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Group photo in the Viñales Valley, Pinar del Río. In the background: the Hoyos de San Antonio Valley and Mogote La Mina, a classic example of tower karst morphology.

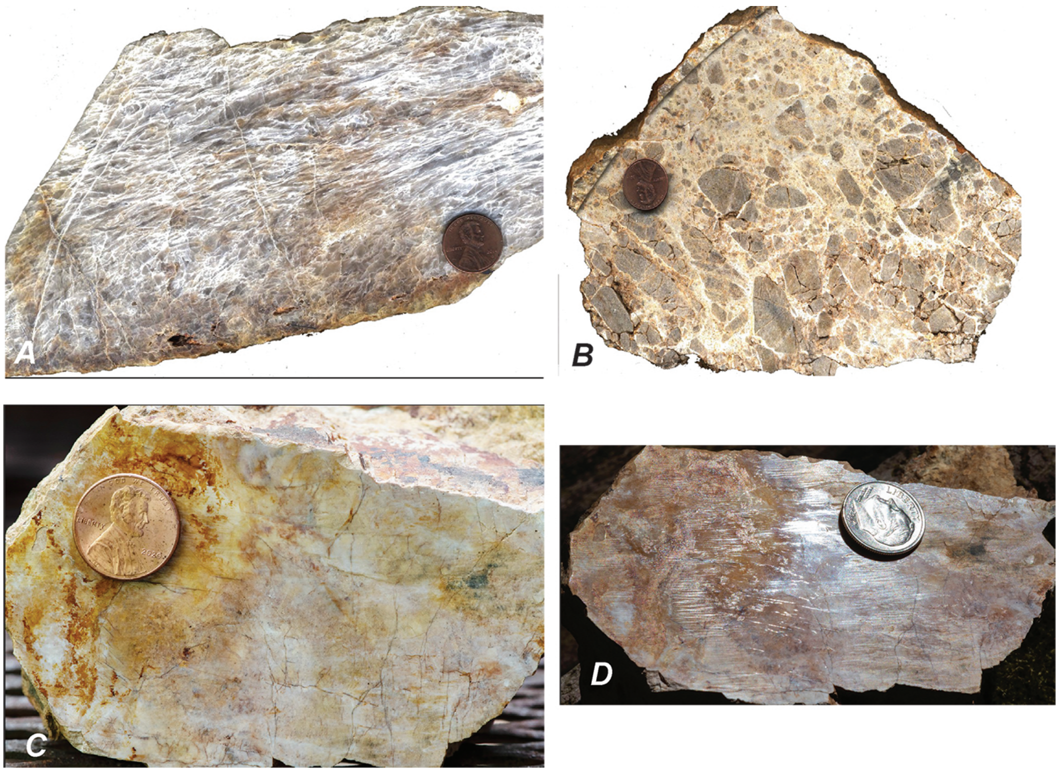

Figure 1. Similar starting materials produce two different types of fault rocks: quartz mylonite and cataclasite. (A) Quartz mylonite from the Towaliga fault zone, central Georgia Piedmont, south of Jackson, Georgia. Protolith was either quartzite or vein quartz. Note well-developed dextral S-C fabric indicating dextral motion. White mineral is feldspar. Specimen long axis is 13.5 cm. (B) Quartz arenite cataclasite from the Appalachian Valley and Ridge near Harrisonburg, Virginia. Specimen long axis is 18.6 cm. (C) Slickensided clear mirror quartz coating a fault surface in anchizone Chilhowee quartzite near the Great Smoky fault in southeastern Tennessee. The quartz likely formed along mesoscale faults from precipitation of silica gel dissolved by pressure dissolution under higher temperatures at greater depths. Clear slickensided quartz surface is visible in incident light. Striae are faintly visible in the upper part of the photo to the right of the coin, and in the lower right-hand corner of image. (D) Striae of highly reflective quartz surface in direct sunlight. White lines delimit slight weathering along joints.

Fault Rocks: A Fourth Class of Rocks

Robert D. Hatcher Jr.[1,*]

ABSTRACT

Geology students learn three classes of rocks: igneous, sedimentary, and metamorphic, which fit neatly into the rock cycle. A fourth class of rocks—fault rocks derived from the other three classes—does not fit into any of the three, or the rock cycle. Fault rocks have unique textures produced from the surface into the mantle by heterogeneous simple shear in fault and shear zones, and along faults in impact structures—and these textures strongly modify existing fabrics. Mylonites form over a range of temperatures, pressures, and strain rates at both high-temperature and low-temperature retrograde conditions and at high temperatures under prograde conditions, both involving crystal-plastic deformation and grain-size reduction. Cataclasites also form largely in near-surface environments at low temperatures and pressures by heterogeneous simple shear along shallow faults and in their associated damage zones. They produce fragments that are progressively reduced in size without changes in mineralogy or internal composition. Pseudotachylite forms under high strain rates by frictional heating in fault zones and impact structures. Hypervelocity (bolide) impacts produce faults bearing abundant cataclasite, pseudotachylite, unique rocks and microstructures, and ultrahigh-pressure minerals. Slickensides on movement surfaces contain minerals that crystallize over a range of temperatures. Quartz precipitates from fluids on moving fault surfaces following pressure dissolution at elevated temperatures. These also are fault rocks/minerals. Fault rocks should be provided the recognition they deserve as a separate class.

INTRODUCTION

From Geology 101, geologists are taught there are three classes of rocks: igneous, sedimentary, and metamorphic.

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This tripartite subdivision was completed when Charles Lyell in 1833 suggested the term "metamorphism" for the process and "metamorphic rocks" as the products. The other two classes had been recognized for centuries, although the origin of igneous rocks was debated until Nicholas Desmarest around 1763 demonstrated in the French Auvergne region that volcanic rocks crystallized from melt. James Hutton in 1785 demonstrated from observations in Scotland that granite crystallized from magma and intruded other rocks. These three classes were ingrained in geologic thought by the late eighteenth and early nineteenth centuries and remain an integral part of geologic thought. We also are taught that all rocks fit nicely into the rock cycle—and most do.

There is, however, a class of rocks, derived from the other classes, that does not fit any of the three traditional classes: fault rocks (Figs. 1 and 2). This class includes the two best-known fault rock types, mylonite (including phyllonite) and cataclasite, but it also includes less common pseudotachylite and other rocks that form in fault/shear zones and faults in hypervelocity impacts. The environments where fault rocks are produced range from the surface to the base of the lithosphere. Add the range of temperatures and pressures of rocks and fluids, and the variable of strain rate of active faults (e.g., during the earthquake cycle), and it is easy to understand why fault rocks do not fall into the usual three classes. Mylonite was first defined by Lapworth (1885) from his observations along the Moine and Arnabol thrusts in Scotland. Many geologists since have considered faults and mylonites to be the products of brittle deformation, despite the ductile character of mylonite embodied in Lapworth's original definition.

My purpose here is to present the case for the fourth class—fault rocks—and to advocate that they should be recognized as a separate class—equal in stature with the other long-established rock classes. My intent is not that these ideas should be incorporated into introductory courses. They are produced by processes that operate in unique environments along faults, in mostly simple shear (less frequently pure shear), and they have unique textures (Fig. 1). Some consider mylonite a type of metamorphic rock (e.g., Brodie et al., 2007; Fettes and Desmons, 2007; Trouw et al., 2010), and it is (with additional attributes discussed herein), but where does that leave pseudotachylite, fault rocks formed by cataclasis, and rocks formed along faults in hypervelocity impacts (e.g., suevite, impactite, tektites, etc.)?

Sibson (1977) provided a framework and physical model for a strike-slip fault that is identified on the surface but penetrates the entire crust into the lithosphere. Near the surface, such a model fault is relatively narrow in cross section and would produce cataclasite possibly with a narrow damage zone. Deeper in the crust, however, the fault zone widens as crystal-plastic deformation becomes dominant until the fault becomes a ductile shear zone dominated by mylonite (and phyllonite). Sibson's model follows the standard mechanical model for the crust and upper mantle, which follows Byerlee's law for linear elastic behavior in the upper crust and plastic (or viscoplastic) flow laws below the brittle-ductile transition.

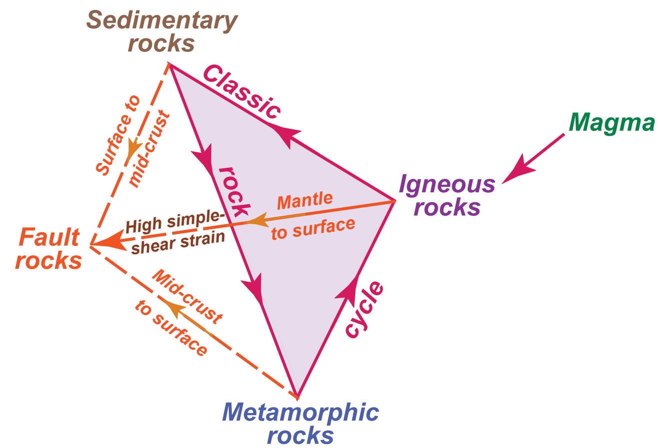

Figure 2. Rock tetrahedron integrating fault rocks with the standard rock cycle end members, and the corresponding environments.

Sheath folds are common to abundant in fault/shear zones. They too mostly form in an environment dominated by high strain and heterogeneous simple shear. Their recognition is partly a function of visible strain markers, as well as rheology. Ideally, sheath folds are most easily recognized in rocks where prominent layering, either (transposed?) bedding or compositional layering, is present. Sheath folds form from progressive amplification of incipient asymmetric buckle folds, where the axial surfaces evolve with increasing strain from parallelism with the x-y plane of the strain ellipsoid to maximum strain and extreme elongation of the hinge lines parallel to the x axis of the strain ellipse (where axial surfaces remain in the x-y plane; Hudleston, 1986; Mies, 1993).

CLASSIFICATIONS

My purpose here is to not erect yet another classification of either mylonites or fault rocks. Trouw et al. (2010) provided excellent examples of fault rock textures and microtextures, employing a simple classification. Many attempts have been made to classify fault rocks (e.g., Lapworth, 1885; Waters and Campbell, 1935; Higgins, 1971; Bell and Etheridge, 1973; Lister and Snoke, 1984; Wise et al., 1984; Schmid and Handy, 1991; Passchier and Trouw, 2005; Brodie et al., 2007). Until we recognized that they form both above and below the brittle-ductile transition, many geologists assumed, based on strict interpretation of Lapworth's original definition of mylonite, that all fault rocks form under brittle conditions.

Wise et al. (1984) attempted to address the spectrum of fault rocks by employing the basic fault rock types (Fig. 3) and emphasizing strain rate and recovery rate without augmenting the already crowded jargon. This scheme and that of Wintsch and Dunning (1985) readily incorporated the field-experimental, temperature-calibrated processes of primarily quartz recovery/recrystallization of Stipp et al. (2002a, 2002b), which has been widely adopted (Fig. 3).

TEXTURAL DIFFERENCES

The basis of most fault rock classifications lies in differences in texture, influenced by fluids, mechanics, and mineralogy. Mylonites were first recognized by their textures,

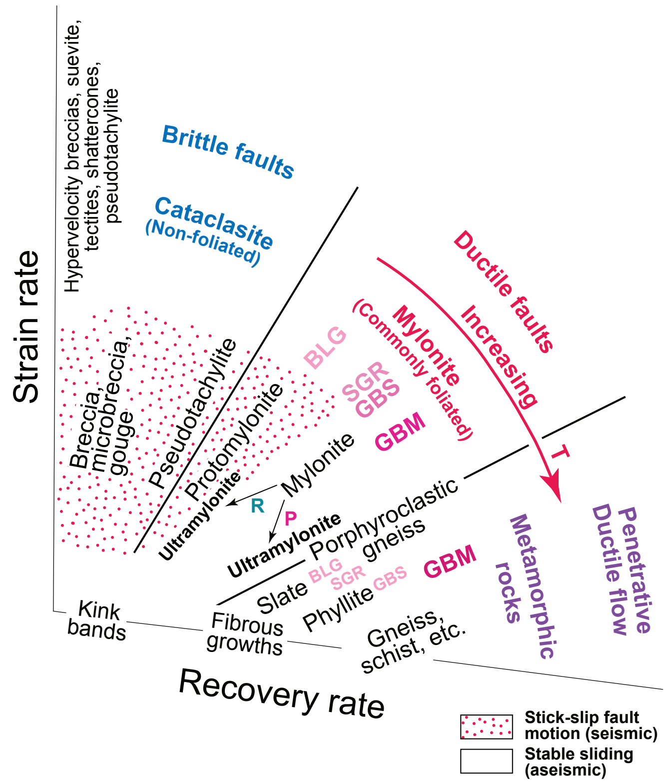

Figure 3. Strain rate versus recovery rate of fault and related rocks (modified from Wise et al., 1984; with suggestions from R. Wintsch). Mylonite (in red type) refers to the entire class of fault rocks formed from quartzofeldspathic rocks. Phyllonite may form from pelitic protoliths or by hydration and retrogression of quartzofeldspathic rocks, and commonly contains an S-C fabric. T—temperature; P—prograde; R—retrograde. Quartz microstructural development with increasing strain and temperature: BLG—bulging; SGR—subgrain rotation recrystallization; GBS—grain-boundary sliding; GBM—grain-boundary migration recrystallization. Quartz microstructure terminology is from Stipp et al. (2002b).

which contrast with those of the rocks from which they were derived (Lapworth, 1885). Fault rocks in ductile fault zones, particularly retrograde fault rocks and some cataclasites, may contrast markedly with protolith rocks because of changes in mineral composition produced by water. Important changes also occur in rock texture by decreasing grain size in both prograde and retrograde mylonites and cataclasites, with the ultimate products being relatively uniform-textured, frequently banded and lineated, ultramylonite and gouge (Hatcher et al., 2017, their fig. 4; Merschat et al., 2023, their fig. 4).

FLUIDS IN FAULT/SHEAR ZONES

The role of fluids, mostly water, in lubricating faults has been known for almost a century, by applying Terzaghi's equation for the role of fluids in shear resistance of soils to faults (e.g., Hubbert and Rubey, 1959),

$$\tau = \mu(\sigma_n - P_w) = \mu S, \quad (1)$$

where τ is shear stress, μ is the coefficient of friction, σ_n is normal stress, P_w is fluid pressure, and S is effective normal stress. The abundance of micas and other hydrous phases in ductile fault zones, such as the Alpine fault in New Zealand and the Brevard fault in the Appalachians (e.g., Hatcher et al., 2017), has long provided hints that large volumes of fluids flux through ductile shear zones during movement. Sinha et al. (1988), however, provided quantitative evidence from the Brevard fault zone in southwestern North Carolina, not only that very large volumes of fluids move through ductile shear zones, but also that fluids are responsible for the mobility of silica on a massive scale, along with changes in both major- and trace-element mineral compositions.

NATURE OF FAULT ROCKS

Although Lapworth (1885) first defined mylonite from his observations of fault rocks in the Northwest Highlands of Scotland, processes related to mylonite formation were not well understood until the latter half of the twentieth century. Fault rocks have been known and written about since before Lapworth (1885) published his paper defining mylonite. His definition recognized that mylonites possess "fluxion" structure, acknowledging their ductile character, and recognized the importance of grain-size reduction in the formation of mylonite. Nevertheless, Lapworth emphasized the brittle nature of many fault rocks and included them in the broad class of mylonites. Other geologists who studied fault rocks during the first half of the twentieth century emphasized Lapworth's focus on brittle behavior, but many acknowledged the evidence for ductile flow in the fine-grained representatives of these rocks, and even in Lapworth's definition (see Waters and Campbell, 1935). The following is directly from Lapworth (1885, p. 558–559):

> ... The old planes of schistosity become obliterated, and new ones are developed; the original crystals are crushed and spread out, and new secondary minerals, mica and quartz, are developed. The most intense mechanical metamorphism occurs along the grand dislocation (thrust) planes, where the gneisses and pegmatites resting on those planes are crushed, dragged, and ground out into a finely laminated schist (Mylonite, Gr. mylon, a mill) composed of shattered fragments of the original crystals of the rock set in a cement of secondary quartz, the lamination being defined by minute inosculating lines (fluxion lines) of kaolin or chloritic material and secondary crystals of mica. Whatever rock rests immediately upon the thrust-plane, whether Archaean, igneous, or Palaeozoic, &c. [*sic*], is similarly treated, the resulting mylonite varying in colour and composition according to the material from which it is formed. The variegated schists which form the transitional zones between the Arnaboll gneiss and Sutherland mica-schists are all essentially mylonites in origin and structure, and appear to have been formed along many dislocation planes...They show the fluxion-structure of the mylonites; but the differential motion of the component particles seems to have been less, while the chemical change was much greater...

Many earlier researchers recognized and described varieties of "mylonite" (sensu lato) and attempted to address the observed microstructures (Waters and Campbell, 1935).

Today, a definition of mylonite emphasizes ductile, crystal-plastic deformation as the dominant process involved in mylonite formation in an environment of heterogeneous simple shear. This requires they form at depths and temperatures above 350 °C where quartz will flow (Stipp et al., 2002a, 2002b; Trouw et al., 2010; see also Fig. 1). Fault zones are the best places to find evidence of large amounts of simple shear parallel to the shear zone boundaries, so ductile shear (fault) zones are dominated by mylonite, and brittle faults are dominated by cataclasite, but faults with complex movement histories may produce mylonite overprinted by cataclasite. Fracturing (cataclastic behavior) of minerals that behave as hard objects in mylonites, such as feldspar and garnet, have higher temperature-pressure thresholds for ductile deformation. Evaporites and glacial ice also form mylonite at near-surface conditions.

Another common misconception about mylonites is that all mylonites are products of retrograde processes. Retrogression is common in many shear zones (e.g., Hatcher et al., 2017, their fig. 4), because many shear zones form at lower ambient temperatures in the presence of fluids than the conditions that formed the protoliths. So, many high-grade minerals are recrystallized and hydrated at lower temperatures, retrograding biotite and garnet to chlorite, plagioclase and kyanite to sericite, etc. Retrograde mineral reactions are accompanied by grain-size reduction (Lapworth, 1885), with ultramylonite being the end product. A parallel sequence can be identified at high temperatures within prograde and retrograde fault zones (e.g., Merschat et al., 2023, their fig. 4), with both processes resulting in grain-size reduction. A megacrystic granite may undergo deformation at high subsolidus temperatures (postcrystallization), e.g., under middle- to upper-amphibolite-grade conditions, with feldspar megacrysts becoming progressively rounded and smaller, developing tails of recrystallized feldspar and quartz, while the groundmass continues to recrystallize. Grain-size reduction of megacrysts continues until the product is a recrystallized ultramylonite. Without tailed megacryst shear-sense indicators, it is difficult to distinguish the ultra-mylonite or the groundmass of intermediate products from fine- to medium-grained granitoid, conglomerate, or metagraywacke.

