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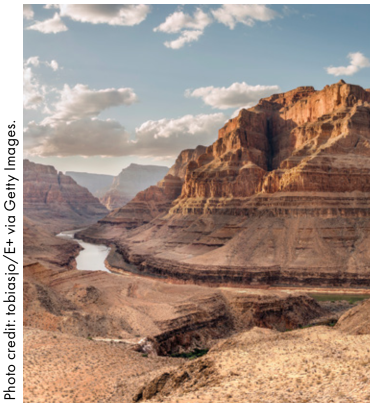

Photo credit: tobiasjo/E+ via Getty Images.

The Colorado River carves through the Grand Canyon, exposing layers of ancient rock. West Rim, Grand Canyon National Park, Arizona, USA. See related article on pages 4–11.

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DEPARTMENTS

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Corrigendum to Landing, E., and Bartholomew, A.J., 2024, Lester Park: Global "type locality" for stromatolite fossils: GSA Today, v. 34, p. 8–12, https://doi.org/10.1130/GSATG117GH.1.
On page 11 of this article, the authors stated:
"Further work on legacy slabbed pieces and thin sections made by Goldring (1938) of *C. proliferum* in the NYSM by F. Neuweiler (Université Laval) and colleagues has involved optical petrology, cathodoluminescence, fluid inclusion analysis, and U-Pb dating of primary carbonate fabrics and several generations of carbonate (calcite and dolomite) cements. The results (unpublished data) illuminate the burial history and tectonics of Lester Park and eastern New York."

Instead, this passage should have referenced a pre-print version of the work by F. Neuweiler and colleagues, and this oversight is now corrected by replacing this text with:
"Further work on legacy slabbed pieces and thin sections made by Goldring (1938) of *C. proliferum* in the NYSM by Neuweiler et al. (2024) has involved optical petrology, cathodoluminescence, fluid inclusion analysis, and U-Pb dating of primary carbonate fabrics and several generations of carbonate (calcite and dolomite) cements. Neuweiler et al.'s (2024) results illuminate the burial history and tectonics of Lester Park and eastern New York."

The full reference corresponding to this citation should have appeared in the reference list as follows:
Neuweiler, F., Mueller, M., Walter, B., Landing, E., Beranoaguirre, A., Sendino, C., Amati, L, and Kershaw, S., 2024, Fossil record misconstrued: Sponge-like fabrics reflect incipient carbonate metamorphism: Preprint, v. 1, Research Square: https://doi.org/10.21203/rs.3.rs-4394609/v1, available 22 May 2024.

We apologize for this oversight.

THE GEOLOGICAL SOCIETY OF AMERICA®

The Cambrian of the Grand Canyon: Refinement of a Classic Stratigraphic Model

Carol Dehler,[1*†] Frederick Sundberg,[2†] Karl Karlstrom,[2] Laura Crossey,[2] Mark Schmitz,[3] Stephen Rowland,[4] and James Hagadorn[5]

ABSTRACT

The Cambrian Tonto Group of the Grand Canyon was used by Edwin McKee in 1945 to make an insightful visual representation of how sedimentary facies record transgression across a craton—a common conceptual framework still used in geologic education. Although the tenets of McKee's facies diagram persist, the integration of new stratigraphy, depositional models, paleontology, biostratigraphy, and other data is refining the underlying dynamics of this cratonic transgression. Instead of McKee's interpretation of one major transgression with only minor regressions, there are at least five stratigraphic sequences, of which the lower three are separated by disconformities. These hiatal surfaces likely represent erosion of previously deposited Cambrian sediments that were laid down on the tropical, pre-vegetated landscape. Rather than being fully marine in origin, these sequences were formed by a mosaic of depositional environments including braided coastal plain, eolian, marginal marine, and various shallow marine environments. McKee, not having the insights of sequence stratigraphy and plate tectonics, concluded that the preservation of these sediments were due to predepositional topography and subsidence of the "geosyncline." Our modern interpretation is that accommodation space was a result of eustasy and differential subsidence on the continental margin. Our modified depositional model provides a more effective teaching tool for fundamentals and nuances of modern stratigraphic thinking, using the Tonto Group as a still-influential type location for understanding transgressive successions.

INTRODUCTION

Edwin McKee's 1945 model of marine transgression in the Grand Canyon (Fig. 1) has influenced generations of geoscientists (Sloss, 1963; Bond and Kominz, 1984; Runkel et al., 2012; Łabaj and Pratt, 2016; Handkamer et al., 2023) and is showcased in many textbooks (Boggs, 1995; Stanley and Luczai, 2014). Using the physical stratigraphy and trilobite biostratigraphy of the Cambrian Tonto Group in the Grand Canyon, together with Walther's law (Walther, 1894), he hypothesized that the shallow water Tapeats Sandstone, deeper water Bright Angel Shale, and the deepest water Muav Limestone transgressed across a slowly subsiding geosyncline—experiencing only minor regressions.

Here we review the evolution of thought since McKee's pre–sequence-stratigraphic and pre–plate tectonic work and show how new results refine his model. Our work builds on growing awareness that the Cambrian Tonto Group consists of five formations representing a diverse array of depositional environments and timing (Fig. 2; see Table S1 in the Supplemental Material[6]). For example, Wanless (1975) interpreted one member of the Bright Angel Formation to be terrestrial and suggested that the Muav Limestone reflects peritidal rather than deep water deposition. Similarly, many workers have reinterpreted the "marine" Tapeats Sandstone to represent a range of depositional environments including braided fluvial, deltaic, and eolian settings (Table S1). Most recently, new geochronologic constraints from U-Pb zircon maximum depositional ages for the Tapeats Sandstone, combined with reevaluation of trilobite zones, indicate that the time represented by the Tonto Group is short (Fig. 2; Karlstrom et al., 2020; Sundberg et al., 2020; Cothren et al., 2022; Rowland et al., 2023). A synthesis of these data leads us to identify at least five time-calibrated stratigraphic sequences within the Tonto Group.

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[6] Supplemental Material. Figures S1 and S2: Maps of measured sections and disconformity images. Tables S1–S3: Facies, fossil localities, and C-isotope data tables. Please visit https://doi.org/10.1130/GSAT.S.27239115.v1 to access the supplemental material; contact editing@geosociety.org with any questions.

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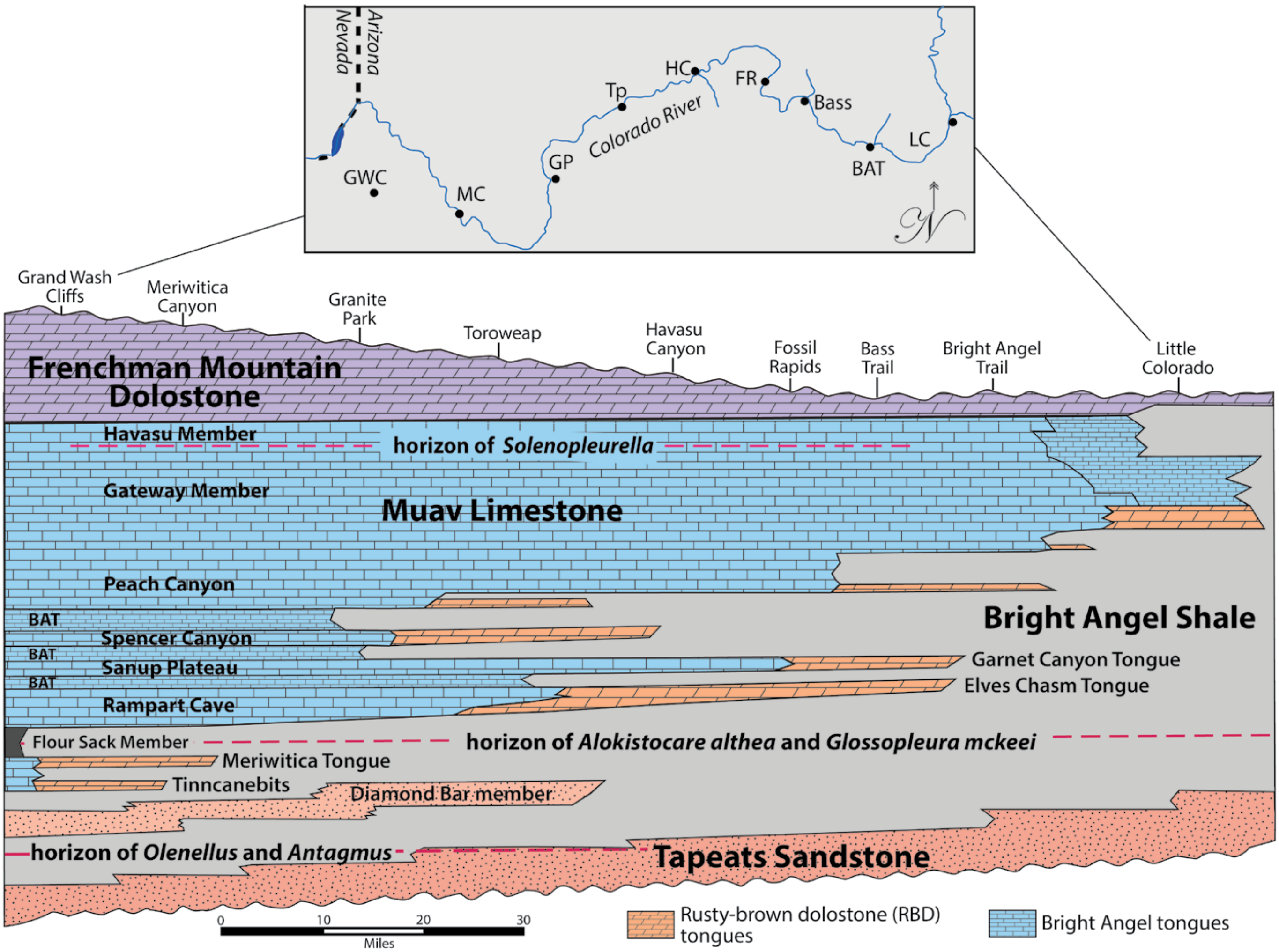

Figure 1. Adaptation of McKee's (1945, fig. 1) panel diagram of the Tonto Group in the Grand Canyon. Colors match the rock types in Figures 2 and 3. BAT—Bright Angel tongues (modified from "silty platy limestones").

REEVALUATION OF THE MCKEE MODEL

Stratigraphic Methods

More than 50 stratigraphic sections were measured or updated, including historic sections that span most of the 500-km-wide Grand Canyon region (Fig. S1). Thickness and Wheeler diagrams (Figs. 2 and 3) were constructed based on 28 sections arranged by longitude from the restored position of the Frenchman Mountain section in the west to the Palisades section in the east. To synthesize data for this publication, detailed stratigraphic sections were generalized to reduce heterolithic complexity and produce a fence panel that illustrates overall stratigraphic and temporal relationships (Fig. 2).

Paleontological information was derived from reevaluation of trilobites and associated faunas in museum collections as well as our 169 new fossil localities, most of which represent in situ occurrences in our measured sections. Biostratigraphy is detailed by Sundberg and all other authors (2024, pers. observ.) and used to constrain correlation of sections (Table S2). Our Wheeler diagram (Fig. 3) uses the relative durations of zones based on graphic correlation of the Laurentian traditional middle and upper Cambrian (CONOP [CONStrained OPtimization algorithm] results from Farrell and all other authors [2024, pers. observ.]) and comparison of zones from the traditional lower to middle Cambrian in the Pioche area, Nevada (Webster, 2011b, 2011c; McCollum et al., 2011), providing a robust relative-time axis. Preliminary C-isotope data are presented from the Fossil Rapids area to aid in correlation with our relatively unfossiliferous Frenchman Mountain section (Table S3), and major faults are shown to assess local influences of tectonics on deposition.

