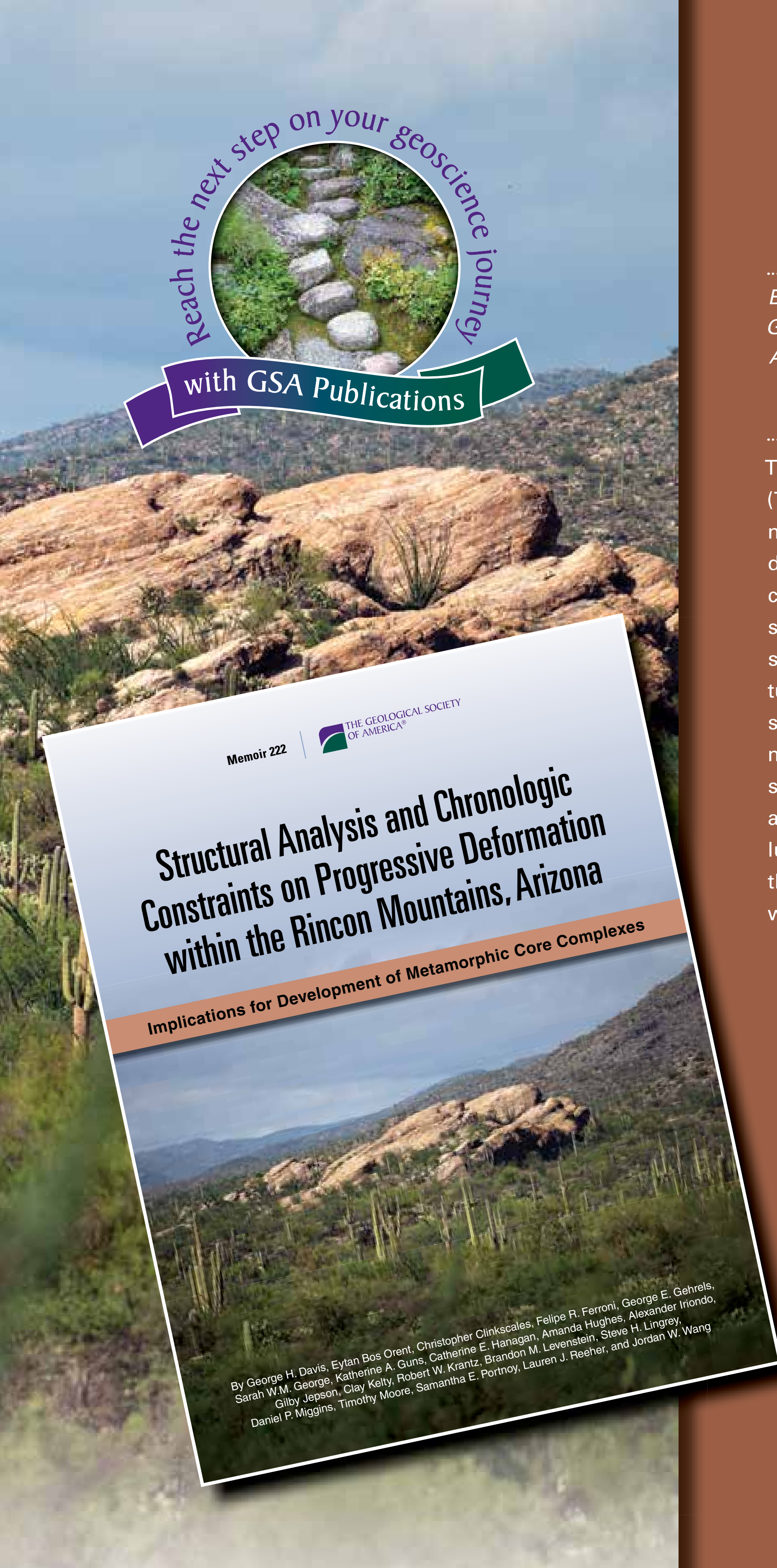

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Structural Analysis and Chronologic Constraints on Progressive Deformation within the Rincon Mountains, Arizona: Implications for Development of Metamorphic Core Complexes

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