This contrasts with cataclasite (breccia, gouge) that forms in fault zones and in hypervelocity impact structures at shallow depths as products of brittle deformation or at high strain rates (Fig. 1). Cataclasite is produced by fracturing and reduction of the grain size of minerals without recrystallization or alteration of the mineral composition (Fig. 1). Interestingly, brittle deformation producing cataclasite frequently overprints mylonite in fault zones, suggesting the fault was either unroofed from the depth where ductile deformation dominated, and was deformed brittlely, or increased strain rate forced the deformation process into brittle behavior at the original depth. Fault gouge or ultracataclasite may undergo cataclastic flow in the interstices between larger fragments at temperatures below the threshold for quartz recrystallization, but recrystallization may occur in carbonate rocks.

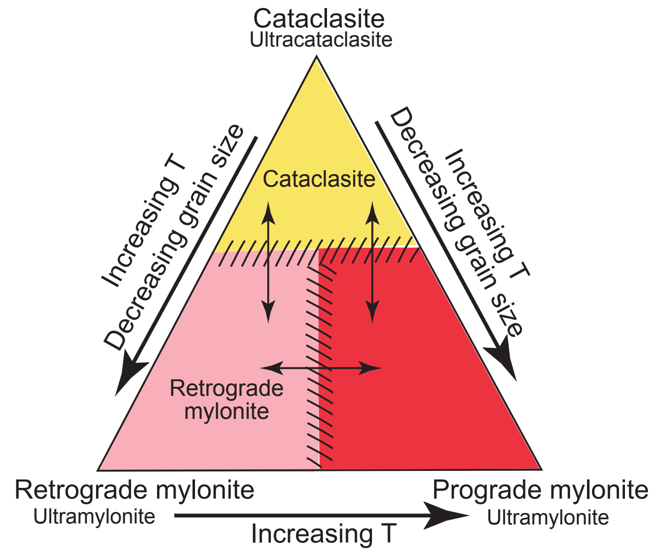

Figure 4. Tetrahedral diagram of interrelationships between various classes of fault rocks. Cataclasite is the dominant product of fault movement under near-surface and hypervelocity impact conditions. Ductile conditions and mylonitization begin as temperature increases to the threshold of quartz plasticity (~350 °C).

Tectonic stylolites are common in both carbonate and quartz-rich rocks, accompanying pressure dissolution in the transition in pressure-temperature conditions below massive ductile and crystal-plastic behavior. These conditions doubtlessly overlap with tectonic anchizone (subgreenschist facies) conditions at the threshold of pressure-dissolution cleavage formation. This process involves quartz dissolution at grain boundaries, diffusion of dissolved solids at grain contacts, or precipitation at grain boundaries or by diffusive transport into open pore spaces or fractures (Gundersen et al., 2002). Parallel recrystallization of illite into sericite also appears here.

Many brittle faults have knife-sharp contacts that contain very narrow zones of cataclasite, if any, whereas others contain broad damage zones from a few centimeters to tens to hundreds of meters wide. Ductile shear zones range from microscopic to kilometers in width. This is where other rock types become fault rocks.

Faults may be weakened at low temperatures by fault zone–dissolved amorphous silica gel that coats fault surfaces, dehydrates, and either solidifies into chalcedonic quartz (Hemley et al., 1988; Brady and Walther, 1990; Nakamura et al., 2012; Kirkpatrick et al., 2013) or crystallizes into shiny slickensided surfaces of clear ("mirror") quartz (Figs. 1C and 1D). This material is neither mylonite nor cataclasite, but the product of low-temperature brittle deformation and quartz pressure dissolution and redeposition during fault movement. This texture has also been identified along faults where the material deposited on the mirror surface consists of calcite, and possibly other minerals, attesting to formation under anchizone to lower-greenschist-facies condition (Pozzi et al., 2018). So, how should fault-generated materials like this be considered in the context of being solely the product of metamorphic processes? Moreover, this material does not fit any existing classification for mylonites.

Similarly, while they are products of faulting, how do tectonic stylolites, which form under shallow burial conditions, fit into a scheme describing mylonites? Also, what about deformation bands (e.g., Davis, 1999) and scaly fabrics (e.g., Moore, 1986) that form in unconsolidated sediments in subduction zones and elsewhere? These, too, are largely the products of fault-related deformation.

Faults in hypervelocity impacts produce a unique suite of rocks and textures that are frequently called impactites. While pseudotachylite occurs in fault zones, it is also common in impact structures, along with suevite, melt breccia (Gulick et al., 2019), shatter cones, shocked quartz (Horton et al., 2009, their fig. 8C), and stishovite, along with geochemical anomalies.

DISCUSSION

Fault rocks are impossible to place in the rock cycle because they form in unique solid-state environments (with or without fluids) as products of heterogeneous simple shear over a range of temperatures and pressures. Fault rocks comprise a unique group linked by several common threads. They: (1) are derived from other rocks; (2) are mostly the products of heterogeneous simple shear; (3) involve grain-size reduction; and (4) are produced in fault zones and impact structures with textures that contrast texturally and frequently compositionally with the rocks from which they are derived. Depth in the crust, and strain rate, determine whether or not cataclasite or mylonite forms (Fig. 3). Strain rate, however, can influence the nature of fault rocks.

Resulting fabrics are unique and largely controlled by the depth in Earth where they form. Add the variables of deformation rate along faults, fluids, and hypervelocity impacts (Fig. 3), and it is easy to understand why fault rocks do not fall into our usual three classes.

The ductile environment of heterogeneous simple shear produces unique textures, such as asymmetric porphyroclasts, S-C fabrics, sheath folds, and intrafolial folds. These also form in pure shear via transposition, producing rotated porphyroclasts and other textures.

Hypervelocity impacts involve surface protoliths and are the products of strain rates so high (10+6 to 10+8 s–1; Melosh, 1989; Zwiessler et al., 2017) that cataclasis is inevitable, with accompanying melting preserved as pseudotachylite, produced from heat generated too rapidly for dissipation by normal heat-conduction and fluid-flow processes. Well-mapped impacts reveal a plethora of radial and concentric faults and fault rocks (e.g., Wilson and Stearns, 1968). In contrast, geologic strain rates of 10–14 to 10–15 s–1 calculated from naturally deformed rocks (Fagereng and Biggs, 2019) accompany ductile flow in the deep crust. Here, recovery and recrystallization processes can proceed to produce fault rocks with textures that contrast with those of metamorphic rocks that form predominantly by pure shear (Fig. 3).

Fault-related rocks and textures are derived from a broad spectrum of lithologies, pressure-temperature conditions, and fluid availability, but they fit into a unique suite of phenomena related to faulting. Because of their textures, contrasting modes of formation with different protoliths, variable pressure-temperature conditions, and their parallel processes of formation, fault rocks deserve recognition as a separate class of rocks equal in status to the other established classes.

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GSA Officers

July 2025 - June 2026

PRESIDENT

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Ann Arbor, Michigan, USA

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Glenn Thackray
University of Idaho
Pocatello, Idaho, USA

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Brian G. Katz
Environmental Consultant
Weaverville,
North Carolina, USA

GSA Councilors

July 2022–June 2026	July 2023–June 2027	July 2024–June 2028	NEWLY ELECTED July 2025–June 2029
 **Carol D. Frost** University of Wyoming Laramie, Wyoming, USA	 **Craig H. Jones** University of Colorado Boulder, Colorado, USA	 **Martha Cary (Missy) Eppes** University of North Carolina at Charlotte Charlotte, North Carolina, USA	 **Alyssa L. Abbey** California State University Long Beach, California, USA
 **Kathleen DeGraaff Surpless** (Sections Liaison) Trinity University San Antonio, Texas, USA	 **Patricia Persaud** University of Arizona Tucson, Arizona, USA	 **Eric Kirby** (Council Member-at-Large) University of North Carolina at Chapel Hill Chapel Hill, North Carolina, USA	 **Kathleen Counter Benison** West Virginia University Morgantown, West Virginia, USA
 **Richard M. Ortiz** Lettis Consultants International Inc. (LCI) Sacramento, California, USA	 **Nicholas P. Lang** (Divisions Liaison) NASA Planetary Science Div. Mercyhurst University Erie, Pennsylvania, USA	 **Darryl Reano** Arizona State University Tempe, Arizona, USA	 **James A. Heller** Alabama Department of Environmental Management Montgomery, Alabama, USA

GSA Student Advisory Council

VOTING MEMBERS OF COUNCIL
Term: June 2025–July 2026

CHAIR
Esther O. Oyedele
Virginia Tech
Blacksburg, Virginia, USA

IMMEDIATE PAST CHAIR
Madison Rafter
University of Minnesota–Twin Cities
Minneapolis, Minnesota, USA

Newly Elected Student Advisory Council Members

Term: July 2025—June 2027

Tiana Dinham
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina, USA

Chinyere Eunice Eme
University of Memphis
Memphis, Tennessee, USA

Piper Hattenbach
Mount Holyoke College
South Hadley, Massachusetts, USA

Haley Meyrowitz
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina, USA

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Missouri University of Science and Technology
Rolla, Missouri, USA

Ashley Prow-Fleischer
Syracuse University
Syracuse, New York, USA

Noshin Sharmili
Pennsylvania State University
University Park, Pennsylvania, USA

Sage Turek
University of Texas at Austin
Austin, Texas, USA

2025 GSA Medal & Award Recipients

The Geological Society of America bestows medals and awards to recognize individuals who have, through their outstanding achievements, made significant contributions to the geosciences.

GSA globally upholds excellence and innovation by annually paying tribute to those who are making remarkable impacts.

2024 GSA Medal and Award Recipients with 2024 GSA President Christopher (Chuck) Bailey.

Presidential Address and Awards Ceremony

GSA is honored to celebrate these extraordinary geoscientists at GSA Connects 2025 in San Antonio on Sunday, 19 October.

"Dr. Cerling is an exceptional, a ward-winning geoscientist, who has advanced our understanding of Earth history through groundbreaking isotope geochemistry work in forensics, cosmogenic dating, and paleo-CO2 records of biological and geological significance. This impactful work has addressed major scientific questions and societal issues. His outstanding science, service, and mentoring make him one of the most influential, creative living scientists and fully deserving of GSA's highest honor."

—Marjorie Chan, Penrose Medal Nominator

"I nominated Dr. Dong for the Day Medal for his breadth, depth, and originality in the fields of microbial and environmental geochemistry (>340 articles, >19,300 citations, h index of 72). Moreover, Dr. Dong has served the geochemical community in many ways from serving as an NSF Program Director, to editorship (Chief Editor Chemical Geology and now Geochimica et Cosmochimica Acta), and training more than 40 graduate students to be next generation of microbial and environmental geochemists."

— Jason Rech, Day Medal Nominator

Penrose Medal

Thure E. Cerling, University of Utah

President's Medal

OpenTopography Facility

Ramon Arrowsmith, Arizona State University
Chris Crosby, EarthScope
Viswanath Nandigam, San Diego Super Computer, University of California, San Diego
Chelsea Scott, Arizona State University

Arthur L. Day Medal

Hailiang Dong, China University of Geosciences, Beijing

Young Scientist Award (Donath Medal)

Julia Kelson, Indiana University

Florence Bascom Geologic Mapping Award

Scott Southworth, U.S. Geological Survey

Randolph W. "Bill" and Cecile T. Bromery Award

Rocío Caballero-Gill, George Mason University

GSA Distinguished Service Award

Steve Boss, University of Arkansas

Patrick Burkhart, Slippery Rock University

GSA Public Service Award

Andrea Dutton, University of Wisconsin

Doris M. Curtis Outstanding Woman in Science Award

Penny Wieser, University of California, Berkeley

James B. Thompson, Jr. Distinguished International Lectureship

Maria Rose Petrizzo, University of Milan, Italy

Kathleen Counter Benison, West Virginia University

GSA International Honorary Fellow Award

Fabian Waddsworth, Durham University

Alberto Guadagnini, Politecnico di Milano

Gladys W. Cole Memorial Research Award

Arjun Heimsath, Arizona State University

W. Storrs Cole Research Award

Christina Woltz, Royal School of Mines, Imperial College London

AASG/GSA John C. Frye Environmental Geology Award

Peter McLaughlin, Jaime Tomlinson, and Amanda Lawson, Delaware Geological Survey

2025 GSA Division and International Primary Awards

Energy Geology Division

Gilbert H. Cady Award
Joan S. Esterle,
University of Queensland

Environmental and Engineering Geology Division

Edward B. Burwell Jr. Award
Scott McDougall,
University of British Columbia
Paul Santi,
Colorado School of Mines
Jakob Matthias, deceased

Geoarchaeology Division

Rip Rapp Archaeological Geology Award
Sheryl Luzzadder-Beach,
University of Texas at Austin

Geobiology and Geomicrobiology Division

Distinguished Career Award
Pieter Visscher,
University of Connecticut

Geoinformatics and Data Science Division

M. Lee Allison Award for Geoinformatics
Wenwen Li,
Arizona State University

Geology and Health Division

Meritorious Service Award
Malcolm Siegel,
LJS Consulting

Geophysics and Geodynamics Division

George P. Woollard Award
Richard Gordon,
Rice University

Geoscience Education Division

Biggs Earth Science Teaching Award
Kelsey S. Bitting,
Elon University

GSA International

GSA International Distinguished Career Award
Prosun Bhattacharya,
KTH Royal Institute of Technology, Sweden

History, Philosophy, and Geoheritage Division

Mary C. Rabbitt History and Philosophy of Geology Award
Renee Clary,
Mississippi State University

Hydrogeology Division

O.E. Meinzer Award
Michelle Walvoord,
U.S. Geological Survey

Limnogeology Division

Israel C. Russell Award
Erik Brown,
University of Minnesota Duluth

Planetary Geology Division

G.K. Gilbert Award
Scott L. Murchie,
Johns Hopkins Applied Physics Laboratory

Quaternary Geology and Geomorphology Division

Kirk Bryan Award
Alan Nelson, U.S. Geological Survey (Emeritus)

Sedimentary Geology Division

Laurence L. Sloss Award
Tim Lawton, Bureau of Economic Geology,
University of Texas at Austin

Structural Geology and Tectonics Division

Career Contribution Award
Mike Williams,
University of Massachusetts Amherst

John C. Frye Memorial Award in Environmental Geology

Did you know that John C. Frye was Executive Director of GSA from 1974 to 1982? He was a triple-threat geologist: researcher, teacher, and administrator.

In cooperation with the Association of American State Geologists (AASG), GSA makes an annual award for the best paper on environmental geology published either by GSA or by one of the state geological surveys.

McLaughlin, P.P., Tomlinson, J.L., and Lawson, A.K., 2023, Aquifers and Groundwater Withdrawals, Kent and Sussex Counties, Delaware: Delaware Geological Survey Bulletin no. 22, 105 p., plates.

The 2025 awardees will be recognized at GSA Connects 2025 in San Antonio, Texas, USA, for their outstanding publication.

AASG Association of American State Geologists

Cole Awards

W. Storrs Cole was a GSA Fellow for 58 years, a member of the Cushman Foundation, and one of the Society's leading benefactors. He established the Gladys W. Cole Research Award in memory of his wife in 1982. The first presentation of the W. Storrs Cole Memorial Research Award was in 1991 after his passing in 1989.

W. STORRS COLE MEMORIAL RESEARCH AWARD

Christina Woltz, Royal School of Mines, Imperial College of London
Christina Woltz will be honored at the Cushman Foundation for Foraminiferal Research Meeting and at the GSA Presidential Address and Awards Ceremony at GSA Connects 2025 in San Antonio, Texas, USA.

GLADYS W. COLE MEMORIAL RESEARCH AWARD

Arjun Heimsath, Arizona State University
Arjun Heimsath will be honored at the GSA Quaternary Geology and Geomorphology Division Annual Awards Ceremony and at the GSA Presidential Address and Awards Ceremony at GSA Connects 2025, in San Antonio, Texas, USA.

Cushman Foundation for Foraminiferal Research

Join the Global Geoscience Community in San Antonio!

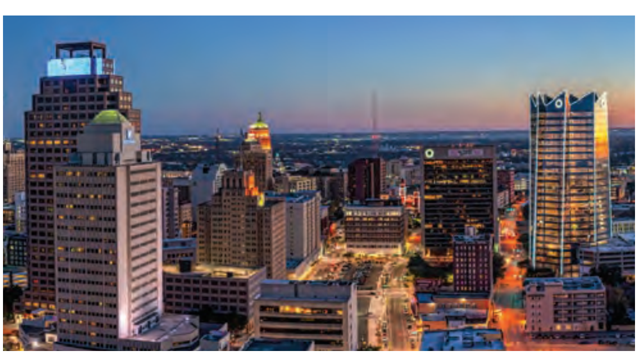
GSA Connects 2025 is more than a meeting—it's a celebration of science, connection, and community. Don't miss your opportunity to be part of it.

Registration & Travel

GSA offers three registration tiers—Early, Standard, and Late—so register early to lock in the best rate and make travel arrangements while hotel rooms are still available.

Register for GSA Connects 2025: connects.geosociety.org/register

Book your hotel now near the Henry B. González Convention Center: connects.geosociety.org/travel/hotels-transportation



Key Dates

Abstracts Deadline	5 August
Early Meeting Registration Rate Deadline	27 August
Student Travel Grant Application Deadline	27 August
Standard Meeting Registration Opens	28 August
Space Request Deadline	29 August
Cancellation Deadline	12 September
Housing Reservation Deadline	24 September
Standard Meeting Registration Rate Deadline	2 October
Late Meeting Registration Opens	3 October

Hosting a Non-Technical Event?

GSA welcomes your business meetings, receptions, luncheons, and more. Submit your request via the Event Space Request Form by 29 August to avoid late fees. Space is limited and first come, first served! Please use the form for:

- Events held at the Henry B. González Convention Center.
- Events held at the Grand Hyatt San Antonio River Walk (HQ Hotel).
- Off-site events (events that are being held at another location in San Antonio that you have arranged on your own).

Submit at: connects.geosociety.org/networking/events/request-space

Showcase Your Brand at GSA Connects 2025

EXHIBIT • SPONSOR • ADVERTISE

s2.goeshow.com/gsa/annual/2025/

Join the global geoscience community at the Geological Society of America's premier event—GSA Connects 2025—happening 19–22 October in San Antonio, Texas, USA.

With 5,000+ attendees from over 50 countries, this is your opportunity to engage directly with researchers, educators, students, and industry leaders from across the earth sciences.

Why Get Involved?

- Reach Decision-Makers – 50% of attendees have 11+ years of experience
- Engage Rising Talent – 40% are students exploring career opportunities
- Expand Your Impact – Attendees from 49 countries in 2024
- Boost Visibility – Reach 34,000+ geoscientists through exhibits, sponsorships, and advertising

Exhibit at the Heart of the Action

s2.goeshow.com/gsa/annual/2025/become_an_exhibitor.cfm

The Exhibit Hall is the beating heart of the meeting: a dynamic, high-energy space designed to spark connection. With 23 hours of exhibit time, heavy foot traffic, and direct access to qualified decision makers, GSA Connects offers unmatched visibility and face-to-face engagement.