Biostratigraphic Scheme

Cambrian strata in the Grand Canyon span at least the global Stage 4 of Series 2 to the Drumian Stage of the Miaolingian Series (Fig. 2; Karlstrom et al., 2020; Sundberg et al., 2020). The rocks of the Tonto Group are poorly fossiliferous, and no individual section contains a continuous

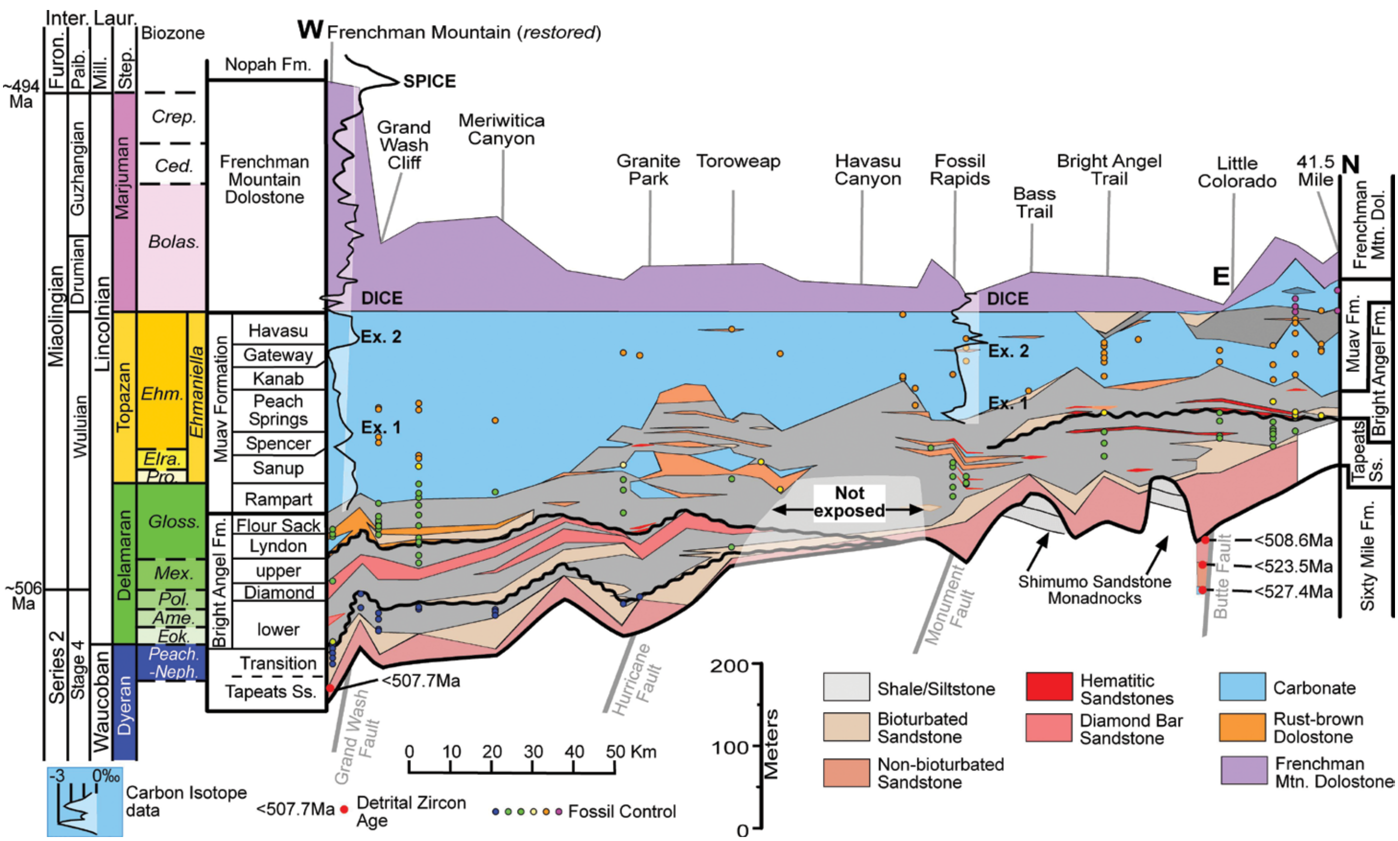

Figure 2. Stratigraphic thickness diagram that leverages updated historic and new measured sections as well as new and reinterpreted paleontology, fault relations, and $\delta^{13}C$ chemostratigraphy. Frenchman Mountain is shown in its restored position. Zone/Subzone abbreviations: *Peach.-Neph.—Peachella iddingsi* to *Nephrolenellus multinodus*; *Eok.—Eokochaspis nodosa*; *Ame.—Amecephalus arrojosensis*; *Pol.—Poliella denticulata*; *Mex.—Mexicella mexicana*; *Gloss.—Glossopleura walcotti*; *Pro.—Proehmaniella*; *Elra.—Elrathiella*; *Ehm.—Ehmaniella*; *Bolas.—Bolaspidella*; *Ced.—Cedaria*; *Crep.—Crepicephalus*. Member abbreviations: Gateway—Gateway Canyon; Kanab—Kanab Canyon; Spencer—Spencer Canyon, Sanup—Sanup Plateau; Rampart—Rampart Cave; Lyndon—Lyndon Limestone; upper—upper slope unit (used by McKee, 1945); Diamond—Diamond Bar; lower—lower slope unit (of McKee, 1945); Series/Stage/Rock abbreviations: Inter.—International; Furon—Furongian, Paib.—Paibian; Laur.—Laurentian; Mill.—Millardan; Step—Steptoean. Other abbreviations: Fm.—Formation; Ss.—Sandstone; Mtn.—Mountain; Dol.—Dolostone; Ex—excursion; SPICE—Steptoean positive isotope carbon excursion; DICE—Drumian isotope carbon excursion.

fossiliferous succession to determine the stratigraphic ranges of taxa. Hence, boundaries between zones cannot be accurately identified in most measured sections. Nonetheless, the strata contain representatives of seven Laurentian trilobite zones (Sundberg and all other authors, 2024, pers. observ.).

The lowest zones are the *Peachella iddingsi*, *Bolbolenellus euryparia*, and *Nephrolenellus multinodus* zones, which occur in the basal Bright Angel Formation in the westernmost Grand Canyon region (Webster 2011a, 2011b). These zones are equivalent to the *Olenellus* zone of McKee (1945). Disconformably overlying these olenellid zones at Frenchman Mountain is the ptychoparioid trilobite *Mexicella* cf. *M. robusta* that is probably from the middle *Eokochaspis nodosa* or lower *Amecephalus arrojosensis* zones (Lincolnian Series, Delamaran Stage; McCollum and Sundberg, 2000). There is no paleontological evidence that strata of the *A. arrojosensis* to *Poliella denticulata* zones occur elsewhere in the Grand Canyon. McKee (1945) did not recognize this biostratigraphic interval. In contrast, the *Albertella* zone was recognized based on a single pygidium. This zone is now referred to as the *Mexicella mexicana* Zone (McCollum and Sundberg, 2007); taxa of this zone occur in our Frenchman Mountain and Rampart Cave sections (Fig. 2; McKee, 1945). Taxa of the *Glossopleura walcotti* Zone occur throughout the Grand Canyon area from below the Tincanebits Tongue through the Rampart Cave Member (Fig. 2). In the western Grand Canyon, this zone lies disconformably above the *M. mexicana* Zone. The trilobite fauna is relatively diverse (McKee, 1945) and may represent only the upper portion of the zone, due to its faunal similarity and stratigraphic position below the *Ehmaniella* Zone in Utah (Sundberg, 2005). The *Ehmaniella* Zone is subdivided into the *Proehmaniella*, *Elrathiella*, *Ehmaniella*, and *Altiocculus* subzones (Sundberg, 1994). In the western Grand Canyon, the *Proehmaniella* subzone is represented by taxa in the Elves' Chasm tongue and Sanup Plateau Member. The *Elrathiella* subzone is represented by three species and commonly occurs within the densely glauconitic facies of the Bright Angel Formation directly above the *G. walcotti* Zone in the eastern Grand Canyon.

Differentiating between the *Ehmaniella* and *Altiocculus* subzones in the Grand Canyon is difficult given the Muav Formation's limited fauna. There are no robust criteria to separate the two subzones in the Grand Canyon given the stratigraphic ranges of trilobites in the Peach Springs to Gateway

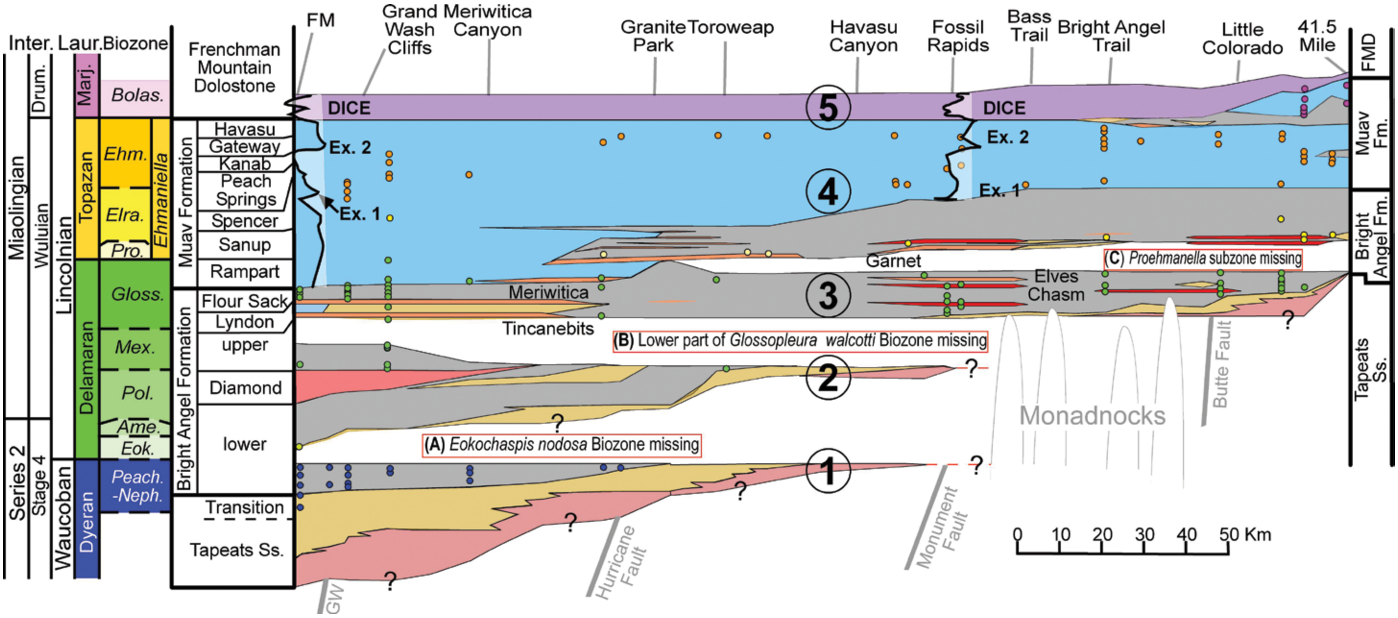

Figure 3. Wheeler diagram of the Tonto Group, illustrating hypothesized depositional sequences, labeled 1–5. Because the geochronology of the Sixtymile Formation is poorly constrained, it is not depicted here. Vertical axis is based on relative thickness of zones based on CONOP (CONstrained OPtimization algorithm) analysis (see text). Question marks indicate that basal clastics lack biostratigraphic and geochronologic control beyond maximum depositional ages; thus, their duration could be substantially shorter than graphically depicted here, and coarse clastics associated with deposition of sequences 1 and 2 could extend into the eastern Grand Canyon. FM—Frenchman Mountain (restored); GW—Grand Wash fault. For other abbreviations and lithologic types, see Figures 2 and 4; Tables S1 and S2; and Figures S1 and S2.

Canyon members of the Muav Formation. As a result, only the *Ehmaniella* subzone is used. This zone is represented by taxa distributed across the Grand Canyon. This fauna is partly equivalent to the *Solenopleurella* horizon of McKee (1945).

In the easternmost Grand Canyon, we discovered a new trilobite fauna (*Glyphaspis tetonensis*, *Crepicephalus*? *upis*, *Solenopleurella*? *quadrata*, and *Modocia* sp.) from the uppermost Muav Formation and lowermost Frenchman Mountain Dolostone (Sundberg and all other authors, 2024, pers. observ.). These taxa are known from the *Bolaspidella* Zone elsewhere in Laurentia (Rasetti, 1963; Schwimmer, 1973; Melzak and Westrop, 1994). *Bolaspidella* time is also present in the Frenchman Mountain Dolostone type section and at our Fossil Rapids, where the Drumian Isotope Carbon Excursion (DICE) is recorded (Rowland et al., 2023; Table S2).

Preliminary $\delta^{13}C$ Calibration in Grand Canyon

The $\delta^{13}C$ profile from the Fossil Rapids area is similar to the $\delta^{13}C$ record from Frenchman Mountain (Rowland et al., 2023; Table S3) and aids in correlation. The lowermost robust shared pattern is a –1.5‰ negative shift in the lower *Ehmaniella* Zone, referred to as Excursion 1 (Ex. 1; Fig. 2). This pattern is succeeded by a rise in $\delta^{13}C$ values to near zero in the upper *Ehmaniella* Zone, termed Excursion 2 (Ex. 2). In the Frenchman Mountain Dolostone, there is a complex negative anomaly of two stacked 0% to ~-2.5‰ excursions in the lower *Bolaspidella* Zone that may represent the DICE (Howley and Jiang, 2010; Rowland et al., 2023).