Whether you're looking to network, demo products, connect with prospects, or boost brand recognition, there's a space for you—commercial, educational, not-for-profit, or society affiliated.

Exhibit Dates:

Sun., 19 Oct.: 4:30–7 p.m.
Mon.–Tues., 20–21 Oct.: 10 a.m.–6:30 p.m.
Wed., 22 Oct.: 10 a.m.–2 p.m.

Booth Rates

Commercial	$2,600
Educational / Not-for-Profit	$1,500
Campus Connection	$1,450
Associated Societies	$850
Each Exposed Corner	+$100

Partner with Purpose: Sponsor GSA Connects 2025

s2.goeshow.com/gsa/annual/2025/become_a_sponsor.cfm

Sponsorship at GSA Connects is flexible, impactful, and tailored to your goals. Whether you're interested in brand exposure, student engagement, or scientific visibility, we'll help you create a package that fits.

Let's build something together. Options include:

- Student travel or networking support
- Branded lounges, experiences, or giveaways
- Sponsored talks, workshops, or receptions
- Digital advertising and meeting app visibility

And more—bring us your ideas!

Your sponsorship = your story, your impact.

GSA Connects 2025 is where science, community, and opportunity converge. **Don't miss your chance to be seen, heard, and remembered.**

Learn more and explore resources at s2.goeshow.com/gsa/annual/2025/.

Questions?

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Your Research. Your Community.

GSA Connects 2025 is your chance to share your work with thousands of geoscientists from around the world—and we want to hear from you! Whether you're presenting your latest research, leading a workshop, or joining a field trip, your participation shapes the geoscience conversation.

Submit Your Abstract for GSA Connects 2025!
19–22 October | San Antonio, Texas, USA
Deadline: 5 August 2025
connects.geosociety.org/program/technical-sessions/abstracts

Abstract Guidelines

Two-Abstract Rule

You can submit up to two abstracts as the presenting author if:

- One is for a poster presentation, and
- Both abstract submissions cover different content.

Invited submissions to Pardee Keynote Symposia or topical sessions do not count against your abstract limit.

Abstracts submitted to a session conducted in Spanish do not count toward your abstract limit.

Fees

GSA Members: Professionals $60 | Students $25
Non-Members: Professionals $80 | Students $50

Invited speakers must also pay the abstract fee.

Know Before You Submit

Submissions to GSA Connects are a commitment to research integrity and scientific excellence.
As a presenter, you agree to:

Commit to Present: Submitting your abstract means you are planning to be there, ready to share and discuss your work.

Maintain Integrity in Research: Stay true to your abstract's content and conclusions as reviewed, ensuring high quality and honesty throughout.

Recognize All Efforts: Celebrate collaboration! Ensure any co-authors are acknowledged, have contributed significantly, are informed of, and consent to their inclusion.

Ensure Quality: Craft a presentation that reflects your dedication to excellence in research.

Your Journey Starts Here:

Student & Early Career Opportunities at GSA Connects 2025

Whether you're presenting your first abstract or exploring your career path, GSA Connects 2025 is your place to grow, connect, and be inspired. From volunteering and travel support to career workshops and mentorship, there's something here for every student and early career geoscientist.

Student Volunteer Program

Get an insider's look at how the meeting comes together, enjoy free registration, and make a real impact—all by volunteering just eight hours at Connects 2025. It's a rewarding way to get involved, expand your network, and experience the meeting from a fresh perspective.

connects.geosociety.org/register/volunteer

Not a student member yet? Join now to take advantage of this opportunity and more! Student memberships are only $25/year.

Become a member: www.geosociety.org/membership

Student Travel Grants

We want you at Connects—let us help you get there. GSA travel grants assist with lodging, transportation, and other travel costs so you can focus on making the most of your time at the meeting.

Application deadline: 27 August
Don't miss out—apply and take a meaningful step in your geoscience journey!

connects.geosociety.org/travel/grants

Mentoring: Share Stories, Build Futures

Want to give back? Or ready to learn from someone who's been there? GSA Connects offers mentoring for all levels—from casual conversations to guided career advice.

Opportunities to Be a Mentor:

- Résumé/CV Review
- Drop-In Mentoring
- Table Mentoring (GeoCareers Day)
- Women in Geology Program
- Networking Event Mentoring

Sign Up: geosociety.co/MentorInterestForm

Short Courses & Field Trips: Learn, Explore, and Earn CEUs

GSA's short courses and field trips are the perfect way to deepen your expertise, gain hands-on experience, and earn Continuing Education Units (CEUs).

Short Courses

Topics include AI in geoscience, geospatial tools, geochemistry, stratigraphy, and science communication. Formats include online, hybrid, and in-person. Earn up to 0.8 CEUs per course.

Field Trips

Explore Texas and beyond—from karst landscapes and fault zones to impact craters and ancient reefs—on field trips led by expert geoscientists.

Learn more:
connects.geosociety.org/program/field-trips

Questions?
shortcourse@geosociety.org | fieldtrip@geosociety.org

GeoCareers: Your Path to Career Success

Whether you're exploring your future or actively entering the workforce, the GeoCareers program at GSA Connects 2025 offers the resources, insights, and connections to help you move forward with confidence.

This year's program features two major components: GeoCareers Day and the GeoCareers Corner—each offering unique opportunities to learn, network, and take charge of your career journey.

GeoCareers Day | Sunday, 19 October, 9 a.m.–1 p.m.

A focused, one-day event designed to kickstart your career. This is the place to connect directly with professionals from industry, government, and beyond. Through panels, workshops, and informal mentoring, you'll gain practical advice, new contacts, and an inside look at what employers are looking for.

Sessions include:

- Résumé & USAJobs Workshop
- Company Connection (meet with employers)
- Mentor Roundtables (get your questions answered)
- GeoCareers Panel Luncheon (includes lunch)

Who should attend? Anyone entering the job market, supporting early career professionals, or curious about career options outside academia.

Cost: $20 (includes lunch)
Sign up online when you register for the meeting.

GeoCareers Corner | Sun–Wed, 9 a.m.–5 p.m. Daily

Your go-to career hub throughout the conference.
Located in the Henry B. González Convention Center, the GeoCareers Corner offers drop-in resources, expert advice, and community connections in a relaxed and welcoming space.
No registration required—just show up!

Drop by for:

- One-on-One Résumé Reviews
- Mentoring with Geoscience Pros
- Career Pathway Presentations
- Early Career Coffee Meetups
- Women in Geology Program
- Geology Club Meetup
- Job Postings & Hiring Boards
- Networking Events
- A relaxing place to recharge between sessions

Who's it for?
Everyone attending GSA Connects 2025—whether you're a student, postdoc, early career professional, or established geoscientist.

Pardee Keynote Symposia

Make attending the Pardee Keynote Symposia a top priority! These high-profile symposia, held throughout the meeting, feature insights and inspiring new directions that are shaping the future of geoscience.

P1. Expanding Neurotypical Borders: Building a Future of Inclusion with Disabled and Neurodivergent Perspectives in Geoscience

Sunday, 19 October

Conveners: Taormina Lepore, Jennifer Wagner, and Ian O. Castro

We invite contributors and audience participants of all backgrounds to learn, lead, and celebrate disability and neurodivergence as core to our fields and our collective and intersectional science identities.

Endorsed by: American Geophysical Union (AGU); Association for Women Geoscientists; GSA Diversity in the Geosciences Committee; GSA Geobiology and Geomicrobiology Division; GSA Geoarchaeology Division; GSA Geology and Society Division; GSA History, Philosophy, and Geoheritage Division; GSA Hydrogeology Division; GSA Karst Division; GSA Planetary Geology Division; GSA Quaternary Geology and Geomorphology Division; History of Earth Science Society; International Association for Geoscience Diversity; International Association for Promoting Geoethics (IAPG); International Medical Geology Association; Mineralogical Society of America; Mineralogical Society of the UK and Ireland; NAGT Geoscience Two-Year College Division (Geo2YC); NAGT Teacher Education Division (TED); National Association of Geoscience Teachers (NAGT); National Earth Science Teachers Association; Paleontological Society; Society of Vertebrate Paleontology.

P2. Groundwater in Achieving the Sustainable Development Goals

Monday, 20 October

Conveners: Abhijit Mukherjee, David Kreamer, Prosun Bhattacharya, Timothy Parker, and Donald O. Rosenberry

The growing impact of changing climate, land use, and water pollution has underlined the link between groundwater, environment, and society. This Pardee Session reinforces the importance of groundwater in achieving the sustainable development goals.

Endorsed by: American Geophysical Union (AGU); Association of American State Geologists (AASG); GSA Continental Scientific Drilling Division; GSA Geobiology and Geomicrobiology Division; GSA Geoinformatics and Data Science Division; GSA Geology and Society Division; GSA History, Philosophy, and Geoheritage Division; GSA Hydrogeology Division; GSA International; GSA Karst Division; History of Earth Science Society; International Association for Promoting Geoethics (IAPG); International Association of Geomorphologists (IAG); International Association of Hydrogeologists; International Medical Geology Association; International Society of Groundwater for Sustainable Development (ISGSD); Mineralogical Society of the UK and Ireland.

P3. Geoheritage Without Borders: International Perspectives on the Conservation and Celebration of Geodiversity

Tuesday, 21 October

Conveners: Priscilla Grew, Jack J. Matthews, John H. Calder, Carles Canet, Mauricio Faraone Pimenta, Maria da Gloria Motta Garcia, and Sherene James-Williamson

Every nation has a story to tell about its geodiversity—-but what are best practices to promote conservation of our geoheritage? This GSA-ProGEO Western Hemisphere session explores innovative partnerships to conserve geoheritage and celebrate geodiversity.

Endorsed by: American Geophysical Union (AGU); American Geosciences Institute; Association for Women Geoscientists; Association of American State Geologists (AASG); GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geology and Society Division; GSA Geoscience Education Division; GSA History, Philosophy, and Geoheritage Division; GSA Hydrogeology Division; GSA International; GSA Karst Division; GSA Planetary Geology Division; GSA Quaternary Geology and Geomorphology Division; History of Earth Science Society; International Association for Promoting Geoethics (IAPG); International Association for the Conservation of Geological Heritage (ProGEO); International Association of Geomorphologists (IAG); International Association of Hydrogeologists; International Medical Geology Association; Mineralogical Society of America; Mineralogical Society of the UK and Ireland; National Earth Science Teachers Association; Society for American Archaeology; Spanish Geological Society - Geoheritage Commission.

P4. Impact Cratering and the Evolution of Life

Wednesday, 22 October

Conveners: Nadja Drabon and David Kring

This session explores the role of impact cratering in life's evolution throughout Earth's history, from the origin of life to mass extinctions. It highlights connections between impacts, evolutionary change, and planetary processes.

Endorsed by: American Association of Petroleum Geologists; American Geophysical Union (AGU); Cushman Foundation for Foraminiferal Research; GSA Continental Scientific Drilling Division; GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Geoinformatics and Data Science Division; GSA Geophysics and Geodynamics Division; GSA History, Philosophy, and Geoheritage Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Planetary Geology Division; GSA Sedimentary Geology Division; History of Earth Science Society; International Medical Geology Association; Mineralogical Society of the UK and Ireland; Paleontological Society; SEPM (Society for Sedimentary Geology).

Field Trips at GSA Connects 2025

connects.geosociety.org/program/field-trips

Industry Tracks

- Economic Geology
- Energy
- Engineering Geology
- Environmental Geology
- Hydrogeology

All field trips depart from San Antonio unless otherwise specified.

FT25CN401. An Educator's Look at West Texas Geology

Thurs.–Sat., 16–18 Oct., noon (first day)–9 a.m. (last day). US$470 for students and ECPs; US$510 for professionals. CEUs: 1.6.

Location: El Paso, Texas, USA

This tour highlights the geological wonders between El Paso and San Antonio, emphasizing the Franklin Mountains, Guadalupe Mountains, and Carlsbad Caverns. Participants will explore tectonic, sedimentary, and karst landscapes. We plan a day and a half in the field exploring these sites as well as "meta" level discussions about field trip organization and facilitation. We hope for vibrant and rich discussions set in some of the most mind-blowing geological sites of west Texas. Cost includes transportation (mini vans), two nights at the Hilton Garden Inn El Paso (double occupancy), meals, snacks, and water.

FT25CN402. Architecture of a Seismic-Scale Normal Fault Zone: The Hidden Valley Fault, Canyon Lake Gorge, Texas

Thurs., 23 Oct., 8 a.m.–5 p.m. US$95. CEUs: 0.8.

This field trip focuses on fault zone architecture and deformation processes in the seismic-scale Hidden Valley fault zone at Canyon Lake Gorge, part of the Balcones fault system. Located approximately one hour from San Antonio, Texas, this is an exceptionally well-exposed site to observe fault and fracture networks in mechanically layered carbonates of the Cretaceous Glen Rose Formation. The Hidden Valley fault zone has provided a study area for deformation analyses for over two decades and is an excellent analog for deformation and fluid flow in mechanically layered reservoirs and aquifers. Cost includes transportation (mini vans), entrance fees, lunch, snacks, and water.

FT25CN403. Building San Antonio: Geology, Water, and Building Resources in the Historic "Valley of the Missions"

Sat., 18 Oct., 8:30 a.m.–5 p.m. US$95. CEUs: 0.8.

The valley of the San Antonio River was the focus for the foundation of five Spanish mission complexes (1718–1731, now a World Heritage Site) and civilian settlement. The valley provided irrigable land, steady water supplies, and varied materials for building. This trip provides an overview of these resources, and how they shaped the early settlement of the 'Valley of the Missions' and the city of San Antonio. We will visit springs, acequias, quarries in limestone and tufa, downtown and mission structures. Results of recent mapping of the San Antonio quadrangle will be included. Cost includes transportation (bus), lunch, snacks, and water.

FT25CN404. Cambrian Earth Systems in Western Laurentia and Tonto Group of the Western Grand Canyon Region

Wed.–Sat., 15–18 Oct., 5 p.m. (first day)–noon (last day). US$800. CEUs: 2.4.

Location: Las Vegas, Nevada, USA

Explore the iconic Cambrian Tonto Group strata in westernmost Grand Canyon and near Las Vegas to discuss results of new research and implications for long-standing questions about Cambrian Earth systems. Topics include the Sauk transgressions, the Great Unconformity, Cambrian subsidence mechanisms, a sequence stratigraphy re-interpretation of Eddie McKee's classic Tonto Group stratigraphy, new biochronology, precise geochronology, and C-isotope chemostratigraphy. How do new datasets from the Grand Canyon inform understanding of the Cambrian Earth System and its rapid, ever-shrinking time scale? Cost includes transportation (mini vans), one night in Las Vegas (double occupancy), and two nights at the Dude Ranch (double occupancy), meals, snacks, water, and boat usage.

FT25CN405. Cave Monitoring in Central Texas: Insights into Paleoclimatology, Karst Vadose Zone Hydrogeology, and Cave Geomorphology

Sat., 18 Oct., 7:30 a.m.–6 p.m. US$40 for students and ECPs; US$60 for professionals. CEUs: 0.8.

We will visit two central Texas caves, Cave Without a Name and Natural Bridge Caverns, which have been studied as a part of the longest-running cave monitoring program in the world. Led by Professor Jay Banner and PhD student Alex Janelle, participants will be brought to both caves to discuss insights from cave monitoring and paleoclimate studies. Participants will be taken through the geologic history of Texas, from the significant events leading to development of the caves to modern processes occurring above the cave. Texas BBQ will be provided for lunch (dietary restrictions accommodated). Cost includes transportation (school vehicles), lunch, snack, and water.

FT25CN406. Cretaceous of the Trans-Pecos: Effects of Eustacy, Bottom-Water Chemistry, Karsting, and Tectonics on Carbonates and Mudrocks

Thurs.–Sat., 23–25 Oct., 7:30 a.m.–6 p.m. US$355. CEUs: 2.4.

This trip examines the spectacular outcrops exposed in the Trans-Pecos region. The trip focuses on the organic-rich marlstones and limestones of the Boquillas, and includes discussions on OAE2, bottom-water chemistry, fracture patterns and structure, and eustacy, which are compared to the equivalent subsurface Eagle Ford. The trip also examines karsting in the rudist-rich Devil's River Ls, thickness and stacking patterns of the Del Rio and Buda, and fractures and channels in the Austin Chalk. Hikes are short except for the tour of the Fate Bell Shelter in Seminole Canyon State Park. Cost includes transportation (mini vans), two nights at the Ramada Inn Del Rio (double occupancy), park entrance fees, lunch, snacks, and water.

FT25CN407. Energizing the Future: Innovative Energy Production and Environmental Stewardship in Texas

Sat., 18 Oct., 7:30 a.m.–6 p.m. US$25. CEUs: 0.8.

This field trip for 5th- to 12th-grade teachers and university students explores subsurface energy technology and innovation. Participants will visit San Antonio field sites to learn about energy resource engineering and geology and explore energy sector careers. Organized by UT Austin's Choose Energy K–12 Outreach Program and the Railroad Commission of Texas, the trip includes 8 CPE hours for teachers, lunch, and transportation.

FT25CN408. Exploring The K/Pg Boundary in the Gulf of Mexico at the Brazos River Outcrops and the Gulf Coast Core Repository

Sat., 18 Oct., 6 a.m.–7 p.m. US$80 for students and ECPs; US$100 for professionals. CEUs: 0.8.

We propose to explore K/Pg boundary deposits across the Gulf of Mexico, with stops at the outcrops along the Brazos River near Rosebud, Texas, and the IODP Gulf Coast Repository (GCR) in College Station, Texas. Brazos River outcrops contain cross-stratified sandstone likely formed by a tsunami, interbedded with layers of impact spherules and overlain by an ~3 m succession of early Paleocene marine sediments recording the recovery of life. Cores at the GCR from the Chicxulub crater, Gulf of Mexico, and Caribbean record impact processes and environmental changes at different distances from the crater. Cost includes transportation (bus), breakfast, lunch, snacks, and water.

FT25CN409. Exploration of the Balcones Escarpment: Its Hydrogeologic Evolution and Geoheritage Attributes

Sat., 18 Oct., 8 a.m.–5 p.m. US$145 for students and ECPs; $185 for professionals. CEUs: 0.8.

The Major Springs of the Balcones Escarpment compose a Texas geoheritage site known for its scientific, aesthetic, educational, and cultural value. Join us for a field trip along this geologic borderland focusing on karst hydrogeology, evolution of the landscape, and cultural history. The trip includes traverses across the Balcones Escarpment, visits to San Marcos, Comal, and San Pedro Springs, and views of the historic Mission San José, a National Historic Site. We will also visit Natural Bridge Caverns. Cost includes transportation (charter bus), lunch, snacks, water, and park fees.

FT25CN410. Guadalupe Mountains and Carlsbad Caverns National Parks: An Exploration of Capitan's Permian Fossil Reef

Thurs.–Sat., 16–18 Oct., 6:30 a.m. (first day)–4 p.m. (last day). US$550. CEUs: 2.4.

Join us on an exciting three-day adventure as we explore the remarkable limestone formations of the Permian Capitan Reef. We will begin at the Henry B. Gonzalez Convention

Center in San Antonio and make our way to Guadalupe Mountains National Park, with stunning views of Guadalupe Peak and El Capitan. Day 2 will start below ground, with a natural cave entrance tour of Carlsbad Caverns and the remarkable Big Room, before spending the afternoon exploring the Salt Basin Dunes. Day 3 we will return attendees to the convention center. Cost includes transportation (15-passenger van), two nights at the Sleep Inn Carlsbad, New Mexico (double occupancy), meals, snacks, and water.

FT25CN411. Investigating Confirmed and Suspected Impact Sites in Western and Central Texas

Thurs.–Fri., 23–24 Oct., 8 a.m. (first day)–5 p.m. (last day). US$260 for students and ECPs; US$300 for professionals. CEUs: 1.6.

This trip provides a great opportunity to bridge terrestrial and extraterrestrial geology through the lens of impact sites. We will visit two confirmed impact craters of drastically different size and style: the ~8-mi-diameter Sierra Madera structure near Fort Stockton and the Odessa crater and meteorite field in Ector County. We also will visit two proposed structures: Bee Bluff, south of Uvalde, and Hico, southwest of Fort Worth. We will discuss impact geology and terrestrial structures as planetary analogues. Cost includes transportation (full-size SUVs), one night in Fort Stockton (double occupancy), lunch, snacks, and water.

FT25CN412. Kilbourne Hole and the Potrillo Volcanic Field: A Planetary Analog Site

Fri.–Sat., 17–18 Oct., 8 a.m. (first day)–5 p.m. (last day). US$250 for students and ECPs; US$300 for professionals. CEUs: 1.6.

Location: El Paso, Texas, USA

Kilbourne Hole, a Quaternary maar volcano in the Potrillo volcanic field of south-central New Mexico, has been the subject of several past and ongoing planetary analog studies and has served as a training site for both the Apollo and Artemis lunar exploration programs. On this field trip, we will study the physical volcanology of Kilbourne Hole and its surroundings, its place in the regional context of the southern Rio Grande Rift, and the unique lunar and planetary science perspectives it offers. Cost includes transportation, one night at the Fairfield Inn & Suites El Paso (double occupancy), lunch, snacks, and water.

FT25CN413. Kirk Bryan Field Trip: Quaternary Landscape Evolution, Soils, and Geoarchaeology in the Medina River Valley, South-Central Texas

Sat., 18 Oct., 7:30 a.m.–1:30 p.m. US$0 for the first 10 students; US$45 for professionals. CEUs: 0.6.

The Kirk Bryan Field Trip will focus on Quaternary landscape evolution, soils, and geoarchaeology in the Medina River valley at the deeply stratified Richard Beene archaeological site on the south side of San Antonio. The sequence of cultural and alluvial deposits at the site is one of the most complete records of Holocene human occupation and sedimentation documented in North America and is very important to the interpretation of the cultural history of the Inner Gulf Coastal Plain and adjacent areas of the Southern Plains. This trip is partially funded by the Geoarchaeology Division and the Kansas Geological Survey. The cost includes transportation (bus), boat fees, lunch, snacks, and water.

FT25CN414. Kirk Bryan Field Trip & The Hydrology of the Edwards Aquifer and the Geoarchaeology of Spring Lake, South-Central Texas

Sat., 18 Oct., 7:30 a.m.–6 p.m. US$0 for the first 10 students and/or ECPs; US$85 for professionals. CEUs: 0.8.

This trip will include the Kirk Bryan Field Trip in the morning and conclude with the Geoarchaeology Field Trip in the afternoon. The San Marcos Springs in Hay County, Texas, are part of a significant landscape for geological, hydrological, and archaeological interests. The artesian springs are among the largest in Texas and provide an exceptional opportunity for GSA attendees to study aquifer dynamics, karst geomorphology, and human history. This field trip proposes to lead attendees on a glass bottom boat tour, hiking tour of the fault zones of the escarpment, and tour of the cultural materials recovered over the years at the archaeological site. This trip is partially funded by the GSA Geoarchaeology Division and the Kansas Geological Survey. The cost includes transportation (bus), boat fees, lunch, snacks, and water.

FT25CN415. Regional Perspective of the Eagle Ford and Austin Chalk Groups in and Around San Antonio.

Thurs.–Sat., 16–18 Oct., noon (first day)–5:30 p.m. (last day). US$375 for students; US$475 for professionals. CEUs: 2.0.

Survey outcrops of the Eagle Ford and Austin Groups in and around San Antonio, to show off their sequence stratigraphy and regional correlations into the subsurface. Cost includes transportation (bus), lunch, dinner on night one, snacks, water, one night at the Ramada Inn Del Rio (double occupancy), and one night in San Antonio (double occupancy).

FT25CN416. San Miguel Lignite Mine Tour

Sat., 18 Oct., 7:30 a.m.–6 p.m. US$99 for students and ECPs; US$140 for professionals. CEUs: 0.8.

The Association of Environmental & Engineering Geologists (AEG) Texas Chapter will run a tour of the San Miguel lignite mine in Christine, Texas. This South Texas mine is currently in operation under the North American Construction Group. The morning will cover talks about the history of the mine itself, the geology and site planning of the area, and the environmental permitting and reclamation process through the future. After lunch, we'll be taking a tour of the active mine site for an up-close look. PPE: safety glasses, hard hats, closed toe or steel toe boots, high visibility vest. Cost includes transportation (bus), lunch, snacks, and water.

FT25CN417. Sedimentologic, Biostratigraphic and Chemostratigraphic Insights into the Wilcox Group: Implications for Stratigraphic Correlations, Depositional Trends, Paleoclimate and CO_2 Storage

Fri.–Sat., 17–18 Oct., 8 a.m.–5 p.m. US$310 for students; US$350 for professionals. CEUs: 0.8.

Location: Austin, Texas, USA

The core workshop aims to instruct the attendees on the sedimentology and stratigraphy of the Wilcox Group, onshore Texas. Several key drill cores, associated wireline well-logs, and palynological and geochemical datasets are used to illustrate the dominant sedimentary processes and depositional system evolution, as well as provide insights into paleoclimate, paleogeography, and the potential for regional correlation. Petrophysics will provide estimates of the reservoir properties and assessment of the controls on reservoir quality and feasibility for CO_2 storage. The field course focuses on Paleocene-Eocene Thermal Maximum (PETM) deposits of the Wilcox Group near Bastrop, Texas. This is an extension of the core workshop and will allow participants to see laterally extensive outcrops that contain some of the facies they saw in core. The goal is to examine sedimentologic, ichnologic, biostratigraphic, isotopic, and geochemical trends within the PETM interval and overlying Carrizo Sandstone, discuss paleoenvironmental evolution, and propose regional correlations based on this new dataset. Outcrops will provide the opportunity to discuss stratal architectures and examine key surfaces that are not evident in drill core. Cost includes transportation for the field trip (bus), one-night stay in Austin, Texas (double occupancy), use of materials at the facility, lunches, snacks, and water.

FT25CN418. Subduction, Underplating, and Exhumation in a Hot Subduction Zone

Wed.–Sat., 15–18 Oct., 8:45 a.m. (first day)–8:45 a.m. (last day). US$399 for students and ECPs; US$480 for professionals. CEUs: 2.4.

Location: Santa Catalina Island, California, USA

The trip will explore the structure and petrology of the Catalina Schist terrane on Santa Catalina Island, California. The island exposes rocks of oceanic origin metamorphosed under various grades from lawsonite-blueschist to upper amphibolite/eclogite, in a series of tectonic slices, separated in part by ultramafic melange carrying high-grade blocks. The trip will consider the implications of the inverted metamorphic sequence and the significance of the tectonic contacts in terms of the thermal and mechanical evolution of the subduction complex during subduction, underplating, and exhumation. Cost includes transportation from the airport (shuttle) to the island (boat), bunk space at the Wrigley Center, and meals.

FT25CN419. The 10th Texas Hydro~Geo Workshop

Sat., 18 Oct., 6 a.m.–10 p.m. US$130. CEUs: 1.6.

The Texas Hydro~Geo Workshop is centered on the collection, processing, analysis, and evaluation of hydrologic, geologic, and biologic field data. The workshop serves as an excellent introduction for aspiring geology, hydrology, wildlife biology, and environmental science students, as well as seasoned professionals. The event is in its 10th year and has been popular with college-level STEM students. Approximately 40 separate modules will be presented, including field safety, map reading, GPS use, water samples, stream gauging, tracer testing, and more. Prepare yourselves for a unique evening of yodeling, hog calling, and a 7 p.m. night lecture inside a cave (125 steps in and out). Visit the workshop at www.hydrogeoworkshop.org. Cost includes transportation (bus), lunch, and meeting registration (includes dinner).

FT25CN420. The Edwards Aquifer of South-Central Texas: An Aquifer Under Stress

Thurs., 23 Oct., 8 a.m.–6 p.m. US$65 for students; $95 for professionals. CEUs: 0.8.

The Balcones Fault Zone segment of the Edwards Aquifer in south-central Texas is one of the most productive aquifers in the U.S. The San Antonio segment extends a distance of approximately 180 miles. The aquifer is the primary source of water for 2.1 million people and agriculture and industry in the region. The San Antonio area is one of the fastest growing areas in the U.S. The field trip will visit the Contributing, Recharge, and Artesian zones and discuss development, water quality, recharge and drought, and endangered species issues in this important karst aquifer. Cost includes transportation (bus), lunch, snacks, and water.

FT25CN421/FT25CN422. On To the Future (OTF): The Flow of Sustainability: Inside the San Antonio Water System

Offered Sat., 18 Oct., Time TBD, or Wed., 22 Oct, 1–5 p.m.. $30 for students; $75 for professionals. CEUs: 0.4.

Explore the innovative water management strategies of the San Antonio Water System (SAWS), a leader in conservation and sustainability. This field trip offers a behind-the-scenes look at SAWS facilities, including groundwater, desalination, and recycling operations. Learn about the region's unique hydrogeology, the Edwards Aquifer, and how SAWS balances urban demand with environmental stewardship. Ideal for those interested in water resources, infrastructure, and policy, this trip provides insight into cutting-edge solutions for sustainable water management. Cost includes transportation (bus), snacks, and water.

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FT25CN423. Volcanic Stratigraphy of the Paradise Mountain–Pine Peak Caldera Complex, Davis Mountains Volcanic Field, Texas

Thurs.–Sat., 16–18 Oct., 8 a.m.–5 p.m. US$399 for students; US$450 for professionals. CEUs: 2.4.

This field trip incorporates recent field mapping and petrologic analysis of the Paradise Mountain Caldera Complex. The first day will provide an overview of the Davis Mountains Volcanic Field, from Balmorhea to Alpine. The second day will focus on the Caldera Complex, with emphasis on the revelations from new mapping on Mounts Locke and Fowlkes at the McDonald Observatory. Most of the day will be spent examining outcrops of units exposed along the roads and on short hikes at McDonald Observatory. There will be three short stops before returning on the third and final day. Cost includes transportation (15-passenger van), lunch, snacks, water, and two nights at The Holland Hotel (double occupancy).

FT25CN424. Walking in the Footprints of Giants: Dinosaur Tracks and Trackways in Albian Series of the San Antonio Region

Fri.–Sat., 17–18 Oct., 8 a.m.–6:30 p.m. US$230 for students; US$290 for professionals. CEUs: 1.6.

Sponsored by: Paleontological Society
Dinosaurs are some of the best ambassadors for geoscience to the public, yet their iconic footprints in the rock record of Central Texas are at risk to disappear because of urbanization, climate change that augments weathering, and intense flooding events. This two-day field trip will include several famous sites of tracks and trackways in the stratigraphy of central Texas, at Canyon Lake Gorge, the Heritage Museum of the Texas Hill Country, the Mayan Dude Ranch, and the Davenport Ranch. Cost includes transportation (full-size SUVs), all meals and snacks, entrance fees, and one night at the Mayan Dude Ranch (double occupancy). The Paleontological Society will sponsor two students to attend this trip.

FT25CN425. Warren Hamilton Field Trip: The West Texas Nexus: Orogeny, Magmatism, K-Pg Boundary, Vertebrate Biostratigraphy, and Chihuahuan Desert Geohydrology

Tues.–Sat., 14–18 Oct., 2 p.m. (first day)–5:30 p.m. (last day). US$715. CEUs: 4.
Location: Midland, Texas, USA

Big Bend structures, strata, and waters record >500 Ma of Earth history. On this trip we'll visit Paleozoic strata of the Marathon Basin; the Marathon fold-thrust belt recording Pangea assembly; Early Cretaceous marine platform carbonates; Late Cretaceous megafauna (Alamosaurus and Quetzalcoatlus); the K-Pg boundary; Laramide contractional structures of the Terlingua Uplift and the Sierra del Carmen; some of the 48–18 Ma Trans-Pecos magmatic province, including calderas, lavas, ignimbrites, pluton-associated mercury mineralization, and the Solitario lacco-caldera; Rio Grande rift structures with exposed kinematic history; and the Rio Grande/Rio Bravo, plus springs from cross-border aquifers. Cost includes transportation (full-size SUVs), one night at the Riata Inn in Marfa (double occupancy), two nights at the Chisos Mining Co. Motel in Terlingua (double occupancy), one night at the Marathon Motel in Marathon (double occupancy), meals, snacks, and water. Students can apply for the Warren Hamilton Fund to defray the cost of the trip.

FT25CN426. Highlights of the Hill Country: A Trip Through the Llano Uplift

Thurs., 23 Oct., 7 a.m.–8 p.m. US$85 for students; US$110 for professionals. CEUs: 0.8.

This one-day field trip will explore highlights of central Texas and Hill Country geology in and around the Llano uplift. The Llano uplift contains complexly deformed Grenville-aged metavolcanic and metasedimentary rocks that are intruded by syn- and post-tectonic granites. This Mesoproterozoic rock is overlain by Cambrian and younger sedimentary rocks along the flanks of the uplift. We will explore the igneous and metamorphic rocks of Enchanted Rock, a spectacular example of an exfoliation dome, and an excellent location to explore the rocks formed by the continent-continent collision during and following the Grenville orogeny. We will visit an outcrop of the uniquely Texan rock llanite, as well as beautiful exposures of the Cambrian Hickory Sandstone, which nonconformably overlies crystalline basement. Outcrops on this trip range are all accessible either along the roadside or via a short hike. An optional longer hike at Enchanted Rock will be offered. Cost includes transportation, lunch, snacks and water. We will stop for dinner in town before heading back to San Antonio.

FT25CN427. Bracken Cave Bat Flight

Mon., 20 Oct., 5:30–9 p.m. US$65. CEUs: 0.35.

Bracken Bat Cave is located near Garden Ridge, Texas, about a 45-minute ride from downtown San Antonio. Bracken Cave is the summer home of more than 15 million Mexican free-tailed bats, making it the world's largest bat colony and one of the largest concentrations of mammals on Earth. The emergence of these millions of bats, as they spiral out of the cave at dusk for their nightly insect hut, is an unforgettable sight. During October, the bat flight is more limited but will last too long after dark. The cave is formed in the Edwards Limestone, also home to the Edwards Aquifer. This visit will include a short talk on the natural history of bats, their use of the cave, and threats to these important consumers of insects. This field trip will not enter the cave. Cost includes transportation, snacks, water, and program fee.

Short Courses at GSA Connects

SC25CN501. GeoGPT: The One-stop AI Research Platform for Geoscientists

Sat., 18 Oct., 8 a.m.–noon. US$20 for students; US$32 for ECPs; US$46 for senior members; US$75 for professionals. CEUs: 0.4.

Industry Tracks: ● Economic Geology, ● Energy

Discover how AI is transforming geoscience research with GeoGPT, a free, open-source AI assistant built on large language models (LLMs) and trained specifically on geoscience literature. GeoGPT offers flexibility in choosing foundational LLMs and features high-precision, real-time document parsing using retrieval-augmented generation (RAG) technology. Participants will explore GeoGPT's public geoscience library and learn how to integrate their own data for customized research. Continuously evolving through collaboration with geoscientists, GeoGPT helps tackle real-world scientific challenges. This hands-on workshop offers a practical introduction to GeoGPT's powerful tools, including paleontology classification, document reading and extraction, geological map recognition and generation, idea development, 3-D Earth modeling, and automatic knowledge graph construction. The course is structured around three segments: an introduction to GeoGPT; application examples such as the evolution of life and the spatial-temporal distribution of igneous rocks; and GeoGPT-based solutions like petroleum geology knowledge systems and fossil taxonomy agents. Each segment includes time for discussion, with optional breakout sessions for participants to explore their own projects or research questions. Attendees are encouraged to bring their own data and ideas—just a laptop is needed. Come ready to learn, collaborate, and imagine the future of AI-enhanced geoscience.

SC25CN502. Aquifer Storage and Recovery Short Course and Field Trip

Sat., 18 Oct., 8 a.m.–5 p.m. US$255. CEUs: 0.8.

Industry Tracks: ● Engineering Geology, ● Hydrogeology, ● Environmental Geology

Join two of the most experienced practitioners in the field—R. David G. Pyne, PE, and Grant L. Snyder, PG—for an in-depth, practical workshop on Managed Aquifer Recharge (MAR) using wells. Designed for professionals at all levels, this session explores the technical, scientific, and engineering aspects of ASR systems, with a focus on real-world applications. David Pyne, author of ***A Guide to Groundwater Recharge through Wells***, brings over 45 years of experience and a legacy of presenting at ISMAR, BSMAR, and ASCE events. Grant Snyder, a seasoned hydrogeologist with 35+ years of field expertise in Texas, brings firsthand knowledge of ASR systems like SAWS and NBU. Through a mix of presentations and interactive discussion, you'll learn how to evaluate ASR feasibility, design recharge systems, and assess operational performance across various water sources and aquifer types. Economic and regulatory considerations will also be addressed, with illustrative case studies—particularly from the Edwards Aquifer. An optional field trip to the San Antonio Water System H2Oaks Center will provide a hands-on look at one of the region's key ASR facilities. Whether you're new to MAR or refining your expertise, this workshop delivers essential insight and tools for developing successful, sustainable ASR projects.

SC25CN503. Building a Culture of Access for Geoscientists with Disabilities in the Workforce (Hybrid)

Sat., 18 Oct., 8 a.m.–5 p.m. US$0. CEUs: 0.8.