Depositional Model

The most fitting paleogeographic model to explain the Tonto Group is similar to that presented by Palmer (1960) in which the Tapeats and Bright Angel formations represent the "inner detrital belt" and the Muav and Frenchman Mountain formations represent the "middle carbonate belt." The "Rusty Brown dolostones" (RBDs) and "Bright Angel tongues" of McKee (1945; Figs. 1 and 2) are transitional facies between these belts, with the RBDs indicating transgression. In contrast, we interpret the tongues of Bright Angel Formation interbedded with the Muav Formation to indicate regression (Fig. 1). This deepening and widening of the inner detrital belt caused a landward shift of the shoreline and coeval onlapping onto the carbonate bank, resulting in a return to more normal marine conditions as evidenced by an increase in open-shelf macrofaunal taxa and siliciclastic mud (Fig. 4).

Disconformities

The majority of the Tonto Group above the Sixtymile Formation was deposited in paralic environments on a flat, stable margin of the Laurentia in a pre-vegetated, tropical setting. Given the overall low-relief topography (hundred-meter-high monadnocks notwithstanding; Fig. 4), in combination with sea-level fluctuations, the presence of unconformities within the succession is expected, especially farther inboard. Short-term hiatal surfaces within the Tapeats and Bright Angel formations are common (Rose, 2006, 2011) due to incision during channel migration of the broad braid plain and reworking of sediments by storms, tides, and intermittent exposure. However, some surfaces represent more substantial periods of erosion that were not recognized by earlier workers. These disconformities are like surfaces that have been recognized in the predominantly shelfal Delamaran sections of Nevada (McCollum and McCollum, 2011).

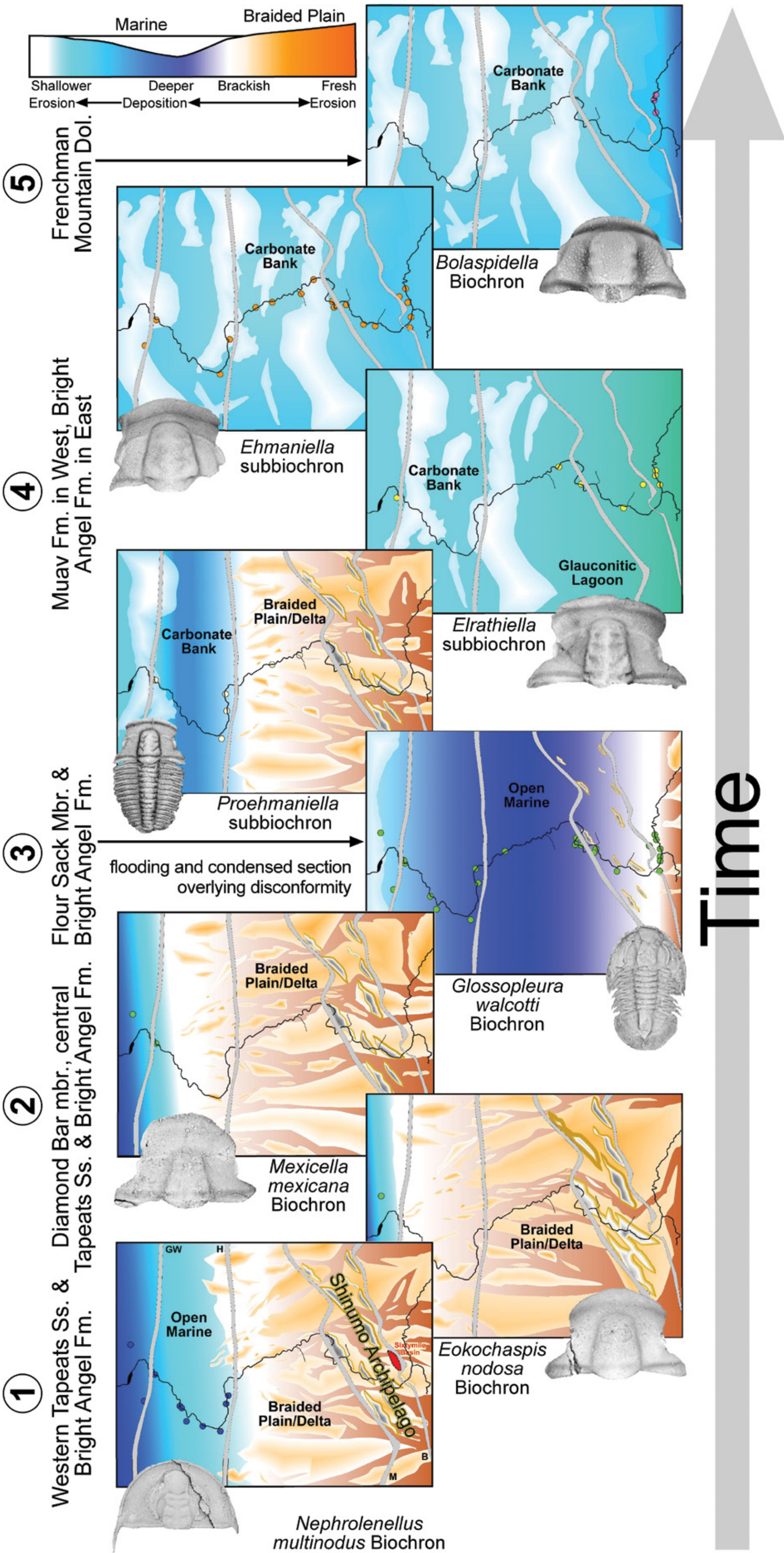

Figure 4. Paleogeographic maps and key trilobites of representative Tonto Group landscapes. Gray lines represent Cenozoic faults, which are labeled on lowest diagram and may have been active during Cambrian time: GW—Grand Wash; H—Hurricane; M—Monument; B—Butte.

At least three new disconformities, labeled (A) to (C), are recognized (Fig. 3) on the basis of missing biozone intervals, erosional features, and facies changes (Sundberg and all other authors, 2024, pers. observ.; Table S1):

(1) At Frenchman Mountain, a thin (2 m) bioturbated sandstone containing the middle(?) portion of the *E. nodosa* Zone sharply overlies a bioturbated shale and sandstone facies that overlies a shale facies containing the *N. multinodus* Zone (Fig. 2; Table S1; Fig. S2). This disconformity between the Dyeran and Delamaran stages becomes more pronounced eastward, and eventually *G. walcotti* Zone trilobites appear in the shale facies, overlying the bioturbated sandstones of the lower Bright Angel Formation. Based on lithologic correlations, this disconformity appears to extend into the lower *M. mexicana* Zone in the central Grand Canyon. It is unlikely that many strata of the Dyeran age, if any, exist eastward.

(2) The disconformity between the *M. mexicana* and *G. walcotti* zones in our Rampart Cave section is expressed as an erosional surface (Fig. S2). The green shale facies, containing *M. mexicana* Zone trilobites, is locally incised with a relief of >1.5 m across a 5-m horizontal interval. Overlying this incised surface are bioturbated shale and sandstones that contain *G. walcotti* Zone fauna. Additional support for the eastward extension of this disconformity is the disappearance of shale above the Diamond Bar non-bioturbated sandstone member and progressive removal of this member eastward. The fauna of the *G. walcotti* Zone appear to represent only the upper part of the zone, which suggests that the hiatus represents the uppermost *M. mexicana* to lower *G. walcotti* zones.

(3) This disconformity lies between the *G. walcotti* Zone and the overlying *Elrathiella* subzone in the eastern

Grand Canyon. An erosional boundary occurs 10 m below the fauna of the *Elrathiella* subzone at the base of a prominent cliff of the red sandstone facies, which overlies the *G. walcotti* Zone-bearing shale facies (Fig. S2). Missing is the *Proehmaniella* subzone, although it is present in our Diamond Creek section. Trilobites representing the *Elrathiella* subzone are rare in the western Grand Canyon. This contact can be traced hundreds of meters in outcrop (Fig. S2) and is inferred to be regional based on the missing biozones.

Other disconformities likely exist higher in the Muav and Frenchman Mountain formations (Rowland et al., 2023), but at present there is no paleontological or stratigraphic evidence to suggest additional breaks. In general, stratigraphic breaks are hypothesized to become more pronounced eastward due to increasing exposure and decreased subsidence rates farther east of the depocenter.

Tonto Group Sequence Stratigraphy

Multiple stratigraphic sequences occur in the Tonto Group. The lowest are in the Sixtymile Formation, but because they have larger temporal uncertainty and limited aerial extent (Karlstrom et al., 2020), we do not treat them here. Above the Sixtymile Formation, the first succession (Sequence 1 in Fig. 3) represents the Tapeats Sandstone in its most basinward position, onlapping eastward time-transgressively in a stepwise fashion, as recognized by McKee (1945, figs. 11, 13). The lateral extent and age duration of Tapeats Sandstone are unknown in the eastern Grand Canyon due to a lack of fossils. This sequence indicates progressive retrogradation of siliciclastic facies shoreward (Fig. 4). The top of Sequence 1 (and Sequences 2 and 3) are capped by clay-rich shale and articulated trilobites, suggesting maximum flooding intervals that have been truncated by erosion (Fig. S2A–C). Sequence 2 is characterized by four sets of prograding sand bodies, culminating with the Diamond Bar member in the west. Sequence 2 is the only sequence that records an interval of delta plain progradation and a major basinward shift of the shoreline (Fig. 4). Sequence 3 represents impoundment of Tapeats sediments in the very eastern part of the field area and the first appearance of RBDs to the west. In Sequence 3, the Tincanebits and Meriwitica tongues, the black shale of the Flour Sack Member, and the Elves Chasm and Garnet tongues define a transgressive systems tract that represents more normal marine conditions.

Above the third disconformity and the conformable surface to the west is Sequence 4, the base of which is marked by onlapping and stacked bioturbated sandstone and associated RBDs (Figs. 2 and 3). Sequence 4 becomes dominated by onlapping and aggradation of the Muav Formation from west to east. This sequence marks the development of estuarine/lagoonal environments as the carbonate platform grew upward and shoreward during transgression (Fig. 4). The lower boundary of Sequence 5 coincides with the Muav-Frenchman Mountain Dolostone contact, except in eastern Grand Canyon, where the contact is between upper members of the Muav Formation. The sequence is marked by fine-grained siliciclastic material at its base in the easternmost sections (Figs. 2 and 3) and the overwhelming dominance of dolomitic facies of the Frenchman Mountain Dolostone across the canyon. Throughout the region, Sequence 5 is truncated by the sub-Mississippian or sub-Devonian unconformity. This sequence reflects marked transgression and the predominance of the middle carbonate belt (Fig. 4).

Controls on Tonto Group Deposition

The primary control on Tonto Group deposition is the rise and fall of eustatic sea level, whereby: (1) carbonate facies move landward during sea-level rise; (2) sandstones move landward during sea-level rise and prograde basinward during sea-level fall; and (3) the intervening shale facies belt widens and onlaps both the carbonate bank basinward and the shoreline moves cratonward during sea-level rise.

Other analogous Cambrian sequences are also thought to be controlled by eustatic sea-level rise (Montañez and Osleger, 1996; Haq and Schutter, 2008; Snedden and Liu, 2010; Keller et al., 2012). Younger analogs exist as well, such as the Aptian passive-margin record of the Arabian Peninsula, which has a strikingly similar depositional pattern to the Tonto Group, spans a similar duration (~14 m.y.), and hosts three unconformities (Davies et al., 2002).

McKee's work predated plate tectonics, when geosynclinal theory suggested that "miogeosynclines" subsided due to the weight of accumulated sediment, as amplified by isostasy (Dana, 1873). Modern evidence (Angevine et al., 1990) suggests that sediment loading is a feedback on sea-level change, preexisting topography, and regional subsidence; all three likely helped create space for Tonto Group deposition.

Preexisting topography plus the existence of faults that moved in the early Cambrian are evident in eastern Grand Canyon. The Butte fault (Karlstrom et al., 2020) and other faults define a Cambrian archipelago, here named the "Shinumo Archipelago" in the Tapeats Sea (Fig. 4). These paleo-islands were completely covered by late *G. walcotti* time, leveling out the landscape and allowing greater landward advance of the carbonate belt (Fig. 4).

Two Cenozoic western faults, the Hurricane and Grand Wash faults, are parallel to the Cordilleran hingeline and may mimic older paleo-fault systems that mark the hinge region of the Cordilleran rift margin (Stewart and Poole, 1974). The westernmost Frenchman Mountain Dolostone thickens westward from 200 m to nearly 400 m west of the Grand Wash hingeline, suggesting an increase in accommodation space that cannot be explained solely by eustatic sea-level changes (Christie-Blick et al., 2023). Except for the Butte fault, Cambrian slip on Grand Canyon faults has not been identified, but fault associations with biozone and facies boundaries (Fig. 4) suggest they may have influenced differential accommodation space and subsequent sediment loading of western blocks and isostatic rebound of eastern blocks that influenced the positions of the inner detrital and middle carbonate belts.

A NEW PARADIGM FOR THE TONTO GROUP

We envision the controls on the Tonto Group depositional patterns to include a combination of eustasy and regional differential subsidence high on the shelf of the Cordilleran miogeocline. In contrast, McKee's diagram (1945, Fig. 1) portrayed an interpretation of a time-transgressive eastward-migrating shoreline that deposited vertical sandstone-shale-carbonate stacking patterns as the shoreline moved landward. The then-understood longer timeframe for the Cambrian transgression, along with a gradualist thinking of continuous deposition with no unconformities, and optimistic lithofacies and fossil horizon correlation, led to this interpretation.

The collective body of Tonto Group work since McKee (1945) adds important, necessary modifications. The succession was deposited as a mosaic of sedimentary environments ranging from terrestrial to shallow-marine settings on a relatively flat landscape (Rose, 2011; Fig. 4; Table S2) rather than a progressively basinward-deepening seascape. Thus, the distribution of facies produced by these environments is better envisioned as a broad inner detrital belt consisting of fluvial braid plain, deltaic (or estuarine), tidal, and lagoonal environments in the east and a complex middle carbonate belt to the west (*sensu* Palmer, 1960; Fig. 4).

The succession contains at least five depositional sequences opposed to one long-term transgressive event (Fig. 4). All five sequences are floored by siliciclastic material, and all but one indicate a landward advancement of the shoreline. Biostratigraphy and comparison with other stratigraphic analogs suggest that sequences were geologically short-lived, ~1–2 m.y., and likely of different durations.

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MANUSCRIPT ACCEPTED 1 OCTOBER 2024

Valle de Viñales, Pinar del Río Province, western Cuba. Karstic relief on passive margin Upper Jurassic and Cretaceous limestones. The world-famous Cuban tobacco is grown in this valley.

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

12–18 April 2025

LEADERS

Yamirka Rojas-Agramonte, Christian-Albrechts University of Kiel, Germany
Manuel Antonio Iturralde-Vinent, Empresa de Tecnologías de la Información y Servicios Telemáticos Avanzados (CITMATEL), Cuba
Antonio García-Casco, University of Granada, Spain
Robert J. Stern, University of Texas at Dallas, USA
Mark Gabriel Little, University of North Carolina at Chapel Hill, USA
Walter D. Mooney, U.S. Geological Survey, USA
John Wakabayaski, California State University–Fresno, USA
Joaquín A. Proenza, University of Barcelona, Spain

DESCRIPTION AND OBJECTIVES

Cuba, the largest island in the Greater Antilles (Fig. 1), is key to understanding the interactions between the North American, South American, and Caribbean plates during the Jurassic–Paleogene period (180–45 Myr), as well as the origin of the Caribbean plate. The island contains Mesozoic–Cenozoic fragments of both the Caribbean plate (arc volcanics and intrusives, ophiolites, and mélanges with high-pressure metamorphic blocks) and the North American plate (subducted passive margin and non-subducted units of the Bahamas Platform and Maya/Yucatan margin). This makes Cuba an exceptional example of arc-continental margin "soft collision." The island is also ideal for studying subduction initiation, mature subduction, arc development, and how arcs and terrane accretion contribute to continental crust growth.

Despite its geographical proximity to the United States, Cuba has remained understudied by U.S. geoscientists for over half a century due to political barriers. This Thompson Field Forum aims to renew scientific exchange by bringing together experts to discuss recent findings by Cuban and international researchers. It will serve as a platform to revitalize collaboration among Cuban, U.S., and international geoscientists, highlighting exciting research opportunities in Cuba and the broader Caribbean region.

We will visit key localities in western and central Cuba to study the following:

- North American/Yucatan continental passive margin and basin sections
- Ophiolite complexes and serpentinite mélanges
- Cretaceous Arc and Meta-Arc Complexes
- The metamorphic Caribeana terrane (Escambray Massif)

AGENDA

The seven-day Thompson Field Forum will begin in Havana, Cuba, and then travel to Pinar del Rio in western Cuba. For the first two days, the group will visit localities around Viñales (a UNESCO World Heritage Site). The group will then move to central Cuba for a traverse across the Cuban orogenic belt, spending three nights in Santa Clara and one in Trinidad (another UNESCO World Heritage Site and one of the best-preserved colonial cities in the Caribbean).

April is typically dry, with temperatures ranging from 26–32°C. No special fitness is required, and outcrops will be easily accessible from the road.

Day 1 (12 April): Arrival in Viñales by 11 a.m. Overview of the Viñales valley and introduction to the geology of

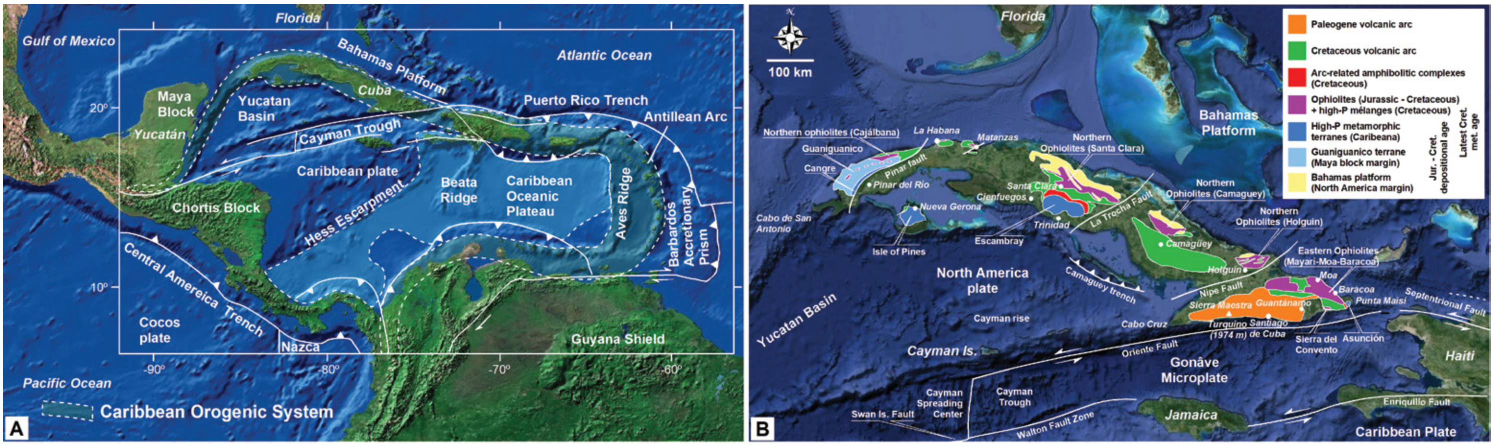

Figure 1. (A) Tectonic map of the Caribbean region. (B) Generalized geologic-tectonic map of Cuba modified from Iturralde-Vinent (2011).

western Cuba. Visits include Late Jurassic (Oxfordian)–Early Cretaceous exposures transitioning from shallow marine to basinal carbonate and chert facies (Jagua–Guasasa Fms.), and deformed Jurassic siliciclastic deposits.

Day 2 (13 April): Examination of the K-Pg boundary and transition from continental margin into foreland sedimentation, mid-Jurassic and Cretaceous basinal protocaribbean deposits, and ophiolites.

Day 3 (14 April): Travel from Pinar del Rio to Santa Clara. Visit to outcrops of passive margin sedimentary rocks of the Placetas belt, Santa Clara mélange, and ophiolites.

Day 4 (15 April): Exploration of ophiolitic mélanges in Santa Clara.

Day 5 (16 April): Study of Cretaceous volcanic arc, volcano-sedimentary packages, and the Upper Cretaceous Manicaragua batholith.

Day 6 (17 April): Visits to amphibolite and granitic rocks of the Mabujina complex and the Escambray metamorphic massif. Overnight in Trinidad.

Day 7 (18 April): Return to Havana after breakfast.

LOGISTICS AND ATTENDEES

The registration fee of US$300 covers six nights' lodging based on double occupancy in hotels or private houses. Due to the embargo, U.S. attendees must stay in private houses. Breakfast, lunch, snacks, dinner, transportation, and field trip guides are included. Single-occupancy rooms are available for an additional fee (US$62 for hotels; US$160 for private houses). The fee is paid once for the entire field forum.

All foreigners entering Cuba must have a visa and health insurance. U.S. geoscientists should check federal travel regulations. Participants should bring sunscreen, long-sleeved shirts, mosquito repellent, and medication for mild tropical illnesses. Detailed health-related travel information can be found on the CDC website (https://wwwnc.cdc.gov/travel/destinations/traveler/none/cuba). Drinking water will be provided throughout the trip. Dietary requirements (e.g., vegetarian, vegan, lactose intolerant, gluten-free) should be specified in advance. Cuban Creole cuisine includes rice, beans, pork, chicken, fish, and seasonal vegetables.

Some financial support is available for students, early career scientists, and those with financial need. Attendees are expected to honor the GSA Code of Conduct (https://www.geosociety.org/conduct).

APPLICATIONS AND REGISTRATION

Application Deadline: 15 December 2024
Registration Deadline: 15 February 2025

Participants must commit to the full seven-day/six-night field conference. Group size is limited to 40 participants. To apply, please complete the GSA Thompson Field Forum 2025 Application (https://forms.gle/vVen2ndhXYdz3zTw9). For questions, contact TFF2025Cuba@geosociety.org

Join the Cuban Convention of Earth Sciences | 7–11 April 2025

We encourage you to arrive early to participate in the **Cuban Convention of Earth Sciences** (7–11 April). This biannual geological congress, hosted by the Cuban Geological Society, offers a special complementary session on the **Geology of Cuba: Key for the Tectonic Evolution of the Caribbean–North American Plates.** It's an excellent opportunity to present research, network, and discuss key topics before the Field Forum begins.

Independent registration required (US$400). For more information, visit: http://www.cubacienciasdelatierra.com or contact Dayima León Sanchidrian (individuales@sprachcaffe.com; +53 7 2045433).

South-Central Section

59th Annual Meeting of the South-Central Section

Dates: 9–11 March 2025*
Location: University of Central Arkansas Conference Center, Conway, Arkansas, USA
** Welcome Reception: 9 March 2025*
Technical Program: Starts 10 March 2025

www.geosociety.org/sc-mtg

CELEBRATING A DIVERSE GEOLOGICAL HISTORY

We are thrilled to host the South-Central Section Meeting in March 2025 and invite everyone to discover the diverse geology Arkansas has to offer. From Proterozoic rifting to passive margins, our technical program explores everything from the Reelfoot Rift, Ouachita Mountains, and Arkoma Basin to the stable Ozark platform. Learn about geologic mapping, the critical mineral resources in the southern mid-continent, and how they may address important issues in our society. It's an exciting time to look at energy sources and sustainability as well as impacts of development on the environment. We will also take on water management and geohazards. We welcome everyone to join our close-knit geologic community for stimulating conversations!

CALL FOR PAPERS

Abstracts Deadline: 17 December 2024

GSA Member Submission Fees: US$18 for students and US$30 for all others

GSA Non-Member Submission Fees: US$36 for students and US$60 for all others

If you have any difficulties submitting your abstract online, please contact the GSA Meetings Department at southcentral@geosociety.org.

THEME SESSIONS

T1. Student Field Experiences in the South-Central U.S.
Michael DeAngelis, University of Arkansas at Little Rock, mtdeangelis@ualr.edu; Liana Stevens, Stephen F. Austin State University, stevenslm@sfasu.edu; Pat Harris, Sam Houston State University, pat-harris@shsu.edu.

T2. Emerging Resources in the Gulf of Mexico Basin.
Ciara Mills, Arkansas Office of the State Geologist, ciara.mills@arkansas.gov; Peng Li, Arkansas Office of the State Geologist, peng.li@arkansas.gov.

T4. Sedimentary Processes and Resources of the Northern Mississippi Embayment.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Hydrogeology Division; GSA Sedimentary Geology Division. Dan Larsen, University of Memphis, dlarsen@memphis.edu; Katherine Knierim, U.S.Geological Survey, kknierim@usgs.gov; William T. Jackson, University of Memphis, wtjckson@memphis.edu.

T5. Discussions on Mass Wasting in the South-Central GSA Region.
Endorsed by GSA Quaternary Geology and Geomorphology Division. Martha Kopper, Arkansas Office of the State Geologist, Martha.Kopper@arkansas.gov; Rick Monk; U.S. Forest Service, Richard.monk@usda.gov.

T6. Geological Mapping in the South-Central Region of the United States.
Sara Patton, Arkansas Office of the State Geologist, sara.patton@arkansas.gov; John Gist, Arkansas Office of the State Geologist, john.gist@arkansas.gov.

T7. Karst Terrains.
Endorsed by GSA Karst Division. Matthew Covington, University of Arkansas–Fayetteville, mcoving@uark.edu; Katherine Knierim, U.S. Geological Survey, kknierim@usgs.gov.

T8. Hills and Valleys: Geomorphology of the Ozark Plateaus.

Endorsed by GSA Quaternary Geology and Geomorphology Division. Stephanie L. Shepherd, Auburn University, slshepherd@auburn.edu.

T9. Water, Water Everywhere: Hydrology and Water Quality in the South-Central U.S.