Learn and collaborate with disabled geoscientists as we explore challenges and opportunities facing us in the workplace, hear from experts on the topic, and brainstorm ideas to improve accessibility and inclusion. Thoughtful pacing and multiple participation modes will provide an accessible workshop format, followed by an optional working group session for networking and proposal development. A limited number of travel grants are available for in-person attendees. To ensure enough seats for disabled participants, an application form is required: **https://forms.gle/tR3CZQBTkG8AQGzt8**

SC25CN504. Collecting Data with StraboField Mobile App and StraboMicro Application

Sat., 18 Oct., 8 a.m.–5 p.m. US$20. CEUs: 0.8.

Industry Tracks: ● Economic Geology, ● Engineering Geology, ● Environmental Geology

The StraboSpot database and applications enable geologic data collection, storage, and sharing across scales and disciplines. StraboField and StraboMicro are designed to help geologists collect data and integrate field data with laboratory (thin-section scale) observations and associated data. Both are designed to allow users to integrate images seamlessly into the database and attribute data flexibly. The data system was developed through community outreach workshops to establish vocabulary and data reporting needs and standards. The short course aims to introduce new users to StraboField and the StraboMicro application and help participants design and build projects for both research and teaching. The systems can be viewed at http://strabospot.org. This course is supported and sponsored by funds from StraboSpot.

SC25CN505. DEEP: An Open Research Platform for Global Geoscience Collaboration.

Sat., 18 Oct., 8 a.m.–noon. US$20 for students; US$32 for ECPs; US$46 for senior members; US$75 for professionals. CEUs: 0.4.

Tour a wealth of global datasets with Earth Explorer; journey into the World Geological Map with links to regional stratigraphic columns and the extensive OneStratigraphy compilation; crunch or plot your own data with a vast menu of geo-oriented tools and AI applications; or create customized views of Earth's history with the TimeScale Creator—these and many other adventures await you at the DEEP Platform.

The DEEP Platform is a free, one-stop online research and geo-teaching environment developed under the Deep-time Digital Earth (DDE) program. This hands-on short course will explore how cutting-edge information technologies can advance data-driven geoscience exploration and geo-instruction and foster international research. We encourage you to bring your own personal datasets or project concepts to investigate using the platform. All you need is a laptop, curiosity, and imagination.

SC25CN506. Digital Outcrop Construction and Analysis for Quantitative Structural Geology

Sat., 18 Oct., 8 a.m.–5 p.m. US$88 for students; US$123 for ECPs; US$175 for professionals. CEUs: 0.8.

Industry Tracks: ● Economic Geology, ● Energy, ● Engineering Geology, ● Hydrogeology, ● Environmental Geology

Digital (or virtual) outcrops are high-resolution, three-dimensional models of geological features created using close-range remote sensing methods such as laser scanning and digital photogrammetry. These models are increasingly used to enhance traditional fieldwork by offering detailed visualizations and powerful analytical tools. However, many early career researchers and those unfamiliar with 3-D modeling may lack experience with the data acquisition and processing protocols required to generate accurate, high-fidelity reconstructions. Small errors in these early stages can significantly impact the precision and reliability of geological interpretations. This hands-on workshop provides a practical introduction to the full digital outcrop workflow, from field data collection to final analysis, emphasizing techniques that minimize error and improve interpretive quality. Participants will explore how choices made during acquisition, processing, visualization, and data extraction directly influence geological outcomes and decision-making. The session will cover essential topics including an overview of digital outcrop technologies, protocols for data acquisition and processing, and techniques for visualization, analysis, and interpretation. Through guided tutorials, interactive discussions, and optional exploration of participant datasets or case studies, attendees will gain a strong foundation in the effective use of digital outcrops for geoscience research and education. No prior experience is required, and the session is designed to be accessible and engaging for all levels. All that's needed is a laptop and a curiosity about how 3-D technology is reshaping geoscience. Participants will leave with practical skills and a clearer understanding of how to critically evaluate and apply digital outcrop models in their own work.

SC25CN507. Empowering Your Outreach with Earth Science Week and Related Resources

Sat., 18 Oct., 1–5 p.m. $US115. CEUs: 0.4.

Industry Track: ● Energy

Designed for professionals passionate about geoscience outreach and education, this interactive short course will include hands-on activities and engaging resources for use in classrooms at all levels and informal learning settings. Participants will receive a 2025 Earth Science Week Toolkit focusing on the theme "Energy Resources for Our Future," and a range of online resources. The goal of this session is to equip attendees with strategies and materials to engage K–12 students and the public about many aspects of the geosciences, including energy resources and the role of geoscience careers in creating a sustainable future.

SC25CN508. Evaporitic Sequences of Texas and Their Relevance for Current Energy Decarbonization Efforts

Fri., 17 Oct., 8 a.m.–5 p.m. US$30. CEUs: 0.8.

Location: Off-site

Industry Tracks: ● Economic Geology, ● Energy

Evaporites play a vital role in petroleum systems, often functioning as regional seals and presenting potential drilling hazards. Their significance has expanded with the growing interest in halite-bearing evaporitic sequences for hydrogen storage in solution-mined salt caverns. Halite's high solubility and inert properties make it an ideal medium for hydrogen storage, but the inherent heterogeneity of evaporitic sequences—characterized by interbedded sulfates, carbonates, and siliciclastic rocks—presents challenges, including hazardous reactions with hydrogen that can affect purity and compromise cavern integrity. This one-day short course, hosted by the State of Texas Advanced Resource Recovery (STARR) program at the Bureau of Economic Geology (BEG), will start with presentations highlighting the technical work conducted by the STARR research group over the past two years, followed by a hands-on core workshop. We will have the opportunity to examine and discuss core samples from the Castile and Salado Formations of the Delaware Basin and Louann domal salt from the Gulf Coast. Participants will gain hands-on experience in analyzing core samples to understand their sedimentology, stratigraphy, depositional interpretations, and geomechanics. The course will integrate core data with seismic, geochemical, and petrophysical datasets, highlighting the role of evaporitic sequences in advancing energy decarbonization efforts, including hydrogen storage in salt caverns. This workshop is ideal for geoscientists and engineers exploring the new role of the subsurface as part of the ongoing energy transition/expansion.

SC25CN509. From Cosmos to the Earth: A Celebrated Astrophysics Research Discovery and Exploration Platform Expanded to the Earth and Planetary Sciences

Sat., 18 Oct., 1–5 p.m. US$145. CEUs: 0.4.

This hands-on short course introduces the Science Explorer platform (SciXplorer.org), a digital research discovery and exploration platform, now offering open access to interdisciplinary resources across the Earth and planetary sciences. The NASA-funded Science Explorer is brought to you by the renowned Astrophysics Data System (ADS) that has served the astronomy and astrophysics community for over 30 years. Science Explorer uniquely combines expert curation with resource enrichment and scientific subject matter expertise, ensuring authoritative coverage of academic literature, complete with metrics and links to external resources. Course participants will learn to navigate Science Explorer's powerful tools for literature, datasets, and software discovery, leveraging modern technology to bridge borders between disciplines, to streamline discovery, manage personal scientific libraries, and brainstorm collaborative research.

SC25CN510. Geology, Health, and Critical Minerals (Online)

Fri., 10 Oct., 1–5 p.m. US$25 for students; US$35 for ECPs; US$50 for professionals. CEUs: 0.4.

Industry Tracks: ● Economic Geology, ● Energy, ● Engineering Geology, ● Hydrogeology, ● Environmental Geology

Critical minerals play a vital role in our modern technology and economy; hence it is important to understand their geologic occurrence as well as the potential environmental and health impact of these resources. This short course will cover topics such as lithium, uranium, and rare earth element deposits and the surrounding environmental and health impacts.

SC25CN511. Introduction to Siliciclastic Depositional Environments

Fri–Sat., 17–18 Oct., 8 a.m.–5 p.m. US$175 for students; $235 for professionals. CEUs: 1.6.

Join us for a comprehensive two-day course on interpreting siliciclastic depositional environments from outcrops and cores. Designed for professionals and students alike, this course covers a range of key settings, including alluvial (meandering rivers and paleosols), coastal (wave-, fluvial-, and tide-dominated), estuarine incised valley fills, deepwater fans (channel fills, levees, lobes), and contourites. Through detailed exercises, participants will apply concepts to real-world datasets, including outcrop photo pans, well logs, high-resolution core images, and seismic data. Taught by a seasoned expert with over 30 years of experience in the petroleum industry, government, and academia—26 of which were at ExxonMobil—this course offers insights from the forefront of siliciclastic facies interpretation. Howard Feldman, course instructor, has authored numerous peer-reviewed publications and led significant research programs in both the private sector and at the Kansas Geological Survey. His expertise is captured in *The Handbook of Siliciclastic Facies* (SEPM), which complements the course content. Participants will receive a copy of this book to supplement their understanding of the topic. Don't miss this opportunity to enhance your skills in siliciclastic facies interpretation and gain insights directly from one of the field's leading experts.

SC25CN512. Landslide Mapping Using Lidar and Ortho Imagery in a GIS: Building Fundamental Mapping Skills for the Next Generation of Landslide Scientists

Sat., 18 Oct., 8 a.m.–5 p.m. US$25. CEUs: 0.8.

Sponsor: GSA Environmental and Engineering Geology Division

Industry Track: ● Engineering Geology

This short course will focus on the foundational elements necessary to build a landslide inventory from lidar and ortho imagery. Landslide inventories are a common tool used by planners, land managers, insurance companies, transportation departments, emergency managers, regulators, homeowners, geologic surveys, and others. The use of inventory maps by a variety of stakeholders makes detailed digitization of landslides an essential skill for a geoscientist. This short course aims to showcase the techniques and tools used to accurately and precisely map landslides using remote sensing tools in a GIS through demonstrations, discussion, and class exercises. We will also explore models used to build landslide hazard maps such as runout and susceptibility. ArcGIS skills and a laptop with an ArcGIS license are required, as is a fundamental understanding of landslides.

SC25CN513. Lithofacies and Reservoir-Quality Analysis of Upper Jurassic Smackover Strata in Northeast Texas; Basic Data for Lithium Exploration

Fri., 17 Oct., 10 a.m.–6 p.m. US$110. CEUs: 0.4.

Location: Off-site

Industry Track: ● Economic Geology

Join us for a unique offsite short course exploring the Smackover Formation in northeast Texas, a promising target for lithium exploration. This course will delve into the Upper Jurassic Smackover's reservoir characteristics, which are crucial for evaluating the economic potential of lithium-rich brines. The Smackover's production potential, much like that seen in Arkansas, depends on the reservoir quality influenced by lithofacies and dolomitization processes. The most promising reservoirs are found in Upper Smackover dolograinstones, with a lithofacies sequence that transitions from anoxic laminated microbial mats to peloidal mudstones, wackestones, oncolitic peloidal packstones, and is capped by ooid grainstones. Led by Dr. Robert Loucks, a research professor at the Bureau of Economic Geology, University of Texas, this course provides invaluable insights into carbonate lithofacies, diagenesis, and reservoir quality. With over 50 years of experience in geosciences and extensive research on the Smackover Formation, Dr. Loucks will guide participants through the key geological processes shaping lithium brine reservoirs. The course will take place offsite, with a bus departing the convention center at 10 a.m. to the facility. Lunch will be provided. This is an excellent opportunity for geoscientists and industry professionals to gain hands-on experience and deepen their understanding of this important geological formation.

SC25CN514. Mastering Quantitative Analysis Using XRF, XRD, and X-ray CT

Sat., 18 Oct., 1–5 p.m. US$25. CEUs: 0.4.

Industry Tracks: ● Economic Geology, ● Energy, ● Engineering Geology, ● Hydrogeology, and ● Environmental Geology

In this practical course, you will learn how to quantify various mineral properties using X-ray fluorescence (XRF), X-ray diffraction (XRD), and X-ray computed tomography (CT). With proper sample preparation and calibration, XRF can analyze elements with 0.01% accuracy. With the Direct Derivation (DD) method, XRD can quantify both crystalline and amorphous phases even without structural information. CT complements these techniques by revealing phase and pore distribution or estimating permeability in core samples. Learn practical tips to avoid common sources of errors and elevate your mineral analysis with the latest techniques and software.

SC25CN515. Methods and Geological Applications in Geo-Thermo-Petro-Chronology I

Fri., 17 Oct., 8 a.m.–5 p.m. US$30. CEUs: 0.8.

Industry Tracks: ● Economic Geology, ● Energy

Part I of this course will focus on chemical systems and geologic questions commonly interrogated by laser ablation inductively coupled plasma–mass spectrometry analysis of minerals including U-Th-Pb, Lu-Hf, and trace elements. The emphasis will be on detrital geochronology and petrochronology of zircon, but will include discussions of additional mineral phases (e.g., apatite, titanite, monazite). Part I will be divided into various modules, each consisting of a first half that will be lecture-based and focus on theory, while the second half will be hands-on data interpretation using MATLAB-based software tools for data reduction, analysis, visualization, and archiving. This course is geared toward geoscience faculty, professional scientists, graduate students, and undergraduate students.

SC25CN516. Methods and Geological Applications in Geo-Thermo-Petro-Chronology II

Sat., 18 Oct., 8 a.m.–5 p.m. US$30. CEUs: 0.8.

Industry Tracks: ● Economic Geology, ● Energy

Part II of this short course will focus on methods and applications of diffusion-based thermochronology and petrochronology. Topics will include an introduction to diffusion, and thermo-petrochonologic applications of the (U-Th)/He, Ar/Ar, Sm-Nd, and U-Pb systems. Topics will incorporate a mix of theory, application, and hands-on activities. This course is geared toward any geoscientist wanting to learn about these topics, including faculty, professional scientists, graduate students, and undergraduate students.

SC25CN517. Modeling of Landscape Evolution and Basin Stratigraphy with goSPL (Hybrid)

Sat., 18 Oct., 1–5 p.m. US$43 for students; US$60 for ECPs; US$85 for professionals; US$25 online. CEUs: 0.4.

Sponsor: Quantitative Clastics Laboratory (QCL) at The University of Texas at Austin

Industry Tracks: ● Economic Geology, ● Hydrogeology, ● Environmental Geology

Global Scalable Paleo Landscape Evolution (goSPL) is an open-source Python-based code to simulate landscape and basin evolution at both global and regional scales. It is the first model designed to evaluate global-scale evolution of Earth's surface and its interaction with the atmosphere, the hydrosphere, the tectonic and mantle dynamics. It can be used to better characterize many aspects of the Earth system ranging from the role of atmospheric circulation on physical denudation, from the influence of erosion and deposition of sediments on mantle convection, to the location and abundance of natural resources to the evolution of life.

SC25CN518. On To the Future and GSA Associated Societies Expo: Finding Your Pathway to Geosciences Professions

Sat., 18 Oct., 9 a.m.–5 p.m. US$0. CEUs: 0.8.

Sponsor: National Science Foundation

A National Science Foundation–sponsored one-day professional development workshop for the 2025 cohort of GSA's On To the Future program, past OTF participants, and mentors recruited from GSA Associated Societies. The morning program engages OTF scholars in activities highlighting their unique attributes and strategies to build social capital. The afternoon session enables OTF scholars and GSA Associated Societies to broaden their social capital/professional networks through one-on-one conversations. Associated Societies share value propositions of membership-related to skills training, member networking, and employment information. OTF scholars bring value to Associated Societies by broadening memberships and perspectives, increasing the relevance of the global geosciences workforce for all. By invitation only to On To the Future participants and alumni; workshop fee for invitees will be offset by NSF grants #2333261/62.

SC25CN519. Outcrop3D: A 3D Digital Outcrop Platform for International Geoscience Education

Fri., 17 Oct., 1–5 p.m. US$20 for students; US$32 for ECPs; US$46 for senior members; US$75 for professionals. CEUs: 0.4.

This short course introduces Outcrop3D (outcrop3d.deep-time.org), a web-based platform that provides access to over 185 high-resolution 3-D geological outcrops from Asia, Europe, and Africa. Developed on the Cesium 3-D Earth engine, Outcrop3D supports global collaboration, data sharing, and virtual exploration, offering an innovative solution to expand field access—particularly for educators and researchers working in resource-limited settings. Participants will learn how to generate centimeter-accurate 3-D outcrop models using UAV-based photogrammetry and how to integrate these models into the Outcrop3D platform. The course will explore practical applications of digital outcrops in geological research, virtual field trips, and the preservation of geologic heritage. Topics covered include UAV photogrammetry workflows for creating detailed 3-D models, navigation and functionality of the Outcrop3D platform, and case studies that demonstrate its use in both educational and research settings. The course is structured around hands-on tutorials, live demonstrations, and interactive discussions, ensuring participants gain direct experience with the tools and workflows. Attendees will leave with practical skills and the confidence to incorporate 3-D outcrops into their own research and teaching practices.

SC25CN520. Overview of X-ray CT Data Acquisition, Visualization, and Quantitative Analysis for Geological Applications

Fri., 17 Oct., 8 a.m.–5 p.m. US$70 for students; US$98 for ECPs; US$140 for professionals. CEUs: 0.8.

X-ray computed tomography (XCT) is a non-destructive imaging technique that enables 3-D visualization and analysis of objects. While used by many scientists to view the interiors of geological samples or fossils non-destructively, the true power of XCT data lies in the wealth of quantitative 3-D data analyses that it enables, from basic 3-D petrology (such as full volume modal analysis) to the 3-D orientation and strength of microstructural fabrics. The University of Texas High-Resolution X-ray CT Facility (UTCT) will host a one-day version of their short course on the acquisition, visualization, and analysis of XCT data of geological samples. This course presents a short overview of the acquisition and interpretation of XCT data, followed by hands-on training in basic visualization and advanced quantitative analysis of discrete geological features (e.g., clasts, mineral grains, fractures, pores) and fabrics, using FIJI, Blob3D, and Quant3D (the latter two programs developed at UTCT). Note that XCT applications specific to paleontological or biological specimens (such as morphometric analyses) will not be covered in the course. Participants are required to bring their own laptops (Windows and Mac operating systems supported) and all software and tutorial data will be provided for download and testing prior to the course.

SC25CN521. Plate Tectonics for Science and Teaching Using GPlates Paleo-GIS Software

Sat., 18 Oct., 8 a.m.–5 p.m. US$63 for students; US$88 for ECPs; US$125 for professionals. CEUs: 0.8.

Industry Tracks: ● Economic Geology, ● Energy

Plate tectonic reconstructions allow 4-D visualization and analysis of plate tectonic theory, one of the great geoscience achievements. In this interactive course, you will learn how to visualize and analyze Earth's plate tectonic history for both science and teaching using free GPlates software. The course begins with hands-on learning applied to various plate tectonic case studies such as North America, India-Asia collision, and an industry case. Creating high-quality graphics, movies, and output data is emphasized. Participants then work on a mini-project of interest with guidance from the instructor. Opportunities are provided to share your research or teaching case with the class to inspire new ideas. The course is designed for both beginners, and for intermediate GPlates users seeking to broaden their skills. To increase access, some course materials will be available in both English and Spanish. A PC or Mac is required and participants should download and install the free GPlates software before the course begins.