Endorsed by GSA Geology and Health Division; GSA Hydrogeology Division. Laura S. Ruhl-Whittle, U.S. Geological Survey, lruhl-whittle@usgs.gov; Katherine Knierim, U.S. Geological Survey, kknierim@usgs.gov; Kevin Befus, University of Arkansas–Fayetteville, kmbefus@uark.edu.

T10. Critical Minerals in the South-Central United States.

Endorsed by GSA Sedimentary Geology Division. Thomas Liner, Arkansas Office of the State Geologist, thomas.liner@arkansas.gov; Angela Chandler, Arkansas Office of the State Geologist, angela.chandler@arkansas.gov.

T11. Late Paleozoic Orogenesis from the Southern and Eastern Convergent Margins of Laurentia to the Mid-Continent: Records of Appalachian, Ouachita-Marathon, and Contemporaneous Intraplate Deformation.

Tyson Smith, U.S. Geological Survey, tmsmith@usgs.gov; Brandon Lutz, U.S. Geological Survey, blutz@usgs.gov; Mark Hudson, U.S. Geological Survey, mhudson@usgs.gov.

T12. Advancing Geosciences through Geospatial Innovations.

Endorsed by GSA Environmental and Engineering Geology Division; GSA Geophysics and Geodynamics Division. Mohamed Aly, University of Arkansas, aly@uark.edu; Kashif Mahmud, Midwestern State University, kashif.mahmud@msutexas.edu.

T13. Undergraduate Research (Posters).

Endorsed by the Council on Undergraduate Research, Geoscience Division. Wendi J.W. Williams, South Texas College, wwilliam@southtexascollege.edu; Laura S. Ruhl-Whittle, U.S. Geological Survey, lruhl-whittle@usgs.gov.

T14. Geophysical Investigations in the Mid-Continent.

Endorsed by GSA Geophysics and Geodynamics Division. Kevin Mickus, Missouri State University, kevinmickus@missouristate.edu.

T15. Geology from the Ozark Plateaus to the Arkoma Basin.

John Gist, Arkansas Office of the State Geologist, john.gist@arkansas.gov; Richard Hutto, Arkansas Office of the State Geologist, richard.hutto@arkansas.gov.

T16. Conserving the Sparta (Freshwater) Aquifer of South Arkansas.

Robert M. Reynolds, Union County Water Conservation Board, robertreynolds@suddenlink.net.

T17. Evaluating the Geological Processes Responsible for Sedimentary-Hosted Critical Mineral Resources.

Endorsed by GSA Sedimentary Geology Division. Cameron Manche, Texas A&M University, Cmanche@tamu.edu

T18. Recent Advances in Subsurface Hydrology.

Endorsed by GSA Environmental and Engineering Geology Division; GSA Hydrogeology Division; GSA Karst Division. Kashif Mahmud, Midwestern State University, kashif.mahmud@msutexas.edu; Andrew Katumwehe, Midwestern State University, andrew.katumwehe@msutexas.edu.

T19. Engineering, Geology, and Dam and Levee Safety in the Southeastern Mid-Continent.

Dan Smith, U.S. Army Corps of Engineers, dksrockspg1869@gmail.com.

T20. Carbon Capture and Underground Storage (CCUS), Class VI Underground Injection Control (UIC).

Jay Hansen, Arkansas Department of Energy and Environment–Oil and Gas Commission, jay.hansen@arkansas.gov; Bryan Brown, Arkansas Department of Energy and Environment–Oil and Gas Commission, Bryan.Brown@arkansas.gov.

T21. Hard Rock and Critical Metal: Exploring the Gulf Coast for New Opportunities in Overlooked Resources.

Matthew Loocke, Louisiana State University, mloock1@lsu.edu; Clare Falcon, Louisiana Geological Survey, cfalcon@lsu.edu; Bianca Kennedy, Independent Geologist, kennedybia@gmail.com.

T22. The Value of Core and Cuttings in Obtaining Information on Basement Rocks of the Midcontinent.

Lindsey Hunt, Oklahoma Geological Survey, lehunt@ou.edu; Nicholas Hayman, Oklahoma Geological Survey, hayman@ou.edu; Carter Lewis, Oklahoma Geological Survey, Carter.lewis@ou.edu.

T23. Reelfoot Rift: Past and Present.

Roy B. Van Arsdale, University of Memphis, rvanrsdl@memphis.edu; Randel T. Cox, University of Memphis, randycox@memphis.edu.

T24. Emergency Response and Remediation to Environmental Disasters and Geohazards.

Stephen Ratley, Arkansas Department of Energy and Environment, stephen.ratley@arkansas.gov; Matt Carey, Arkansas Division of Environmental Quality, matthew.carey@arkansas.gov.

T25. Igneous Rocks and Activity in the Midcontinent.

Michael G. Davis, Arkansas Tech University, mdavis@atu.edu.

T26. Cretaceous Magmatism in the Midcontinent.
Endorsed by GSA Geochronology Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Geophysics and Geodynamics Division. Andreas Moeller, University of Kansas, amoller@ku.edu; Pamela Kempton, Kansas State University, pkempton@ksu.edu.

T27. Geohazards Detection Using Remote Sensing Technologies.
Yaqian He, University of Arkansas–Fayetteville, yaqianh@uark.edu.

LOCAL COMMITTEE

Co-Chairs: Scott Ausbrooks, Arkansas Geological Survey, Scott.ausbrooks@arkansas.gov; Angela Chandler, Arkansas Geological Survey, angela.chandler@arkansas.gov

Technical Program Chair: Laura Ruhl, U.S. Geological Survey, lruhl-whittle@usgs.gov

Field Trip Co-Chairs: Richard Hutto, Arkansas Geological Survey, Richard.hutto@arkansas.gov; Thomas Liner, Arkansas Geological Survey, Thomas.liner@arkansas.gov

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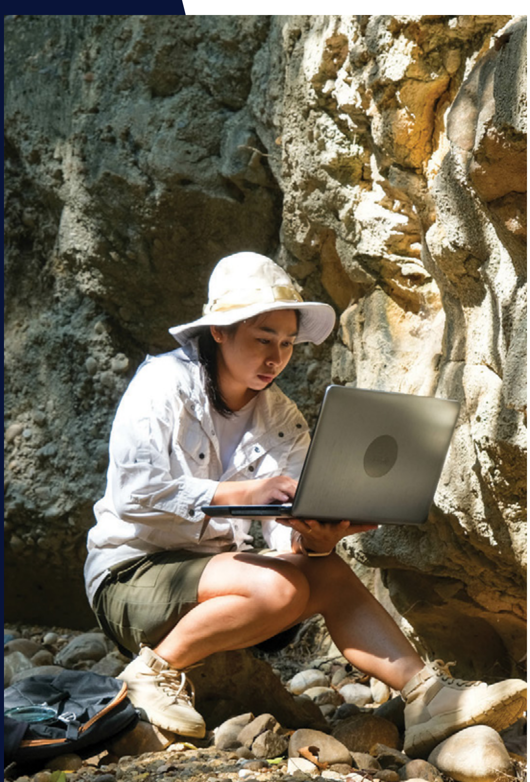
Student Volunteer Coordinators: Dave Mayo, University of Arkansas–Fort Smith, David.mayo@uafs.edu; René Shroat-Lewis, University of Arkansas at Little Rock, rashroatlew@ualr.edu

Workshop Chair: Kathy Knierem, U.S. Geological Survey, kknierim@usgs.gov



Southeastern Section

74th Annual Meeting of the Southeastern Section

Dates: 19–21 March 2025*
Location: Hotel Madison & Shenandoah Valley Conference Center, Harrisonburg, Virginia, USA

** Welcome Reception: 19 March 2025*
Technical Program: Starts 20 March 2025

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The 2025 Meeting of the Southeastern Section of GSA will be held in Harrisonburg, Virginia. Harrisonburg is located on the world-class karst geology in the Shenandoah Valley of the Valley and Ridge province, and offers easy access to the Blue Ridge, Piedmont, and Allegheny plateau. Hotel Madison is the meeting site, and it is next to the historic Bluestone area of James Madison University and just a short walk from the popular restaurants, breweries, shops, and other historic and cultural attractions of downtown Harrisonburg.

CALL FOR PAPERS

Abstracts Deadline: 17 December 2024

GSA Member Submission Fees: US$18 for students and US$30 for all others

GSA Non-Member Submission Fees: US$36 for students and US$60 for all others

If you have any difficulties submitting your abstract online, please contact the GSA Meetings Department at southeast@geosociety.org.

SYMPOSIUM

S1. Geohazards in Appalachia: From the Science to Practice. Yonathan Admassu, James Madison University, admassyx@jmu.edu; Brian Bruckno, Virginia Department of Transportation, brian.bruckno@vdot.virginia.gov.

THEME SESSIONS

T1. Interstate Collaboration in the Southeast US: Using Stratigraphy to Address Mapping, Correlation, and Interpretation Discrepancies More Effectively. *Endorsed by GSA Environmental and Engineering Geology Division; GSA Geology and Health Division; GSA Geology and Society Division; GSA Geophysics and Geodynamics Division; GSA Hydrogeology Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Soils and Soil Processes Division.* William R. Doar III, South Carolina Geological Survey, DoarW@dnr.sc.gov; Robert H. Morrow IV, South Carolina Geological Survey, MorrowR@dnr.sc.gov; Patrick Finnerty, Virginia Department of Energy, Patrick.Finnerty@energy.virginia.gov; Marcie Occhi, Virginia Department of Energy, Marcie.Occhi@energy.virginia.gov.

T2. Cores and Rocks from the Southeast Atlantic Continental Margin to Facilitate Interstate Correlation of Along-Strike Units: A Hands-On Poster Session. *Endorsed by GSA Environmental and Engineering Geology Division; GSA Geochronology Division; GSA Geophysics and Geodynamics Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division.* Kathleen Farrell, North Carolina Geological Survey, Kathleen.Farrell@deq.nc.gov; Marcie Occhi, Virginia Department of Energy, Marcie.Occhi@energy.virginia.gov; Will Doar, South Carolina Geological Survey, Doarw@dnr.sc.gov; Mary Lupo, Florida Geological Survey, Mary.Lupo@floridadep.gov.

T3. Water Quality in the Southeast U.S. *Endorsed by GSA Environmental and Engineering Geology Division; GSA Geology and Society Division; GSA Hydrogeology Division.* Madeline Schreiber, Virginia Tech, mschreib@vt.edu; Margaret-Anne Hinkle, Washington and Lee University, hinklem@wlu.edu.

T4. Recent Advances in Southeastern Hydrology.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geobiology and Geomicrobiology Division; GSA Geology and Health Division; GSA Geology and Society Division; GSA Hydrogeology Division; GSA Karst Division. Steve Baedke, James Madison University, baedkesj@jmu.edu; Jeff Wilcox, University of North Carolina at Asheville, jwilcox@unca.edu.

T5. Advances in Ground Surface Modeling for Hydrological and Environmental Applications.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Hydrogeology Division; GSA Karst Division. Esther Oyedele, Virginia Tech, eoyedel@vt.edu; Oluwaseyi Dasho, Virginia Tech, seyidasho@vt.edu.

T6. Applications of GIS and Remote Sensing Techniques in Geoscience and Environmental Science.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geophysics and Geodynamics Division; GSA Hydrogeology Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Planetary Geology Division; GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Dhanuska Wijesinghe, James Madison University, wijesidb@jmu.edu.

T7. Applied Geophysical Survey Methods and Mapping in the Southeast.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geophysics and Geodynamics Division; GSA Hydrogeology Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Blair R. Tormey, Western Carolina University, btormey@wcu.edu.

T8. Geologic Maps, Geophysical Maps, 3-D Geologic Models, Digital Mapping Techniques, Map Derivatives, and Digital Map Preparation (Posters).
Endorsed by GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geochronology Division; GSA Geology and Society Division; GSA Geophysics and Geodynamics Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division. Randy Kath, University of West Georgia, rkath@westga.edu; Karen Tefend, University of West Georgia, ktefend@westga.edu.

T9. Critical Minerals: Exploration, Occurrence, and New Discoveries.
Endorsed by GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geochronology Division; GSA Geology and Society Division; GSA Geophysics and Geodynamics Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division. Chiara Elmi, James Madison University, elmicx@jmu.edu; Jingyao "Jenny" Meng, Virginia Department of Energy, jenny.meng@energy.virginia.gov.

T10. Geoscience at Work: Current Trends in the Industry.
Endorsed by GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geochronology Division; GSA Geology and Health Division; GSA Geology and Society Division; GSA Geophysics and Geodynamics Division; GSA Geoscience Education Division; GSA Hydrogeology Division; GSA Karst Division; GSA Soils and Soil Processes Division. Chiara Elmi, James Madison University, elmicx@jmu.edu; Matthew Heller, Virginia Department of Energy, matt.heller@energy.virginia.gov.

T11. Prospects and Challenges of Geologic CO_2 Storage in the Eastern United States: Current Research and Applications.
Endorsed by GSA Continental Scientific Drilling Division; GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geophysics and Geodynamics Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Soils and Soil Processes Division. Ryan M. Pollyea, Virginia Polytechnic Institute and State University, rpollyea@vt.edu; Jingyao Jenny Meng, Virginia Department of Energy, jenny.meng@energy.virginia.gov.

T12. Periglacial Processes and Landscape Evolution.
Endorsed by GSA Geochronology Division; GSA Geophysics and Geodynamics Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division. Joanmarie Del Vecchio, College of William and Mary, joanmarie@wm.edu; Michelle Fame, Amherst College, mfame@amherst.edu.

T13. New Frontiers in Soil Geomorphology and Geoarchaeology.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geochronology Division; GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Rebecca Taormina, National Park College, rtaormina@np.edu.

T14. Integrated Approaches in Coastal Plain Research of the Eastern U.S.
Endorsed by GSA Geoarchaeology Division; GSA Geochronology Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division. Michelle Nelson, Virginia Department of Energy, michelle.nelson@energy.virginia.gov; Marcie Occhi, Virginia Department of Energy, marcie.occhi@energy.virginia.gov; David Hawkins, Virginia Department of Energy, david.hawkins@energy.virginia.gov.

T15. Sediment Dynamics and Sediment Management for Back-Barrier and Estuarine Environments.
Endorsed by GSA Marine and Coastal Geoscience Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division. Clark Alexander, University of Georgia Skidaway, clark.alexander@skio.uga.edu; Katie Luciano, South Carolina Department of Natural Resources,

LucianoK@dnr.sc.gov; Ashley McCleaf Long, Bureau of Ocean Energy Management, ashley.long@boem.gov.

T16. The Early Paleozoic of Eastern North America.
Endorsed by GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Sedimentary Geology Division; Pander Society; North American Commission on Stratigraphic Nomenclature; Paleontological Society. Randall Orndorff, U.S. Geological Survey, rorndorf@usgs.gov; Stephen Leslie, James Madison University, lesliesa@jmu.edu; John Repetski, U.S. Geological Survey, jrepetski@cox.net.

T17. From the Land to the Sea: Devonian Depositional Systems of the Appalachian Region.
Endorsed by GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division. Dennis O. Terry Jr., Temple University, doterry@temple.edu; Charles Ver Straeten, New York State Museum, charles.verstraeten@nysed.gov.

T18. Traditional and Innovative Methods of Interpreting Sedimentary Environments: Examples from the Appalachian Basin.
Endorsed by GSA Geochronology Division; GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division. Steve Peterson, State of Delaware and Temple University, stephen.peterson@delaware.gov/sppete@temple.edu; Jesse Thornburg, Temple University, jesse.thornburg@temple.edu; Tim Davis, Temple University, timothy.davis@temple.edu; Chris Oest, State of Pennsylvania, coest@pa.gov.

T19. Co-evolution of Life and its Environment: From Biodiversification Events to Mass Extinction and Everything in Between.
Endorsed by GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Sedimentary Geology Division. Datu Adiatma, Florida State University, yadiatma@fsu.edu; Jay Goodin, Florida State University, jgoodin2@fsu.edu; Amy Hagen, Virginia Tech, amyhagen@vt.edu; Maya Roselli, Florida State University mroselli@fsu.edu; Gwen Barnes, Florida State University, gb23@fsu.edu; Nathaniel Evenson, Florida State University, nc22@fsu.edu.

T20. Biogeochemical Cycling of Elements at the Earth's Surface Across Space and Time.
Endorsed by GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Sedimentary Geology Division; GSA Geology and Health Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Soils and Soil Processes Division. Justin B. Richardson, University of Virginia, dgn8nz@virginia.edu; Margaret Anne G. Hinkle, Washington and Lee University, hinklem@wlu.edu; James M. Kaste, College of William and Mary, jmkaste@wm.edu.

T21. Stable Isotopes in Geologic, Environmental, and Biological Systems.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geobiology and Geomicrobiology Division; GSA Geology and Health Division; GSA Hydrogeology Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division. William Lukens, James Madison University, lukenswe@jmu.edu.

T22. Vertebrate Paleontology Research in North America.
Endorsed by GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Sedimentary Geology Division; Southeastern Association of Vertebrate Paleontology. Joshua X. Samuels, East Tennessee State University/Gray Fossil Site & Museum, samuelsjx@etsu.edu; Rachel Reid, Virginia Tech, rebreid@vt.edu; Blaine Schubert, East Tennessee State University/Gray Fossil Site & Museum, schubert@etsu.edu.

T23. Recent Developments in Paleoecology.
Endorsed by GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Sedimentary Geology Division. Chelsea Korpanty, Eckerd College, korpantyca@eckerd.edu; James Kerr, George Washington University, james.kerr@gwu.edu; John Sime, University of Pennsylvania, sime@sas.upenn.edu.

T24. Metamorphic and Deformational Processes in Collisional Zones.
Endorsed by GSA Geochronology Division; GSA Geophysics and Geodynamics Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division. Sayantan Saha, Florida State University, ss22b@fsu.edu; Lindsi Allman, Florida State University, lallman@fsu.edu; Kanwa Sengupta, Florida State University, ks22ba@fsu.edu.

T25. New Frontiers in Cave and Karst Science.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geobiology and Geomicrobiology Division; GSA Geophysics and Geodynamics Division; GSA Hydrogeology Division; GSA Karst Division; GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Ángel A. Garcia Jr., James Madison University, garci4aa@jmu.edu; Dan Doctor, U.S. Geological Survey, dhdoctor@usgs.gov.

T26. New Frontiers in Tropical Karst.
Endorsed by: GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geobiology and Geomicrobiology Division; GSA Geophysics and Geodynamics Division; GSA Hydrogeology Division; GSA Karst Division; GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Ángel A. Garcia Jr., James Madison University, garci4aa@jmu.edu; Angel A. Acosta-Colon, University of Puerto Rico at Arecibo, angel.acosta2@upr.edu.

T27. Tourism through Cave and Karst Landscapes: Show Cave Management, Education, Research, and Community.
Endorsed by GSA Geology and Society Division; GSA Geophysics and Geodynamics Division; GSA Geoscience Education Division; GSA History and Philosophy of Geology Division; GSA Hydrogeology Division; GSA Karst Division;

GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Austin Shank, Grand Caverns, ashank@ci.grottoes.va.us; Lily Whitman, Grand Caverns, lwhitman@ci.grottoes.va.us.

T28. Geoscience and Public Policy: Putting Our Work to Work for the Common Good.
Endorsed by GSA Geology and Health Division; GSA Geology and Society Division; GSA Geoscience Education Division; Association of American State Geologists. David Spears, Top Rock Geoscience, LLC, toprockgeo@gmail.com; Scott Harris, College of Charleston, HarrisS@cofc.edu.

T29. Geosciences and Community.
Endorsed by GSA Geology and Health Division; GSA Geology and Society Division; GSA Geoscience Education Division. Angel A. Acosta-Colon, University of Puerto Rico at Arecibo, angel.acosta2@upr.edu; Stephen Moysey, East Carolina University, moyseys18@ecu.edu.

T30. Innovations and Advancements in Geoscience Classrooms.
Endorsed by GSA Geology and Society Division; GSA Geoscience Education Division; National Association of Geoscience Teachers (NAGT)–Southeastern Section. Eric J. Pyle, James Madison University, pyleej@jmu.edu; Kurt Kight, Colgan High School, kurtkightvast@gmail.com.

T31. Recent Progress in Teaching Petrology, Earth Materials, Mineralogy, and Geochemistry.
Endorsed by GSA Geoscience Education Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; Mineralogical Society of America. Elizabeth Johnson, James Madison University, johns2ea@jmu.edu, Sarah Mazza, Smith College, smazza@smith.edu.

T32. Undergraduate Research (Posters).
Endorsed by GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geobiology and Geomicrobiology Division; GSA Geochronology Division; GSA Geology and Health Division; GSA Geology and Society Division; GSA Geophysics and Geodynamics Division; GSA Geoscience Education Division; GSA History and Philosophy of Geology Division; GSA Hydrogeology Division; GSA Karst Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Planetary Geology Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division; Council on Undergraduate Research, Geosciences Division. Jeffrey Ryan University of Southern Florida, ryan@usf.edu; Lee Phillips, pleephill@gmail.com.

LOCAL COMMITTEE

General Co-Chairs: Stephen Leslie, James Madison University, lesliesa@jmu.edu; Steven Whitmeyer, James Madison University, whitmesj@jmu.edu

Technical Program Co-Chairs: William Lukens, James Madison University, lukenswe@jmu.edu; Dhanuska Wijesinghe, James Madison University, wijesidb@jmu.edu

Field Trip Co-Chairs: Yonathan Admassu, James Madison University, admassyx@jmu.edu; Ángel A. Garcia Jr., James Madison University, garci4aa@jmu.edu

Exhibits Sponsorship and Events Co-Chairs: Chiara Elmi, James Madison University, elmicx@jmu.edu; Scott Eaton, James Madison University, eatonls@jmu.edu; Matthew Heller, Virginia Department of Energy, matt.heller@energy.virginia.gov

Volunteers Coordinator: Shelley Whitmeyer, James Madison University, whitm2sj@jmu.edu

Short Courses & Workshops: Eric Pyle, James Madison University, pyleej@jmu.edu

Committee Member At-Large: Steve Beadke, James Madison University, baedkesj@jmu.edu

Treasurer: Katie Luciano (Section Treasurer), South Carolina Department of Natural Resources, lucianok@dnr.sc.gov

Joint Northeastern and North-Central Sections

60th Annual Meeting of the Northeastern Section

59th Annual Meeting of the North-Central Section

Dates: 27–30 March 2025*
Location: Bayfront Convention Center, Erie, Pennsylvania, USA

** Welcome Reception: 27 March 2025*
Technical Program: Starts 28 March 2025

www.geosociety.org/ne-mtg

Greetings from the North Coast! GSA IS GOING TO ROCK ERIE! The Northeastern and North-Central Sections are proud to host you at the magnificent Bayfront Landing campus, featuring two waterfront hotels and a spectacular convention center, 27–30 March 2025. The harbor, visible all around, is bounded by Presque Isle State Park, a sand bar more than ten miles long sporting dynamic beaches, a palustrine plain, and a colorful history epitomized by Commodore Oliver Hazard Perry's victory at the Battle for Lake Erie. The geologic story includes evidence for a cascade of glaciations with the modern spit lodged upon a subaqueous Wisconsinan recessional end moraine of the retreating Laurentide Ice Sheet, treacherous beach cliffs, maritime terraces, as well as the captivating paleontology in the underlying Paleozoic stratigraphy. Numerous field trips will explore these nearby features, including the engineering efforts to manage their associated hazards. Overprint this enchanting natural setting with bistros, eateries, and entertainment venues within walking distance to make your visit memorable. Be sure to bring your parka and ski pants in order to enjoy a toasty walk upon the beaches, as the frigid winter winds will have pounded a chill into the sea!

CALL FOR PAPERS

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GSA Non-Member Submission Fees: US$36 for students and US$60 for all others

If you have any difficulties submitting your abstract online, please contact the GSA Meetings Department at northeast@geosociety.org.

THEME SESSIONS

T1. Paleozoic Vertebrate Evolution, Diversity, and Phylogeny.
Endorsed by Wright State University. Charles N. Ciampaglion, Wright State University, chuck.ciampaglio@wright.edu; Daniel S. Cline, Wright State University, Cline.74@wright.edu; Ryan C. Shell, Cincinnati Museum Center, ryanshell501@gmail.com.

T2. Undergraduate Research Poster Session.
Jeffrey Strasser, Augustana College, JefferyStrasser@augustana.edu; Robert Shuster, University of Nebraska–Omaha, rshuster@unomaha.edu.

T3. New Frontiers in Soil Geomorphology and Geoarchaeology.
Endorsed by GSA Geoarchaeology Division; GSA Soils and Soils Processes Division. Rebecca Taormina, National Park College, rtaormina@np.edu.

T4. Bio-Landscaping: Advancing Ichnological and Biogeomorpological Research.
Endorsed by GSA Sedimentary Geology Division; GSA Soil and Soil Processes Division. Ilya V. Buynevich, Temple University, coast@temple.edu; Stephen T. Hasiotis, University of Kansas, usahasiotis@ku.edu.

T5. Geological Connections to Northeast Ohio: Sedimentary, Environmental, and Cultural Aspects of NE Ohio Geology.
Endorsed by GSA Environmental and Engineering Geology Division; Northern Ohio Geological Society (NOGS). Don Hilton, Northern Ohio Geological Society, dhiltonbooks@outlook.com; Joe Hannibal, Northern Ohio Geological Society, jhannibal@uakron.edu.