SC25CN522. Quantitative Analysis, Visualization, and Modelling of Detrital Geochronology Data

Sat., 18 Oct., 8 a.m.–5 p.m. US$50 for students; US$95 for professionals. CEUs: 0.8.

Alongside the growth in detrital geochronology datasets is a developing body of best practices, techniques, and tools for analyzing these data. This course will introduce participants to the technical background necessary to understand and apply recently developed sample comparison and data analysis techniques, including quantitative intersample comparison, data visualization, and mixture modelling. Following a theoretical and hands-on introduction, we will apply existing tools for the expedited analysis of large datasets. This introduction will familiarize users with working in Python and Matlab, but no coding experience is necessary to participate. Participants are encouraged to bring their own datasets, if available.

SC25CN523. Sedimentology and Stratigraphy of Deltas: Old and New Concepts

Sat., 18 Oct., 8 a.m.–5 p.m. US$88 for students; US$123 for ECPs; US$175 for professionals. CEUs: 0.8.

Industry Track: ● Economic Geology

This short course is a series of lectures and exercises on sedimentology and stratigraphy of deltas and recent changes on the Delta Concept. The course will help beginner students gain confidence in recognizing delta deposits, and will offer experienced geologists a discussion on new debates/topics on deltas. The lectures will focus on modern/Holocene deltas and processes, including subaqueous deltas. Sedimentary structures and bed succession criteria will be emphasized for recognition of types of ancient deltas. From modern deltas and sedimentary structures the students will be taught to delve into interpreting outcrop and subsurface datasets of delta deposits, including compound deltas.

SC25CN524. Sustainable Productivity in Academia: Practical Strategies for Efficiency and Balance

Fri.–Sat., 17–18 Oct., 8 a.m.–5 p.m. US$88 for students; US$123 ECPs; US$175 for professionals. CEUs: 1.6.

Industry Tracks: ● Economic Geology, ● Energy, ● Engineering Geology, ● Hydrogeology, ● Environmental Geology

This workshop is devoted to providing the knowledge and tools to encourage sustainable productivity while promoting personal balance. Academia presents unique challenges—balancing research, teaching, grant writing, mentorship, and administrative responsibilities—all while maintaining high scholarly output. Without structured approaches to work management, these competing demands can lead to inefficiency, stress, and burnout. Traditional productivity frameworks often fail to address the specific needs of academics, leaving many to struggle with prioritization, long-term planning, and maintaining motivation. This workshop provides evidence-based, academia-specific strategies to help early and mid-career scholars improve task management, align projects with long-term goals, and optimize their workflows. We will introduce practical tools, including a task management system, time-blocking strategies, risk mitigation plans, and communication frameworks, all designed for real-world academic application. Through hands-on exercises, case studies, and structured discussions, participants will build personalized systems tailored to their specific needs. By the end of the workshop, attendees will leave with a fully developed three-month plan, ensuring they have actionable strategies and concrete systems they can immediately implement. Our focus is not just on increasing efficiency but also on creating sustainable habits that enhance well-being and prevent burnout, setting participants up for long-term success in academia.

SC25CN525. Talking Science: A Communication Course

Sat., 18 Oct., 8 a.m.–5 p.m. US$20 for students; US$40 for professionals. CEUs: 8.

Industry Tracks: ● Energy, ● Engineering Geology, ● Hydrogeology, ● Environmental Geology

Nothing we do in the field or lab matters if we cannot effectively communicate our work to others. Whether it is writing papers, teaching classes, speaking with policymakers, or even just chatting with family at holidays, communicating is a vital skill as a scientist. In this interactive workshop that draws from both science of communication studies and techniques from improvisational theater, participants will practice distilling their work into fun, digestible conversations about geoscience.

SC25CN526. Transforming Undergraduate Geoscience Teaching: Implementing Recommendations from a National Academies Report

Sat., 18 Oct., 1–5 p.m. US$63 for students; US$88 for ECPs; US$95 for professionals. CEUs: 0.4.

In this short course, we will explore the 2025 report from the National Academies titled *Transforming Undergraduate STEM Teaching*. Central to the report are seven core principles that underlie effective teaching, along with recommendations for how to implement them. Our focus will be on applying these principles specifically to undergraduate STEM education in the geosciences. Through interactive discussion and practical exercises, participants will engage with the evidence behind the principles and explore how they can be translated into effective teaching strategies. By the end of the workshop, participants will be familiar with the core principles and the research supporting them, be able to describe specific teaching strategies aligned with each principle, and begin developing an action plan to implement these strategies in their geoscience courses or departmental policies and practices.

SC25CN527. Unleashing MODFLOW's Full Potential Using Modern and Repeatable FloPy Workflows

Fri., 17 Oct., 8 a.m.–5 p.m. US$123 for students; US$172 for ECPs; $245 for professionals. CEUs: 0.8.

Industry Tracks: ● Hydrogeology, ● Environmental Geology

MODFLOW 6 is the current version of the popular MODFLOW groundwater modeling program, developed and supported by the USGS. FloPy is the accompanying Python programming interface for interacting with MODFLOW. This course introduces the capabilities of MODFLOW 6 and demonstrates these capabilities using Jupyter Notebooks, repeatable workflows, and the FloPy package to develop and post-process working groundwater models. The course will demonstrate fundamental concepts for working in this environment. The course will also introduce newer capabilities available in MODFLOW 6, including particle tracking, solute transport, heat transport, variable-density flow, and surface water processes.

SC25CN528. Using Basic Sandstone Petrology Concepts and Petrography Data to Understand the Resource and Storage Potential of Porous and Permeable Formations

Sat., 18 Oct., 8 a.m.–5 p.m. US$63 for students; US$88 for ECPs; US$125 for professionals. CEUs: 0.8.

This course aims to raise awareness that sedimentary petrology and petrography have value in interpreting, assessing, and predicting the resource and storage potential of porous and permeable sandstones. For decades, sandstone petrology concepts, analyses, and data have been used to address questions regarding reservoir provenance, storage, and transmissibility, providing perspective other data (e.g., seismic, well log, core analysis) only indirectly provide, but recently the approach has become underutilized. Furthermore, there is a concerning deficit in the number of young geoscientists trained in and capable of characterizing sandstones at the scale of grains and pores. This course targets these issues. Basic sandstone petrology concepts of provenance, transport, deposition, compaction, and diagenesis will be presented in the context of how they control or influence lithology and reservoir properties. An emphasis on petrographic analysis of mineralogy, texture, paragenesis, and pore systems provides perspective on how rock framework and pore systems control rock properties and complement interpretation and calibration of core analyses, petrophysical logs, and seismic data. Techniques to identify and quantify characteristics will be introduced and practiced. Examples combining techniques and datasets enforce benefits of integrated interpretation. Appropriate for advanced students with a working knowledge of sedimentary geology. Petrography skills not required.

SC25CN529. Value of Applied Geophysics: Theory and Value of Applied Geophysics for Exploration and Production; Subsurface Characterization for CCS, Fault Identification and Mapping for Injection Well Permitting, and General Research

Sat., 18 Oct., 8 a.m.–5 p.m. US$245. CEUs: 0.8.

Industry Track: ● Economic Geology

This course offers a fundamental understanding of geophysical data, particularly seismic reflection data, focusing on its theory, evolution, and value in exploration and production. Geophysical data, especially seismic, play a crucial role in geology by providing foundational data based on a well-understood theoretical framework. This course is ideal for professionals who encounter large amounts of seismic data but lack a geophysical interpreter, including managers making investment decisions, engineers needing to understand geophysical interpretations, and geologists seeking a stronger foundation in geophysics. Participants will gain insights into the acquisition, processing, and interpretation of geophysical data, with a focus on its impact on exploration and resource production, including oil, gas, water, minerals, geothermal energy, and CCUS. The course covers the evolution of geophysical technology, from early gravity and seismic experiments to modern data applications. Additionally, the concept of the Value of Information is introduced, helping participants assess the value of geophysical investments. This course provides a comprehensive overview of geophysics for those involved in decision-making or interpretation based on geophysical data.

SC25CN530. Visualizing Data: Unleash the Power of Interactive Data Dashboards (Online)

Fri., 10 Oct., 8 a.m.–5 p.m. US$40. CEUs: 0.8.

Unlock the power of data visualization tools like Tableau, PowerBI, and Spotfire in this course, which bridges the gap between spreadsheets and coding. You will learn how to create interactive visualizations that reveal data relationships, trends, and insights, enhancing hypothesis testing, educational exploration, and research sharing. By the end of the course, you will be able to design interactive visualizations using diverse datasets, formulate scientific questions, generate hypotheses, and craft and publish compelling science stories online. The course combines both training and hands-on practice, making it ideal for earth science students, teachers, professors, researchers, or anyone eager to explore data visualization tools.

SC25CN531. Introduction to Field Safety Leadership

Sat., 18 Oct., 8 a.m.–5 p.m. US$25 for students; US$45 for professionals; CEUs: 0.8.

Sponsor: KMBohacs GEOconsulting LLC

Industry Tracks: ● Economic Geology, ● Energy, ● Engineering Geology, ● Hydrogeology, ● Environmental Geology

Participants will acquire and practice strategies and tactics to prepare for and lead safe and effective field activities through a holistic approach to physical, mental, and emotional health. This fully interactive course covers injuries and illnesses that occur commonly during field activities, why accidents occur (human factors analysis), and the field safety process in normal operations and emergency response through scenario analysis, problem solving, and role play. Participants will practice using field safety training materials and modules designed for use with students in the field. Participants will learn how to begin the process of customizing these field safety strategies into comprehensive protocols for their own courses, departments/organizations, and campuses. Other topics discussed will include wilderness mental health first aid, briefings, transportation, hiking, risk assessment, intervening for safety, safety equipment use, emergency response drills, group leader and institution liability, and program funding and cost sharing. Participants will receive electronic copies of the training materials and modules as well as key forms for use in the field. Some of the topics will be introduced through pre-course reading and videos. Although not required, having CPR/AED and first aid (basic or wilderness) experience and certifications will greatly enhance the course experience. (This course is not intended to compete with any commercially available first-aid training and participants will not receive any level of official first-aid certification.)

SC25CN532. Advanced Geochemical Modeling for Critical Mineral Resourcing and Processing (Online)

Sat., 18 Oct., 8 a.m.–noon. US$0. CEUs: 0.8.

Geochemical modeling is a powerful tool, which has wide applications such as critical mineral resourcing and processing, CO_2 storage in saline aquifers and basalts, carbonate and clastic diagenesis, and hydrogen fuel storage in aquifers. Recently, new thermodynamic databases with the addition of critical minerals and REEs, code enhancements, and utilities associated with computer programs have expanded the applicability ranges of these modeling tools. This short course will introduce these new tools and use examples to demonstrate these expanded geochemical modeling capabilities with examples. At the end of the short course, students will be able to: (1) become familiar with the concepts, tools, and range of geochemical modeling applications; and (2) use geochemical modeling as a tool to interpret natural and engineered systems

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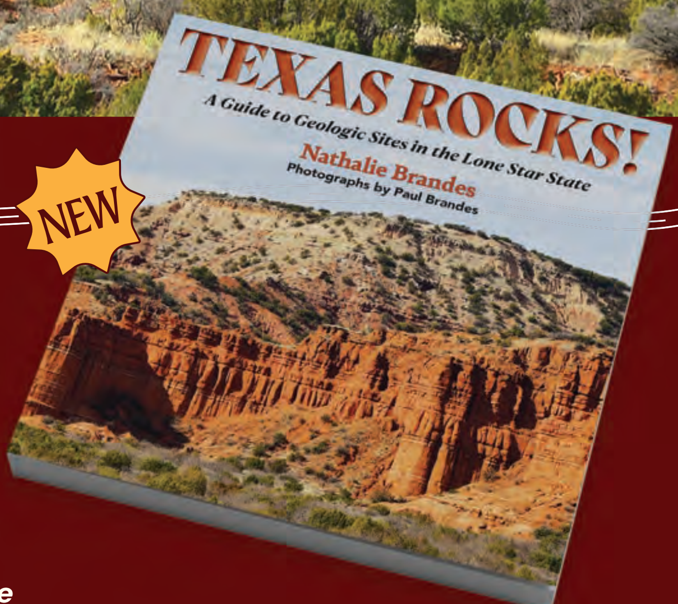

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Nathalie Brandes · Photographs by Paul Brandes

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Group photo in the Viñales Valley, Pinar del Río. In the background: the Hoyos de San Antonio Valley and Mogote La Mina, a classic example of tower karst morphology.

POST-CONFERENCE REPORT

The Geology of Cuba: Key for the Tectonic Evolution of the Caribbean–North American Plates

12–18 April 2025 | Western and Central Cuba

Field Trip Organizers and Leaders

Yamirka Rojas-Agramonte, Heidelberg University, Germany
Antonio Garcia-Casco, University of Granada, Spain
Manuel Antonio Iturralde-Vinent, Empresa de Tecnologías de la Información y Servicios Telemáticos Avanzados (CITMATEL), Cuba
Kenya Núñez-Cambra, Insituto de Geología y Paleontología, Cuba, and President of the Cuban Geological Society
Haoyu Hu, Heidelberg University, Germany

https://www.ugr.es/~agcasco/TFF2025Cuba/

Group photo in the Pinar del Río region. In the background, the Jurassic siliciclastic San Cayetano Formation.

Participants

Rafael Tenreyro-Perez (Cuba), Marcos Enrique Pazo Arango (Cuba), René Yasmany Cobas Torres (Cuba), Robert Ramirez Hernandez (Cuba), Elmidio Estévez Cruz (Cuba), Robert Willians Fuentes Rodriguez (Cuba), Yania Pedraza (Cuba), Mandy Zieger-Hofmann (Germany), Esther Rojo Perez (Germany/Spain), Sonia Sánchez Martínez (Spain), Núria Pujol-Solà (Spain), Idael F. Blanco-Quintero (Spain/Cuba), Eric Calais (France), Samuel Angiboust (France), Sylvie Leroy (France), Frederique Rolandone (France), María Isabel Sandoval (Costa Rica), Pieter Vermeesch (UK), Camilo Bustamante (Colombia), Fabricio Caxito (Brazil), Cristopher M. Bailey (U.S.), Mark Gabriel Little (U.S.), Barbara Reyes (U.S.), Katherine F. Fornash (U.S.), Stephanie Ann Sparks (U.S.), Amanda Lee Bednarick (U.S.), David Antonio Giovannetti-Nazario (U.S.), Ángel A. García Jr. (U.S.), Peter Odds (U.S.), Paul Q. Warren (U.S.). In addition, we had participants from Pinar del Rio University: Maria Elisabet Garcia Crespo, Dayrelis Diaz Cruz, Serati Ntee, Paballo Irine Lebesa; and Empresa Geominera del Centro: Carmen Gloria Galvez, Liván Roque Rodriguez, Yasniel Hernandez Primero, Daniel David Fernandez Amador. GSA staff Kaleigh Fremgen, Elizabeth Long, and Kimberly Ann Von Feldt provided assistance on site to the field forum.

https://www.ugr.es/~agcasco/TFF2025Cuba/participants.htm

Field Trip

The 2025 GSA Thompson Field Forum was held in Cuba from 12 to 18 April, bringing together a diverse group of 40 participants from 10 countries to explore the complex geology of the Cuban orogenic belt as part of the northeastern branch of the Caribbean belt. Participants included senior researchers, early career scientists, PhD candidates, and university students, all engaging directly with the rocks to discuss new results and discoveries in the field. We were particularly proud to host 17 Cuban early career researchers and university students, which created a nice atmosphere for scientific and cultural exchange. The Field Forum was funded by The Geological Society of America and organized in collaboration with the Cuban Geological Society.

The forum began in Havana and then continued west to the Viñales region of Pinar del Río, a UNESCO World Heritage Site renowned for its striking karst landscapes and well-exposed Jurassic–Cretaceous passive margin and Paleogene foredeep sequences. During the first two days, participants explored key sedimentary successions of the Guaniguanico terrane, including the San Cayetano, Jagua, Guasasa, and Pons Formations. Highlights included visits to stratigraphic sections across the Jurassic–Cretaceous (J–K) and Cretaceous–Paleogene (K–Pg) boundaries, as well as exposures of the Manacas Formation, representing Paleogene synorogenic deposits.

In addition to geological investigations, the group enjoyed a brief cultural program featuring the town of Viñales, a stop at the Viñales Geopark Visitor Center, and a visit to the Prehistoric Mural at Dos Hermanas.

On Day 3, the group moved east to Santa Clara, central Cuba, beginning a full traverse across the Cuban orogenic belt. Field stops focused on the structural, magmatic, and metamorphic evolution of the orogenic system. Participants visited:

- Ophiolite mélanges along the Santa Clara–Placetas road, where high-pressure serpentinized peridotites and eclogites reflect subduction-zone processes;

Mabujina amphibolite along the Agabama River, central Cuba.

- Cretaceous volcanic arc sequences, such as the Hilario, Brujas, Mataguá, and Los Pasos Formations;

- The Mabujina Amphibolite Complex, a metamorphosed arc complex, and associated plutonic rocks of the Manicaragua batholith; and The Escambray Complex, a deeply subducted portion of a passive margin complex (Caribeana Terrane), featuring graphitic schists, muscovite+calcite±graphite schists, and Jurassic metacarbonates.

During this second part of the trip in central Cuba, participants spent three nights in Santa Clara and one night in Trinidad, another UNESCO World Heritage Site, known for its colonial architecture and cultural history. On the way to Trinidad, the group visited the Valle de los Ingenios and Manaca Iznaga, adding a cultural dimension to the scientific journey.

Each day in the field was followed by evening discussions to synthesize observations and refine tectonic interpretations. These sessions inspired meaningful scientific dialogue and laid the groundwork for future collaborations.

The forum emphasized key questions in the regional geodynamic framework:

Group photo in the Escambray Complex (Guamuaya Mountains), south-central Cuba.

Eclogite block within the central Cuba serpentinitic mélange.

- How does the geology of Cuba record the complex interactions between the Caribbean and North American plates?
- What is the significance of the obducted ophiolites and HP metamorphic complexes in plate reconstruction models?
- How did the Caribbean arc system evolve from early Cretaceous to Paleogene?

The Field Forum succeeded in its mission to bring together experts from diverse backgrounds to engage directly with the rocks in the field and with each other. It fostered new scientific collaborations and professional connections, and several collaborative projects are already in development. This forum exemplified the spirit of the Thompson Field Forums: immersive, collaborative, and field-driven, providing participants with an unforgettable scientific and cultural experience. The success of this forum also highlighted the value of building scientific bridges and accessing regions rarely visited by the international geoscience community.

Field trip photos by cameraman Eduardo Reyes Aranzaez.

Acknowledgments

We gratefully acknowledge The Geological Society of America and The Geological Society of America Foundation (GSAF) for their financial support of this Thompson Field Forum, as well as the contribution of an anonymous sponsor. Special thanks go to Anaysa Rojas Agramonte and Ismari Hernández Mazo for coordinating participant logistics in Havana, including airport transfers and accommodations. We also thank Carielys Clermont Sánchez, our enthusiastic tour guide from Sprachcaffe, and Yunior Labrada Pompa, our skilled driver from Transtur, for their support throughout the journey. We are grateful to Eduardo Reyes Aranzaez, our Cuban cameraman, for capturing the spirit and highlights of the forum with dedication and professionalism. We also acknowledge Dayima León Sanchidrián and Juan Camilo Cruz from Sprachcaffe for their crucial support in organizing the field forum in Cuba. We thank Mario Alberto Sánchez Carrillo, Director of the Viñales National Park Geopark, for his warm welcome and informative introduction to the park. We are also grateful to Juan Alejandro Gallardo García, our field guide assistant in Pinar del Río.

Group photo in the central Cuba serpentinite mélange. The group rests on top of the Pelo Malo megablock of HP foliated (±dolomite) antigoritite embedded in highly brecciated serpentinites.

Hells Canyon's Ancient Terraces

GEOLOGY THROUGH THE LENS

This view south up the Snake River in Hells Canyon showcases terraces deposited by the Late Pleistocene Bonneville Flood when floodwaters reached a hydraulic dam at this canyon constriction. Suicide Point and the Suicide Point pluton mark the southern extent of the Cougar Creek complex, a mylonized zone of basement rock in the Wallowa Terrane's Seven Devils Group. (Vallier, et al, 2016). Camera data: 1/400 sec. f5.6, 24 mm Canon A640.

Credit: Ellen Morris Bishop is a geologist, photographer, and writer whose life's work has been making science more enjoyable and understandable to non-scientists. Learn more at www.ellenmorrisbishop.com.of a GSA/Chevron Field Trip Award, which enabled his participation in this field trip.

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

Bridging Science and Society:

A Vision for Public Policy at GSA

It's a true honor to step into the role of Director of Geoscience Policy & External Relations at the Geological Society of America. For more than 135 years, GSA has helped shape our understanding of Earth—and our relationship with it. That work continues today, more urgently than ever.

My own path to GSA wound through fossil-strewn terraces of Southern California, the halls of Congress, and multilateral discussions on climate adaptation. I've seen the power of evidence-based policy firsthand, and the consequences of when key voices and perspectives aren't in the room. In joining GSA's geoscience team, I see an opportunity to strengthen the vital bridge between geoscientists and decision-makers—and when I say vital, I mean it. Geoscience helps save lives and livelihoods, a responsibility I know we all take pride in.

GSA's Strategic Plan emphasizes linking geoscience to society, supporting early career scientists, and championing integrity across the profession. My goal is to build on that foundation by expanding the tools and opportunities available to our members to engage in public policy, making the value of our science more visible to the public, and elevating the role of geoscientists in some of the most consequential issues facing our profession.

As we look ahead, I see exciting new opportunities to push forward in key areas including mapping, mining, natural resources, climate, and geohazards. These are not just research frontiers—they are policy frontiers, and geoscientists have critical contributions to make.

I am especially elated to serve GSA's early career and student members—many of whom are exploring dynamic and unconventional career paths at the intersection of science and society. Having walked that path myself, I know how transformative it can be to have mentors, support, and access to policy arenas. That's why I'm particularly thrilled to serve as Director as we mark the upcoming 40th anniversary of the GSA–USGS Congressional Science Fellowship. Each year this fellowship places a geoscientist on Capitol Hill to contribute scientific insight to the legislative process and gain a firsthand understanding of policy. It's a program that embodies our mission—to inform, to connect, and to serve both science and society—and I can't wait to celebrate its continued impact.

Of course, advocacy isn't only about Washington. It's about your fieldwork, labs, classrooms, businesses, and communities. It's about empowering GSA members—at all career stages, from all corners of the discipline—to tell compelling stories about the science you do and why it matters. Whether it be at Connects or one of our section meetings, I'm excited to work with you to reach your public-facing goals.

Looking forward to working together for the future of our profession—and communities,

Emily Orzechowski, Ph.D.
Director of Geoscience Policy & External Relations
The Geological Society of America

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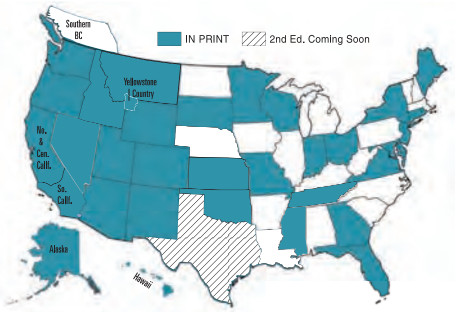

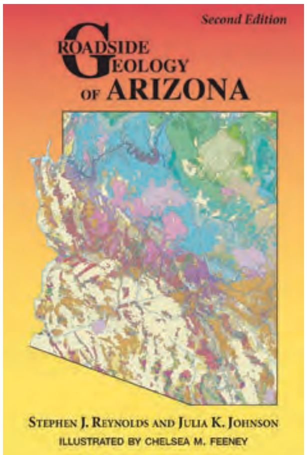

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Call for Nominations: GSA Division Awards

GEOARCHAEOLOGY DIVISION
Richard Hay Student Paper/Poster Award

Nominations due: 30 August
Submit to: gsa.agd@gmail.com
Hay was a long-standing 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's annual meeting. 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.

community.geosociety.org/geoarchdivision/awards/student/hay

HISTORY, PHILOSOPHY, AND GEOHERITAGE DIVISION
History and Philosophy of Geology Student Award

Nominations due: 31 August
Submit to: Christopher Hill, chill2@boisestate.edu

The History, Philosophy, and Geoheritage 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. 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. The award is made possible by a bequest from the estate of Mary C. Rabbitt.

community.geosociety.org/histphildiv/awards/student

PLANETARY GEOLOGY DIVISION
Eugene and Carolyn Shoemaker Impact Cratering Award

Nominations due: 5 September
Apply at: https://www.lpi.usra.edu/Awards/shoemaker/
For questions, contact: David Kring, kring@lpi.usra.edu
The Eugene and Carolyn Shoemaker Impact Cratering 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.

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 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.

community.geosociety.org/pgd/awards/greeley

The 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. Studies of terrestrial volcanoes and volcanic processes are only eligible if the primary focus is on extraterrestrial volcanism.

community.geosociety.org/pgd/awards/mouginis-mark-prize

Figure 1. Photo of the Sage Hen Flat looking southward.

Sage Hen Flat pluton, California, and Increasing Trust by Communicating Uncertainty and Salience

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

Geology logline: *Uncertainty in geological data exists because of inaccuracies in perception and variations in Earth patterns and processes; uncertainty in geological models exists because of the uncertainty in underlying geological data and the prioritization of some data in the construction of models. The result is that both geological data and models are best considered in a probabilistic framework.*

Cognitive science logline: *Collecting information about both the uncertain world and the uncertain mind facilitates the collection of less biased data and cooperative science; it also communicates an important part of the geologist's workflow.*

> *"To know what you know, and what you do not know, that is true knowledge"*
>
> ***—attributed to Confucius***

Sage Hen Flat, in the White Mountains of eastern California, USA, is different from the other locales in this essay series; it is neither widely known nor a place accepted by the discipline as influential (Fig. 1). If it is known at all, it is because of its proximity to the bristlecone pine and a high-elevation University of California field station. Sage Hen Flat, however, became our testing ground for how cognitive science and geoscience could be integrated by externalizing what was already going on in the geologists' minds (Tikoff et al., 2023) and providing new tools to communicate and collaborate (Nelson et al., 2024). In this sense, it thoroughly changed our perspective on the geological mind. In this essay, we try to convey this new view and its implications for geoscience research and training future geoscientists.

Geologically, the Jurassic Sage Hen Flat pluton is interesting because the granitic rock intruded a thick Precambrian–Cambrian section of metasedimentary units without noticeably altering the surrounding bedding orientations (Fig. 2A). Cognitively, the area is interesting because there are two geological maps from the same area with contradictory interpretations for the subsurface geometry (Ernst and Hall, 1987; Bilodeau and Nelson,

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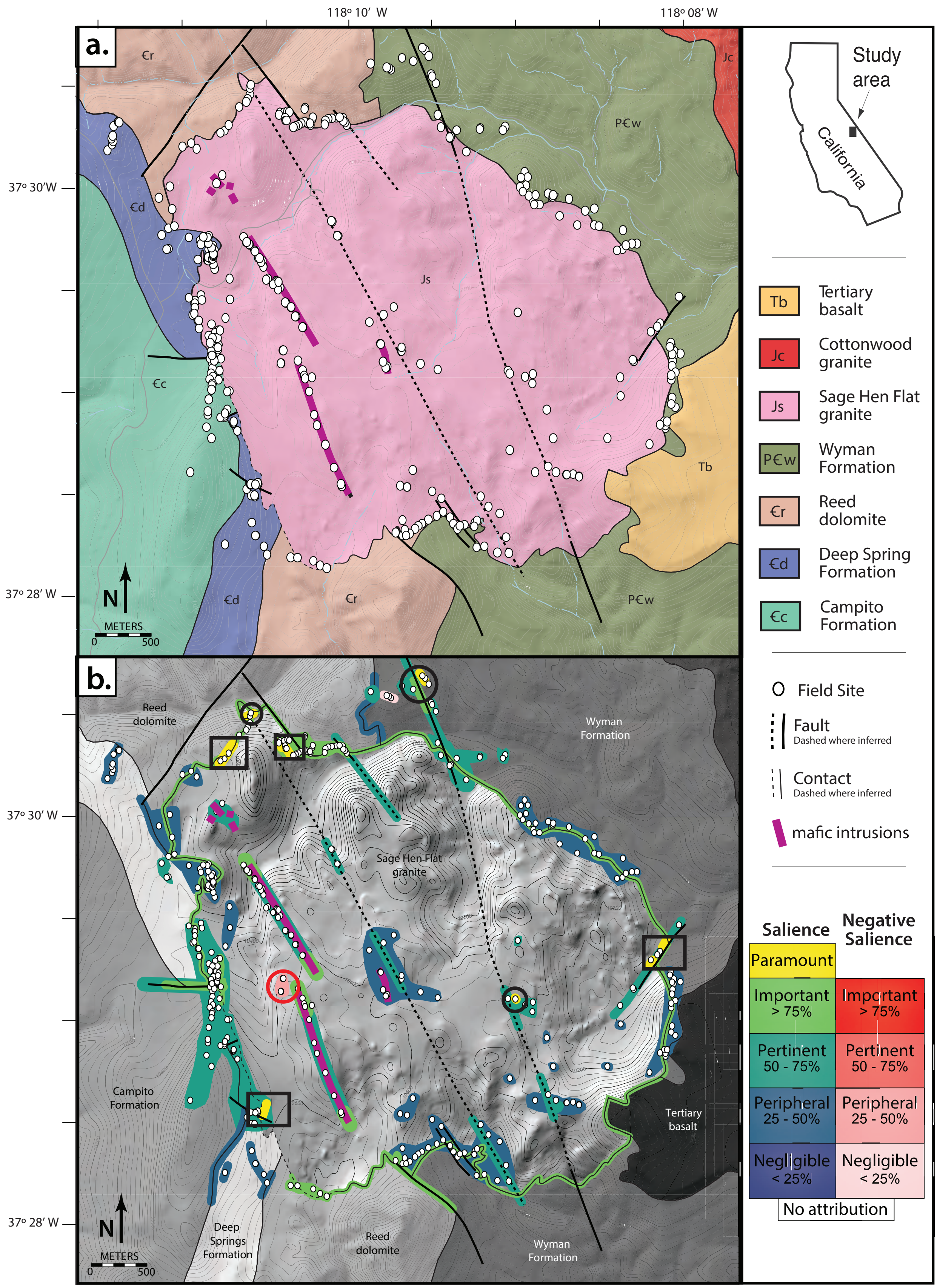

Figure 2. (A) Geologic map of the Sage Hen Flat region, California. (B) Salience map for the horizontal sheet model of the Sage Hen Flat pluton for the same area as shown in A. The salience values for each point are color coded. Four places where the pluton/wall-rock contact is exposed have thxe highest positive salience, highlighted by black boxes. Positive high-salience areas along exposed normal faults are highlighted by black circles. Figure is after Nelson et al. (2024).

1993). We hypothesized Sage Hen Flat to be a region where observational uncertainty was high and could provide insights into geological thinking by considering the cognitive processes that managed uncertainty in individual scientists' practices.

We introduce the Sage Hen Flat pluton as an example of how observations and theories interact when there is uncertainty. We first utilize cognitive science insights about human perception and thought as probabilistic, rather than deterministic. Using these insights, we explore the possibilities of field-based data collection being improved by: (1) recording the probabilistic nature of perception of the world and the variability of Earth patterns and processes through the use of uncertainty; and (2) recording salience to capture the alignment of observations with an interpretation of the world. Using both uncertainty and salience together provides a protocol to de-bias observations and thereby do better science. Communicating these parameters can potentially increase trust among scientists and between scientists and the general public.

PERCEPTUAL, OR OBSERVATIONAL, UNCERTAINTY

Early efforts in psychology to understand perception assumed a deterministic experience where sensory inputs led to specific perceptual experiences. Perception researchers assumed that scientific laws, similar to those discovered for physics, would be revealed to connect sensory input (cause) to experience (effect). That is, researchers expected a direct and simple relationship between what was in the world and what was in the mind. This approach ultimately failed because sensory inputs yielded neither a consistent nor a simple output.

Rather, the same sensory input yielded different perceptual reports in different people. Moreover, even the same person reported different experiences at different times. This variability was initially assumed to be the result of measurement error and/or noise imposed on an underlying deterministic process. It was not until the advent of the field of signal detection, part of the larger field of decision making, that conceptions of perceiving changed from deterministic processes to probabilistic processes. The recommended reading by Green and Swets (1966) discusses how this field initially arose from work on radar operators detecting planes in World War 2 (Marcum, 1947).

A person's everyday experience of the world—seeing, smelling, touching, and hearing—may not feel probabilistic because it is so often correct. Moreover, when perception is incorrect, it is quickly corrected with additional input. However, awareness of this probabilistic reality becomes heightened when our perception is based on imperfect data. For example, a field geologist is sometimes confronted with a complex or chemically altered rock for which the lithology is not clear. In this circumstance, any lithological decision is a likelihood of an observation matching the true state of the world, rather than a certain identification. Thus, what is recorded and reported as an observation will reflect the probable, but not certain, state of the world.

If perception is both uncertain and variable, how can we evaluate how well something is known? Studies in cognitive science indicate that people can reliably assess the quality of evidence for a perceptual decision (Preston and Colman, 2000). The record of their uncertainty is therefore scientifically valuable as an indicator of the likelihood that an observation matches the state of the world. Consequently, the probabilistic nature of perception provides an opportunity to record and share the degree of uncertainty.

UNCERTAINTY: CHARACTERIZING THE PROBABILISTIC NATURE OF PERCEPTION OF THE WORLD

We return the narrative to Sage Hen Flat, California, where we attempted to address the issue of perceptual decision making in a geological field setting. The results for field-based uncertainty are reported by Tikoff et al. (2023). We used a six-point ranking system (no evidence, permissive, suggestive, presumptive, compelling, certain) for the determination of the properties of any outcrop, where properties included certainty of attachedness, lithology, geometry, and kinematics. These categories were chosen because they integrate evaluation of both variation in perception and variation in Earth patterns and processes. To illustrate, consider the concept of attachedness, which we defined as the likelihood that an outcrop was fully attached to the underlying bedrock. It is somewhat difficult to tell if many of the outcrops at Sage Hen Flat are connected to the subsurface. Typically, the decisions about attachedness involved either size (e.g., bigger was more convincing) or consistency (e.g., fabrics had the same orientation in nearby, isolated outcrops).

In our experience, recording the uncertainties required minimal extra time because the geologists were already evaluating this information. That is, experts were already determining the observational evidence for whether a geologic property was present, but now they had a systematic and rapid way of recording the information. Moreover, the experts did not want to mix low-quality and high-quality data without a way to distinguish them in the data set. Thus, for the geologists, the main effect of using the uncertainty ranking system was that additional stops were recorded for outcrops that would have been bypassed otherwise due to their low quality.

Recording and communicating uncertainty are not new aspects in expert practice. A well-known field example is the use of solid versus dashed contacts on geological maps, in which dashed contacts are an assessment of uncertainty. Uncertainty, however, can be applied to all field measurements. In fact, early digital mapping systems allowed uncertainty to be assigned to most attributes (e.g., Walker et al., 1996; Pavlis et al., 2010).

Geologists routinely record and report the variability in all other tools (e.g., instruments) they employ in the field. If so, why is uncertainty of observations not routinely reported in field geology? The answer likely has three parts. First, the mind was not seen as the purview of geologists. We hope by now in this essay series you are thinking, "but of course it is." Second, there was no community tradition or shared vocabulary for evaluating the many facets of uncertainty in field-based observations. Third, there was no mechanism for storing and sharing these observations with the community. The use of digital databases now makes sharing these types of data possible (e.g., Walker et al., 2019).

RECORDING OBSERVATION UNCERTAINTY IN PRACTICE AND TEACHING

Recording uncertainty increases the transparency of the observer's perception in the recorded observation; a workflow that includes uncertainty could lead to a decrease in bias. One way to decrease bias is simply to be more mindful, which typically includes slowing down. Slowing down to reflect on a decision and the evidence for the decision has been found to reduce errors in medical decision making (Pinnock et al., 2021), and slowing down to consider regional histories has been found to reduce errors in seismic profile interpretations (Macrae et al., 2016). These improvements likely arise from active reflection that reduces the influence of expectations on pattern recognition. Thus, reflecting on uncertainty is likely to lead to a reduction in bias.

A familiar way to decrease uncertainty is to make additional measurements, for three reasons. First, when you record more observations, you are less likely to record a single observation that is based on its fit with existing theory. Second, increasing the amount of data collected yields an estimate that is proportionally more robust and therefore more trustworthy. However, optimal aggregation should factor in quality; this is where recording the level of uncertainty becomes critical. Third, variable data are most valuable when there is a lot of data, as aggregation offers a converging estimate of the underlying signal. If more is better, identifying when one has reached a point of diminishing returns becomes important, and that point will depend on the level of uncertainty. Deciding how much data are necessary requires both an understanding of perceptual experience and an understanding of how much variability is typically found in the Earth pattern or process being observed (which can come from prior knowledge).