T6. Back to the Devonian: Revisiting Milestones of Paleontology and Stratigraphy from 1985.
Andrew Bush, University of Connecticut, andrew.bush@uconn.edu; Jeffrey Over, SUNY–Geneseo, over@geneseo.edu; Jay Zambito, Beloit College, zambitoj@beloit.edu.

T7. Outer Space Rocks! Enhancing the Understanding of Our Planetary Neighbors.
Endorsed by GSA Planetary Geology Division. Nicholas P. Lang, NASA, Nicholas.p.lang@nasa.gov; Jen Piatek, Central Connecticut State University, piatekjl@ccsu.edu.

T8. Paleolimnological Records of Climate and Environmental Change.
Tim Cook, University of Massachusetts, tlcoo0@umass.edu; Nick Balascio, Bates College, nbalascio@bates.edu.

T9. Tectonic Processes in the Circum-Atlantic Orogens: A Celebration of the Career of Rob Strachan.
Endorsed by GSA Structural Geology and Tectonics Division. J. Brendan Murphy, St. Francis Xavier University, bmurphy@stfx.ca; R. Damian Nance, Ohio University, nance@ohio.edu; Stephen T. Johnston, University of Alberta, stjohnst@ualberta.ca.

T10. Geoscience Field Experiences: Learning in the Field.
Eric Straffin, Pennsylvania Western University, estraffin@pennwest.edu.

T11. Quantitative and Specimen-Based Approaches to Address Big Paleontology Questions.
Endorsed by GSA Geobiology and Geomicrobiology Division; Paleontological Society; Paleontological Research Institute. Margaret M. Yacobucci, Bowling Green State University, mmyacob@bgsu.edu.

T12. Undergraduate and Graduate Geoscience Student Showcase.
Endorsed by Council on Undergraduate Research Geosciences Division. Claire McLeod, Miami University, mcleodci@miamioh.edu; Ken Brown, DePauw University, kennethbrown@depauw.edu.

T13. Reconstructing Environmental Change from Marine, Lacustrine, and Terrestrial Sedimentary Records.
Endorsed by GSA Limnogeology Division; GSA Marine and Coastal Geoscience Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division. Steven Brachfeld, Montclair State University, brachfelds@montclair.edu; Olga Libman-Roshal, Montclair State University, libmanroshao1@montclair.edu; Kurt Lindberg. University of Buffalo, kurtlind@buffalo.edu.

T14. Petrotectonic Processes in Convergent Margins: Insights from Laurentia and Beyond.
Endorsed by GSA Geochronology Division; GSA Mineralogy, Geochemistry, Petrology and Volcanology Division; GSA Structural Geology and Tectonics Division. Wentao Cao, SUNY–Fredonia, cao@fredonia.edu; Emily Walsh, Cornell College, EWalsh@cornellcollege.edu; William Peck, Colgate University, wpeck@colgate.edu.

T15. Fluvial Geomorphology of Post-glacial (and Other) Rivers.
Endorsed by GSA Quaternary Geology and Geomorphology Division. Karen B. Gran, University of Minnesota Duluth, kgran@d.umn.edu; Amanda Henck Schmidt, Oberlin College, Amanda.schmidt@oberlin.edu; Peter Moore, Iowa State University, pmoore@iastate.edu; Doug Thompson, Connecticut College, dmitho@conncoll.edu

T16. Multidisciplinary Insights from Field and Laboratory Data on Modern and Ancient Plate Margin Processes.
Katherine F. Fornash, Ohio University, kffornash@ohio.edu; Erkan Toraman, Salem State University, etoraman@salemstate.edu.

T17. Groundwater Mapping and Monitoring.
Keith Schilling, Iowa Geological Survey, keith-schilling@uiowa.edu; Steve Domber, New Jersey Geological Survey, steve.domber@dep.nj.gov.

T18. Mapping in the Geosciences: Processes and Products.
Greg Walsh, U.S. Geological Survey, gwalsh@usgs.gov; Kyla Rybacki, Pennsylvania Geological Survey, krybacki@pa.gov; Dave Soller, U.S. Geological Survey, drsoller@usgs.gov.

T19. Urban Geochemistry.
W. Berry Lyons, Ohio State University, lyons.142@osu.edu; David T. Long, Michigan State University, long@msu.edu.

T20. Groundwater Modeling Case Studies and Research Through the Midwest and Northeast.
James Berglund, University of Wisconsin–Platteville, berglundjam@uwplatt.edu; Vince Carsillo, HDR Inc., Vincent.carsillo@hrdinc.com.

T21. Salinization of Freshwater.
Nathaniel Warner, Pennsylvania State University, nrw6@psu.edu; Allison Fenske, Pennsylvania State University, amf7040@psu.edu

T22. Machine Learning Approaches in Hydrology and Water Resources.
Endorsed by GSA Hydrogeology Division. Ari Mukherjee, Ohio University, amukherjee@ohio.edu

T23. Understanding the Coastal Changes in Preparation to Combined Effects of Climate Change and Human Activity.
Endorsed by GSA Marine and Coastal Geoscience Division; GSA Quaternary Geology and Geomorphology Division. Daria Nikitina, West Chester University of Pennsylvania, dnikitina@wcupa.edu; Adrienne Oakley, Kutztown University of Pennsylvania, oakley@kutztown.edu; Sean Cornell, Shippensburg University, SRCornell@ship.edu.

T24. Northeast Water Cycle Research: Collaborative Studies of Watershed Processes to Address Water Resource Challenges in a Changing Climate.
Sean M.C. Smith, University of Maine, sean.m.smith@maine.edu; David Boutt, University of Massachusetts, dboutt@umass.edu; Kalle Jahn, U.S. Geological Survey, kjahn@usgs.gov; Salme E. Cook, U.S. Geological Survey, secook@usgs.gov.

T25. Applied Geological Investigations at State Geological Surveys in the Northeastern and North-Central Sections of GSA.
Jonathan Kim, Vermont Geological Survey, jon.kim@vermont.gov; Benjamin DeJong, Vermont Geological Survey, benjamin.dejong@vermont.gov.

T26. Reaching the Geoscientists of the Future: What Are We Pursuing to Advance Community Engagement and Geoscience Education?
Endorsed by American Association of State Geologists (AASG). Adam Ianno, Pennsylvania Geological Survey, aianno@pa.gov; Gale Blackmer, Pennsylvania Geological Survey, gblackmer@pa.gov; Stacey Daniels, Pennsylvania Geological Survey, stacdaniel@pa.gov.

T27. The Legacy of Coal Mining: Geology, History, Environmental Impacts, and Public Health.
Endorsed by GSA Energy Geology Division; GSA Geology and Health Division; GSA Hydrogeology Division. Jill L. Riddell, Chatham University, j.riddell@chatham.edu; Dorothy J. Vesper, West Virginia University, dorothy.vesper@mail.wvu.edu; Kyle Fredrick, Pennsylvania Western University, fredrick@pennwest.edu.

T28. Great Lakes Coastal Processes and Changes.
Endorsed by GSA Marine and Coastal Geoscience Division. Ethan Theuerkauf, Michigan State University, theuerk5@msu.edu; Anthony Foyle, Penn State Behrend, amf11@psu.edu; John Johnston, University of Waterloo, jwjohnst@uwaterloo.ca; Emma Bouie, Ohio State University, bouie.5@buckeyemail.osu.edu.

T29. Orphan Wells, Fugitive Hydrocarbons, and a Legacy of Efforts Toward a Brighter Future.
Patrick Burkhart, Slippery Rock University, patrick.burkhart@sru.edu; Joe Biaglow, Principal, Greenfields Environmental Corporation, jabman63@gmail.com.

T30. The Origin and Formation of Planetary Interiors.
Heidi N. Krauss, Michigan State University, Heidi.N.Krauss@gmail.com; Allison Pease, Michigan State University, peaseall@msu.edu; Hee Choi, Pennsylvania State University, hxc5400@psu.edu.

T31. Advances in Characterizing and Treating Contaminants in Water Resources.
Eung Seok Lee, Ohio University, leee1@ohio.edu; Ari Mukherjee, Ohio University, amukherjee@ohio.edu.

T32. Recent Research in Late Quaternary Landscapes, Paleoenvironments, and Geoarchaeology of Eastern North America.
Endorsed by GSA Geoarchaeology Division; GSA Continental Scientific Drilling Division; GSA Quaternary Geology and Geomorphology Division. Todd Grote, Indiana University Southeast, tdgrote@iu.edu; Lara Homsey-Messer, Indiana University of Pennsylvania, lmesser@iup.edu; Albert Fulton, University of Buffalo, aefulton@buffalo.edu.

T33. Tell Me a Story! Communication and Outreach in the Geosciences.
Endorsed by GSA Continental Scientific Drilling Division; GSA Energy Geology Division; GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geobiology and Geomicrobiology Division; GSA Geology and Health Division; GSA Geoscience Education Division; GSA Geochronology Division; GSA Hydrogeology Division; GSA Geoinformatics and Data Science Division; GSA Limnogeology Division; GSA Marine and Coastal Geoscience Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Quaternary Geology and Geomorphology Division; GSA Sedimentary Geology Division; GSA Soils and Soil Processes Division; GSA Structural Geology and Tectonics Division; Association for Women Geoscientists; Geoscience Information Society. Abigail Burt, Ontario Geological Survey, abigail.burt@ontario.ca; John W. Johnston, University of Waterloo, jwjohnston@uwaterloo.ca.

T34. Environmental and Engineering Aspects of Karst Terrains.
Endorsed by GSA Environmental and Engineering Division; GSA Karst Division. Wendell Barner, Barner Consulting, LLC, wendell.barner@gmail.com.

T35. Advances in Characterizing and Treating Contaminants in Water Resources.
Endorsed by GSA Hydrogeology Division, National Ground Water Association. Eung Seok Lee, Ohio University, leee1@ohio.edu; Ari Mukherjee, Ohio University, amukherjee@ohio.edu

LOCAL COMMITTEE

Co-Chairs: Northeastern Section: Patrick Burkhart, Slippery Rock University, patrick.burkhart@sru.edu; North-Central Section: Eung Seok Lee, Ohio University, leee1@ohio.edu
Vice Chair: Keith Milam, Ohio University, milamk@ohio.edu
Sponsorship Chair: Patrick Burkhart, Slippery Rock University, patrick.burkhart@sru.edu
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Technical Program Co-Chairs: Wendell Barner, Barner Consulting, LLC, wendell.barner@gmail.com; Peg Yacobucci, Bowling Green State University, mmyacob@bgsu.edu
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Student Presentation Judging Chair: Katherine Fornash, Ohio University, kffornash@ohio.edu
Student Volunteers Chair: Arindam Mukherjee, Ohio University, amukherjee@ohio.edu

Cordilleran Section

121st Annual Meeting of the Cordilleran Section

Dates: 1–4 April 2025*
Location: Holiday Inn Sacramento
Sacramento, California, USA

** Welcome Reception: 1 April 2025*
Technical Program: Starts 2 April 2025

www.geosociety.org/cd-mtg

Get ready for the 121st GSA Cordilleran Section Meeting in Sacramento, California, USA! Sacramento, located on the land of the Nisenan people, is rooted in history as the heart of the 1849 Gold Rush and the terminus of the transcontinental railroad. Today, as California's capital and the "City of Trees," it is at the center of our discussion on how to manage our limited geologic and hydrological resources.

Sacramento is at the intersection of rock, water, and society. To the east lies the majestic Sierra Nevada, with its granite batholith intruding ancient island arcs, deeply incised canyons holding massive reservoirs, and the environmental legacy of gold mining. To the west is the Coast Range, built from ophiolite and subducted rock, cut by the active faults of the San Andreas system, and now generating geothermal energy from recent volcanism. The city itself, built on the floodplain of the Sacramento River, is safeguarded by dams and levees that channel millions of gallons of water into the Delta and onward into the California Aqueduct.

We hope this meeting will serve as a forum where academia, government, the private sector, and geoscience enthusiasts can come together to discuss Earth and society. We especially encourage students from community college through graduate school, along with their future employers, to attend.

CALL FOR PAPERS

Abstracts Deadline: 28 January 2025

GSA Member Submission Fees: US$18 for students and US$30 for all others

GSA Non-Member Submission Fees: US$36 for students and US$60 for all others

If you have any difficulties submitting your abstract online, please contact the GSA Meetings Department at cordilleran@geosociety.org.

THEME SESSIONS

T1. Modeling Water Availability in the Western United States: Hydrology, Tools, Climate Change, and Uncertainty.
Wesley Henson, U.S. Geological Survey, whenson@usgs.gov; Ayman Alraizee, U.S. Geological Survey, aalzraiee@usgs.gov.

T2. Hydrothermal Systems, Processes, and Resources.
Endorsed by GSA Energy Geology Division. Owen Callahan, En Echelon Geosolutions, ocallahan@eegeos.com; Ben Melosh, U.S. Geological Survey, bmelosh@usgs.gov.