Instructors could easily build on the well-known concept of uncertainty in mapping contacts to teach students to think more carefully and broadly about different types of uncertainty. All measurements carry a level of uncertainty associated with the measuring instrument. However, there is also a conceptual issue relating to uncertainty: How sure are you that you are really measuring the feature you think that you are? Some areas and rock types are difficult for students when they are getting started. For example, distinguishing between bedding versus rock cleavage in slate belts is quite challenging. Recording both the observation and the uncertainty of the observation facilitates better measurements because it supports reflection about a measurement. Effectively, it promotes the separation of what is known from what is not known. Additionally, in our experience, some students concerned about being wrong may be reluctant to measure geological features, but they will do so if they know that they can evaluate their measurement as uncertain.

ATTENTIONAL LIMITS AND MODEL UNCERTAINTY

The level of uncertainty is not the only characteristic that influences the value of data. Some data are inherently of higher relevance to a model. Using field geology, examples of high-relevance outcrops include those that expose contacts, clearly show gradients (e.g., sediment grain size), or illustrate a process or history (e.g., offset of intersecting faults). These are informally referred to by some as "Rosetta" outcrops because they uniquely constrain interpretations of data in other areas of the field site. In the absence of a Rosetta outcrop, multiple interpretations of the patterns observed in the remaining outcrops would be permissible.

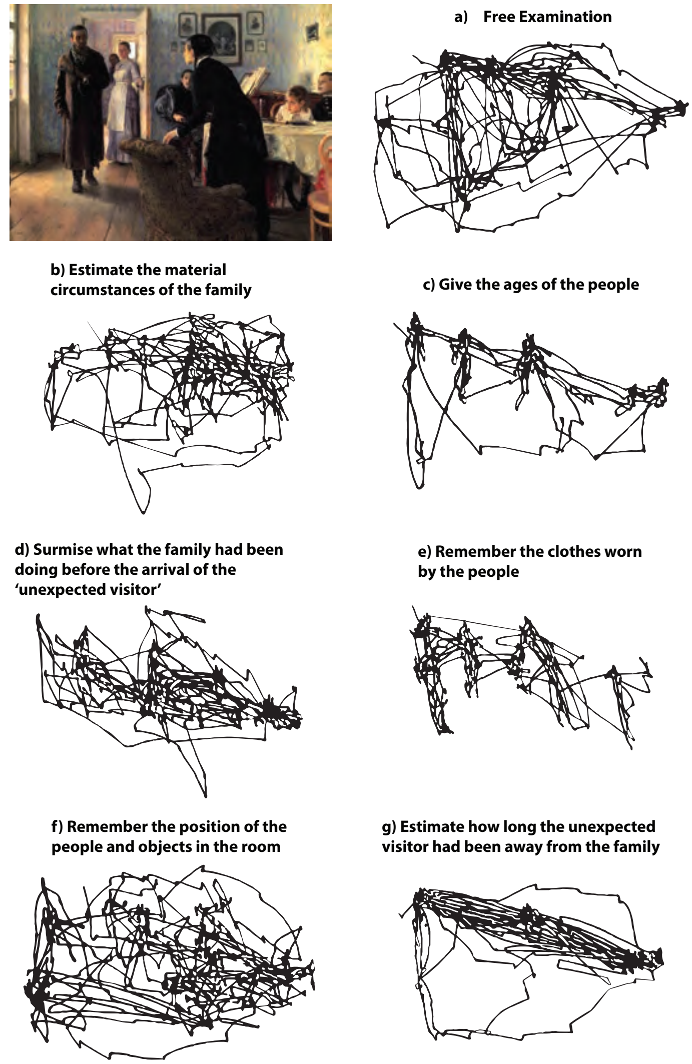

Figure 3. Eye-path looking records, from Yarbus (1967). Adapted from Wikimedia Commons/public domain.

To address why some data are particularly relevant to constructing a model, we return to human perception. Humans can only attend to, and therefore think about, a few things at a time; all else is filtered out. You have but to look up from reading this text to become aware of things happening around you that you had not noticed while focused on reading. The fact that the term "attentional economy" has come into modern parlance reflects the competition for humans' limited attention from a host of sources attempting to monetize viewers' attention (e.g., social media apps). Limited attention is highly functional as it allows the mind to work with a manageable amount of information to guide rapid action, such as avoiding drivers or pedestrians whose attention is distracted.

Cognitive scientists have documented that human capacity to take in perceptual information is limited. Despite the sense of a visually rich 140° view of the world, only a tiny portion (approximately a thumb's width at arm's length) has high-resolution information at any moment. The earliest research on eye tracking found reliable patterns about where people focused on picking up details. For example, when confronted with a picture of people in a room (Fig. 3), most of the viewer's attention was focused on the faces and where each person was looking (Yarbus, 1967). If asked to estimate the wealth of the family, eye tracking indicated that the pattern changed, and people now spent more time on the objects in the room. That is, people literally changed how they were looking at the world, depending on what question they were asked. Observers attend to high-importance (e.g., salient) details and ignore parts that have lower importance. What one looks at—and therefore what one sees—is strongly influenced by an object or event's relevance to the observer's goals.

Attention to a small number of observations can quickly lead to an interpretation. In the case of Figure 3, the interpretation is a narrative of what might be going on in the moment of the image. However, these interpretations guide future looking (data gathering). Thus, the consequence of limited attention is that we produce mental models (interpretations) that guide where to next direct one's attentional resources (Neisser, 1976). While such interpretations are often correct, they are not inevitably correct. The key point is that the initial interpretation of the world around us, and generally all interpretations, is inherently probabilistic and contains some degree of uncertainty.

The same is true for scientific investigations. All scientists have experienced the failure of an initial conceptual model, based on limited data. Moreover, all scientists ignore some data that they think is anomalous or incorrectly collected. Expressed generally, uncertainty in geological models directly arises from the limited observations that were given priority to form the interpretation. Although scientists recognize the need to distinguish levels of data importance with terms such as permissive or compelling, what has been missing is the framework for recording, discussing, and sharing the weighting factor that we give data.

SALIENCE: CHARACTERIZING THE PROBABILISTIC NATURE OF THE MIND WHEN INTERPRETING THE WORLD

Salience is defined as the level of support that a specific observation offers for a specific interpretation. For the scientist, salience informs how interpretations were reached by linking data to an interpretation. As such, salience explicitly acknowledges the mental and practical limits on formulating an interpretation, because not all data enter into the formulation of a model or hypothesis. Recognizing this human limitation can be valuable for understanding why some types of data were collected and others not.

Nelson et al. (2024) proposed the use of salience in a scientific workflow at Sage Hen Flat such that these decisions would be recordable, sharable, and practically evaluated. An observation could be highly important because it either supports a model or is inconsistent with a model. To capture this dichotomy, we diverge from the cognitive science usage of salience as ranging from low (near zero) to high. Rather, we adopt assigned salience with both positive and negative scales. Negative salience values indicate increasing importance due to increasing inconsistency with a model. By including negative salience, it is possible to be explicit about how all evidence influenced the final interpretation, reflecting the preponderance of evidence. Practically, this means that evidence of increasing salience against an interpretation must be balanced by stronger, more compelling evidence for the interpretation.

Salience in this conceptualization can be accumulated and communicated as values or as a map layer for spatial observations. Figure 2B is a salience map for a horizontal sheet model of pluton emplacement in the Sage Hen Flat area (Nelson et al., 2024). We assessed salience at Sage Hen Flat using the "what if it magically disappeared" criterion. That is, when constructing our salience map, we determined the salience of an outcrop by assessing how much the support for the model would suffer if the outcrop was removed. The four places where the pluton/wall-rock contact is exposed have the highest positive salience (highlighted by black boxes on Fig. 2B), as do places that exposed a normal fault (black circles). The pluton at Sage Hen Flat is relatively well exposed, and thus the salience for any of the granitic outcrops was relatively low because of the inherent redundancy. The one area of high negative salience is a vertical, E-W–oriented fault on the west side of the pluton that is on strike with a fault in the wall rock ~0.5 km away (red circle). We observed it, but it does not fit well into our model of the area. A salience map allows a complete account of how all data "map" (in a literal sense) onto a model, which is otherwise not possible because of practical limitations on space in scientific journals and readers' attention.

The salience map is only for a particular model for a particular purpose. We anticipate that the previous published maps of the region (e.g., Ernst and Hall, 1987; Bilodeau and Nelson, 1993) would have had different salience maps. Those studies were more focused on regional geology, rather than pluton emplacement, although the interpretations constrained the geometry of the pluton at depth. However, even another study that explicitly shared our focus on the process of pluton emplacement would likely have a different salience map. The difference between two salience maps would uniquely identify the data that different groups are using to constrain their models.

Similar to uncertainty, the concept of salience is not new to expert practice. Positive salience is implicit in the observations that are mentioned in a scientific report in support of an interpretation. This concept is also central to a familiar practice of showing a visiting colleague around a field area, taking them to the important (positive salience) outcrops that support an interpretation. Perhaps less common, but still part of scientific practice, is to invite colleagues to the baffling (negative salience) outcrops that do not make sense in the context of a particular interpretation.

> *"How do you know what you know?"*
>
> ***—attributed to Socrates***

RECORDING SALIENCE IN PRACTICE AND TEACHING

Recording and sharing salience is not new but could become shared more broadly, and with greater precision, with formalized methods. Experts with a shared understanding of a model, or interpretation, will have a shared sense of what is and is not consistent with the model. Salience as a shared resource thus empowers cooperation, even among individuals with differing interpretations of an area. If salience were part of formal data sharing, it would support reproducibility by pointing those in the field to revisit key locations and "see for themselves." It would also allow community review to confirm the implications of data for an interpretation.

Negative salience is an important, and unexpected, conceptual outcome of this work—unexpected in the sense that we had not previously recognized how contradictory evidence was managed by individuals in the field but rarely shared with the community. Moreover, these nonconforming observations might be extremely valuable for reformulating interpretations. In this sense, negative salience is more important than positive salience. The key to progress is to communicate the nonconforming observations, so that the inconsistencies with a particular model—and hence the opportunities for improvement—are clearly communicated to future researchers.

We think the introduction of salience to students could help to illuminate a hidden part of becoming a professional geologist: understanding the nature of scientific models. A naïve view of science is that scientific models are either right or wrong. However, scientific models are tentative and subject to change because they contain uncertainty and are thus probabilistic. Changes to scientific models occur because salience may be incorrectly assigned, or important observations may have been overlooked. A more powerful and predictive explanation might be possible with a different interpretation using some of the same data, in which the weighting of what data are important (e.g., salience) changes. On topics of active scientific debate, one model or another may be prioritized, depending on which data set is prioritized (for an example, see Tikoff et al., 2025).

In this view, scientific models are part of a process rather than an end state. This recognition is both liberating and powerful. As a first year Ph.D. student, Basil was advised by the senior U.S. Geological Survey geologist Paul Bateman: "You don't need to be right, you do need to be consistent with your data." Including salience in a workflow shifts the focus from a correct end product to refining models to be consistent with the most salient data.

HOW UNCERTAINTY AND SALIENCE FIT TOGETHER: A PROTOCOL FOR DE-BIASING MODEL-DRIVEN SCIENCE

Uncertainty and salience are a package deal. Together, they reflect the reciprocal nature of data and models: Data constrain models, and models guide data collection and interpretation. This interplay creates a significant problem, often pointed out by historians of science (e.g., Oldroyd, 1996): Data and models are not independent, and therefore scientists are biased. Scientific training allows careful collection of complex data, and that complex data afford complex models. Those complex models in turn guide biased data collection. Yet, both perception and the process of science are self-correcting and together will approach a coherent, underlying reality. For geology, correction occurs because data and models are both grounded in Earth's patterns and processes.

High-quality models require converging data, which can be conceived of as redundancy in geological patterns. Salience can be seen as a way to record where to look for data that can be interpreted by taking advantage of such convergence and how uncertain that inference is. With uncertainty to record the noise and salience to record which data are being used, the two together can capture the probability that science has understood the world. Viewed this way, science can become significantly more efficient at self-correcting if both uncertainty and salience are recorded.

In efforts such as field mapping, the utility of the combined uncertainty-salience approach may be clear. Consistent with our geological mapping on Sage Hen Flat, we communicated what outcrops were most important in constraining the models (cross sections, in this case). We were aware of other models (e.g., Ernst and Hall, 1987; Bilodeau and Nelson, 1993), and we utilized multiple working hypotheses (e.g., Gilbert, 1886) to try to collect data that could support any of these models.

In reflecting on our own workflow at Sage Hen Flat, we realized that having multiple hypotheses focused our attention on specific areas. Many of the benefits of using multiple working hypotheses are also available using the uncertainty-salience approach. The act of evaluating the uncertainty in the data and the relevance of that data to a model required continuous assessment by the geologist, and thus resulted in de-biasing data collection. In our experience of working within a framework of assigning positive and negative salience, we were more likely to notice and thus record data that were inconsistent with the working model(s). In other field areas, we have used a single-model (or model-driven) approach. Model-driven science efficiently guides field time. However, it has the tendency to prioritize data that fit into one's model, which inherently yields biased data. The uncertainty-salience approach is particularly useful in cases where a single model is being tested. In such cases, de-biasing occurs as a result of increased awareness of context in making decisions about uncertainty (e.g., how does this outcrop compare to surrounding outcrops) and consideration of the entire data collection for consistency (e.g., recording negative salience).

UNCERTAINTY, SALIENCE, AND TRUST

It is often the role of the scientist within society to offer understandable guidance, based on evidence, and also communicate what is uncertain. The aspects of a topic that are uncertain are liable to change with the accumulation of further evidence, but so too are the high-salience data that matter for the practical guidance regarding any specific topic. In the absence of a clear articulation of both uncertainty and salience, any changes in policy based on data will seem arbitrary. This understanding is important to scientists and the general public alike. Reporting of salience allows multiple independent minds to consider the relationship between observation and interpretation.

Trust, in large part, comes down to effective and transparent communication about how you know what you know and how you know that it is likely correct. Increasing trust is a major reason for characterizing uncertainty and salience. Field scientists who have not been to a particular area are effectively trusting those scientists reporting on an area to be accurate (uncertainty). Telling people how the data were weighted to build a model (salience) further increases trust. Clear scientific communication also requires reporting what is not known. Negative salience provides the opportunity to report an important unknown, data that are nonconforming to a specific model. Future research efforts can effectively be directed at areas of negative salience, leading to new observations and new models.

In conclusion, why did Sage Hen Flat change our minds? The answer lies partly in the nature of Earth patterns here: It is where we could see how uncertainty in observations allowed experts to have differing but reasonable conclusions. Perhaps it is a "sweet spot": Less uncertainty and everyone would map the same way; more uncertainty and a definitive interpretation would not be possible. Similarly, the sparse outcrops meant that some of the outcrops played a greater role than others in guiding reasonable interpretations. Although we started with a more typical attempt to adjudicate between different interpretations, we realized that there was an opportunity to change our workflow, and thereby our minds. It was Sage Hen Flat, itself, that allowed us to confront the interrelationships between data and models, and the opportunity afforded by communicating uncertainty in both.

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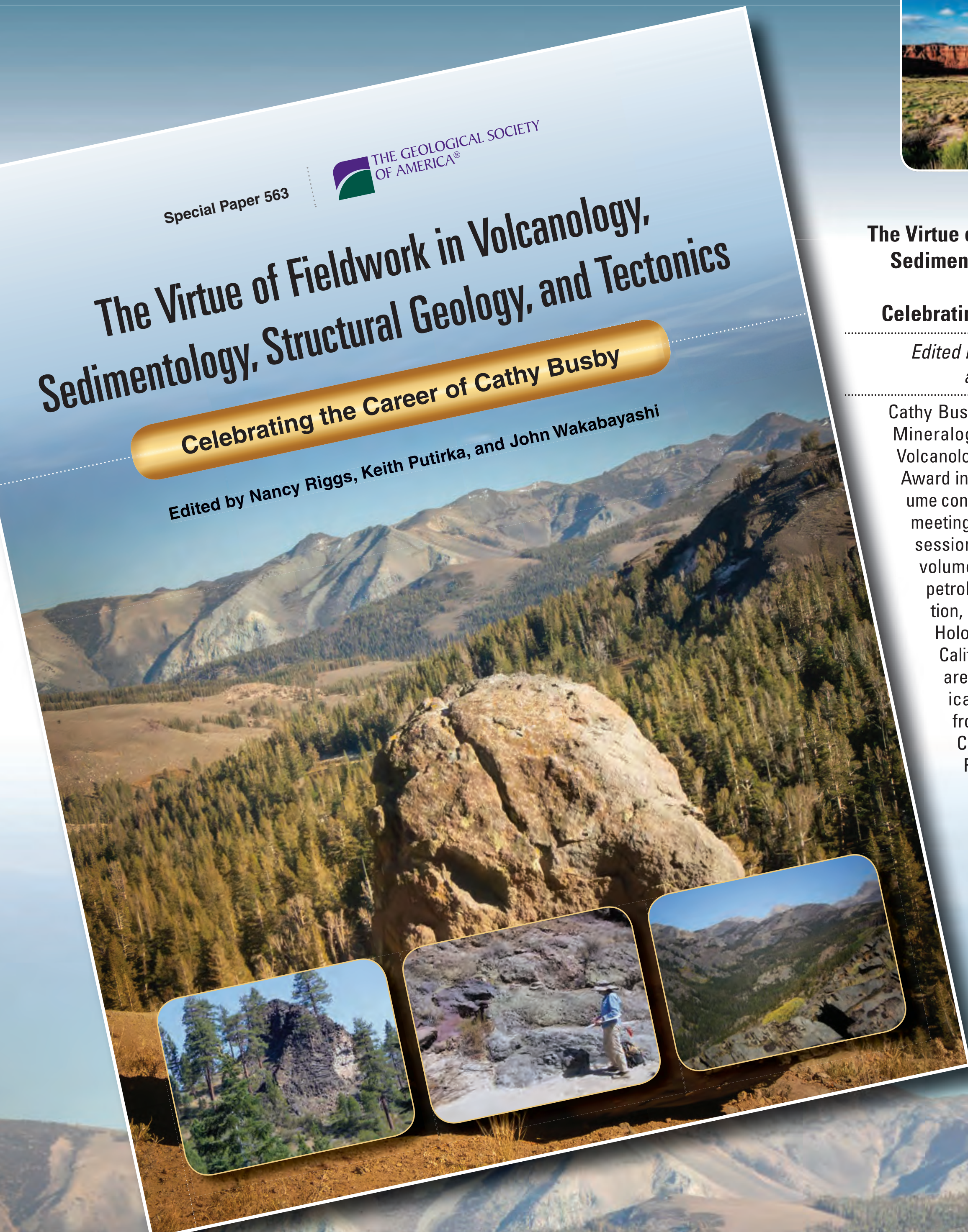

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Edited by Nancy Riggs, Keith Putirka, and John Wakabayashi

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