T3. Hydrogeologic Basin Characterization in California: Integrated Approaches Using Geophysical, Geologic, and Hydrologic Methods.
Nicole Koerth, Woodard & Curran, nkoerth@woodardcurran.com; Mesut Cayar, Woodard & Curran, mcayar@woodardcurran.com.

T4. Investigations of Hydrologic Resources in the Cordillera.
Endorsed by GSA Hydrogeology Division. Michelle Stern, U.S. Geological Survey, mstern@usgs.gov; Geoff Cromwell, U.S. Geological Survey, gcromwell@usgs.gov.

T5. Challenges and Advances in Characterizing Groundwater Systems in Young Volcanic Terranes of the Western U.S.
Hank Johnson, U.S. Geological Survey–Oregon Water Science Center, hjohnson@usgs.gov; Geoff Cromwell, U.S. Geological Survey–California Water Science Center, gcromwell@usgs.gov; Don Sweetkind, U.S. Geological Survey–Geosciences and Environmental Change Science Center, dsweetkind@usgs.gov.

T6. Recent Advances in Subsurface Framework to Assist Groundwater and Carbon Sequestration Applications.
Endorsed by Pacific Section - SEPM. Todd Greene, California State University–Chico, tjgreene@csuchico.edu;

David Shimabukuro, California State University–Sacramento, dhs@csus.edu.

T7. The Search for Potentially Usable Groundwater: Advances in Groundwater Salinity Mapping.

Michael J. Stephens, U.S. Geological Survey–California Water Science Center, mjstephens@usgs.gov; Lyndsay B. Ball, U.S. Geological Survey–Geology, Geophysics, and Geochemistry Science Center, lbball@usgs.gov.

T8. Cordilleran Tectonics: Integrating Field and Analytical Approaches.

Endorsed by GSA Geochronology Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Structural Geology and Tectonics Division. Terry Lee, University of Nevada–Reno, terrywaihol@unr.edu; Dominik R. Vlaha, University of Nevada–Reno, dvlaha@unr.edu.

T9. Mesozoic–Cenozoic Orogenesis along the Pacific Northwest Cordilleran Margin.

Endorsed by GSA Sedimentary Geology Division; GSA Structural Geology and Tectonics Division. Mike Darin, Oregon Department of Geology and Mineral Industries (DOGAMI), michael.darin@dogami.oregon.gov; Melanie Michalak, California State Polytechnic University–Humboldt, melanie.michalak@humboldt.edu; Rebecca Dorsey, University of Oregon, rdorsey@uoregon.edu; Kathleen Surpless, Trinity University, ksurples@trinity.edu.

T10. Cordilleran and Other Orogenic Belt Evolution from Components to Whole.

John Wakabayashi, California State University–Fresno, jwakabayashi@csufresno.edu; David Shimabukuro, California State University–Sacramento, dhs@csus.edu; Jessie Shields, University of Nevada–Reno, jessieshields@unr.edu.

T11. Mysteries of the Sierra Nevada.

Endorsed by GSA Geochronology Division; GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Quaternary Geology and Geomorphology Division; GSA Structural Geology and Tectonics Division. Craig Jones, University of Colorado–Boulder, cjones@colorado.edu; Chris Henry, Nevada Bureau of Mines and Geology, chenry@unr.edu; Matt O'Neal, California Geological Survey, Matt.ONeal@conservation.ca.gov; Peter Holland, California Geological Survey, Peter.Holland@conservation.ca.gov.

T12. Carbon Mineralization Potential of Ultramafic and Ophiolitic Units.

Megan Smith, Lawrence Livermore National Laboratory, smith447@llnl.gov; Kari Finstad, Lawrence Livermore National Laboratory, finstad1@llnl.gov; Amelia Vankeuren, California State University–Sacramento, vankeuren@csus.edu; Brad Gooch, California Geological Survey, Brad.Gooch@conservation.ca.gov; Ben Parrish, California Geological Survey, Ben.Parrish@conservation.ca.gov.

T13. Plumes, Ophiolites and Oceanic Crust: Honoring the Scientific Contributions of John W. Shervais.

Marlon Jean, Colorado Mesa University, mjean@coloradomesa.edu; John Wakabayashi, California State University, jwakabayashi@csufresno.edu.

T14. Volcanic and Plutonic Connections in Cordilleran Arcs: Integrating Studies from Extinct and Active Systems.

Barbara Ratschbacher, University of California–Davis, bratschbacher@ucdavis.edu; Katie Ardill, Texas Tech University, Katie.Ardill@ttu.edu; Madeline Lewis, University of Wyoming, mlewis48@uwyo.edu.

T15. Tectonics and Magmatism in the Modern and Ancestral Cascades Volcanic Arc.

Endorsed by GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Structural Geology and Tectonics Division. Bryant Platt, U.S. Geological Survey, bplatt@usgs.gov.

T16. Multidisciplinary Efforts to Understand Links between Cordilleran Tectonics and Volcanism.

Dawnika L. Blatter, U.S. Geological Survey–California Volcano Observatory, dblatter@usgs.gov; Seth Burgess, U.S. Geological Survey–California Volcano Observatory, sburgess@usgs.gov.

T17. Evolution of Plutons and Batholiths at Different Crustal Levels.

Endorsed by GSA Mineralogy, Geochemistry, Petrology, and Volcanology Division; GSA Structural Geology and Tectonics Division. Madeline Lewis, University of Wyoming, mlewis48@uwyo.edu; Barbara Ratschbacher, University of California–Davis, bratschbacher@ucdavis.edu; Ami Ward, University of North Carolina–Chapel Hill, ami.ward@unc.edu.

T18. Tectonic Controls on Cenozoic Magmatism in the Cordillera.

Endorsed by GSA Mineralogy, Geochemistry, Petrology and Volcanology Division; GSA Structural Geology and Tectonics Division. Cathy Busby, University of California–Davis, cjbusby@ucdavis.edu; Keith Putirka, California State University–Fresno, kputirka@csufresno.edu; Michael Eddy, Purdue University, mpeddy@purdue.edu; Sean Regan, University of Alaska–Fairbanks, sregan5@alaska.edu.

T19. Critical and Metallic Resources of the American Cordillera.

Hannah Aird, California State University–Chico, haird@csuchico.edu; Erik Haroldson, California State University–Sacramento, erik.haroldson@csus.edu.

T20. Earthquake Hazards in Applied Geology.

Chad W. Carlson, California Department of Water Resources, chad.carlson@water.ca.gov; Don F. Hoirup, California Department of Water Resources, don.hoirup@water.ca.gov; Sean L. Dunbar, California Department of Water Resources, sean.dunbar@water.ca.gov.

T21. Quaternary Geology of the Great Central Valley of California: What Have We Learned in the Past 60 Years?
Roy Shlemon, University of California–Davis, rshlemon@jps.net; Julie Griffin, California State University–Sacramento, griffin@csus.edu.

T22. Urban Estuary: Lake Merritt, Jewel of Oakland.
Jere H. Lipps, University of California–Berkeley, jlipps@berkeley.edu; Andrew Alden, Northern California Geological Society, geology@andrew-alden.com.

T23. New Frontiers in Soil Geomorphology and Geoarchaeology.
Endorsed by GSA Geoarchaeology Division; GSA Quaternary Geology and Geomorphology Division; GSA Soils and Soil Processes Division. Rebecca Taormina, National Park College, rtaormina@np.edu

T24. Current Directions in Paleontological Resource Mitigation.
Dr. Russell Shapiro, Sub-Terra Heritage Resource Consultants and California State University–Chico, rshapiro@sub-terraheritage.com; Dr. Alyssa Bell, Stantec Consulting Services Inc. and Natural History Museum of Los Angeles County, alyssa.bell@stantec.com.

T25. Make It Obvious, Make It Attractive: Recruiting and Retaining 2YC Geoscience Students.
Endorsed by National Association of Geoscience Teachers (NAGT); NAGT 2YC Division. Allison D. Jones, Sierra College, ajones124@sierracollege.edu; Theron Sowers, California State University–Sacramento, theron.sowers@csus.edu.

T26. Bridging the Gap: Strategies for Preparing Geoscience Students for the Workforce.
Theron Sowers, California State University–Sacramento, theron.sowers@csus.edu; Allison Jones, Sierra College, ajones124@sierracollege.edu.

T27. Recruiting and Training Geoscience Majors for K–12 Teaching.
Susann Pinter, University of California–Davis, CalTeach/MAST Program, spinter@ucdavis.edu; Maya Wildgoose, Vacaville Unified School District, mayaw@vacavilleusd.org.

T28. Undergraduate and Graduate Geoscience Student Lightning Talk Showcase (Lightning Talks).
Endorsed by Council on Undergraduate Research. James MacDonald, Florida Gulf Coast University, jmacdona@fgcu.edu; Hannah Aird, California State University–Chico, haird@csuchico.edu; Peter Davis, Pacific Lutheran University, davispb@plu.edu.

T29. Undergraduate Research Posters.
Endorsed by Council on Undergraduate Research (CUR) – Geoscience Division. Lydia K. Fox, University of the Pacific, lkfox@pacific.edu.

LOCAL COMMITTEE

Meeting General Chair: David Shimabukuro, California State University–Sacramento, dhs@csus.edu

Technical Program Co-Chairs: Steve Skinner, California State University–Sacramento, steven.skinner@csus.edu; Sarah Roeske, University of California–Davis, smroeske@ucdavis.edu

Exhibits/Sponsorship Chair: Julie Griffin, griffin@csus.edu

Field Trip Co-Chairs: Kurt Burmeister, California State University–Sacramento, k.burmeister@csus.edu; John Wakabayashi, California State University–Fresno, jwakabayashi@csufresno.edu

Student Volunteer and Education Chair: Theron Sowers, California State University–Sacramento, theron.sowers@csus.edu

Rocky Mountain Section

75th Annual Meeting of the Rocky Mountain Section

Dates: 18–20 May 2025
Location: Utah Valley Convention Center, Provo, Utah, USA

** Welcome Reception: 18 May 2025*
Technical Program: Starts 19 May 2025

www.geosociety.org/rm-mtg

We are excited for you to join us at the GSA 2025 Rocky Mountain Section Meeting, to be held in Provo, Utah, USA. Provo is nestled in one of the most geologically diverse settings in America. The meeting will be 3 km from the Wasatch fault, which lies at base of the actively growing Wasatch Range, marking the boundary between the Rocky Mountain and Basin and Range physiographic provinces. Provo is within an hour drive of Precambrian tillite and Mississippian limestone, Sevier and Laramide structures, Tertiary intrusives, volcanics, and ore bodies, shoreline features from Pleistocene Lake Bonneville, Pleistocene glacial morphology, and many more geologic treasures. The meeting will be held at the Utah Valley Convention Center, less than an hour drive from the Salt Lake International Airport and situated among a thriving restaurant scene in downtown Provo. Provo has been ranked by *Outside* magazine as one of the best places to live in the U.S.

CALL FOR PAPERS

Abstracts Deadline: 28 January 2025

GSA Member Submission Fees: US$18 for students and US$30 for all others

GSA Non-Member Submission Fees: US$36 for students and US$60 for all others

If you have any difficulties submitting your abstract online, please contact the GSA Meetings Department at rockymt@geosociety.org.

THEME SESSIONS

T1. The Upper Cretaceous Mancos Group on the Colorado Plateau.
Endorsed by Utah Geological Survey. James I. Kirkland, Utah Geological Survey, jameskirkland@utah.gov; Michael Ryan King, Western Colorado University, mryankingoffice@gmail.com; Josh Lively, Utah State University Eastern, josh.lively@usu.edu.

T2. Laramidia: Biota, Stratigraphy, and Paleogeography of the Late Cretaceous of Western North America.
Ethan Cowgill, Utah Geological Survey, Ecowgill@Utah.gov; Joseph Sertich, Colorado State University, Sertich.j@gmail.com; Brent Breithaupt, Bureau of Land Management, Bbreitha@BLM.gov.

T3. Time of Transition: Cretaceous Climate, Tectonics, and Evolutionary History.
Marina B. Suarez, University of Kansas, mb.suarez@ku.edu; Kate Andrzejewski, Kansas Geological Survey, k173r221@ku.edu; Landon Burgener, Brigham Young University, landon.burgener@byu.edu; Greg Ludvigson, Kansas Geological Survey, gludvigson@ku.edu; Andreas Moeller, The University of Kansas, amoller@ku.edu.

T4. Advances in Rocky Mountain Region Paleontology.
Endorsed by Paleontological Society. Carl Simpson, University of Colorado–Boulder, carl.simpson@colorado.edu.

T5. Extending the Rocky Mountains: Tectonics, Basin Evolution, and Magmatism of Continental Rifting.
Alexander Tye, Utah Tech University, alex.tye@utahtech.edu; Alyssa Abbey, California State University–Long Beach, alyssa.abbey@csulb.edu.

T6. Tectonic Development of the Rocky Mountain Region.
John Singleton, Colorado State University, john.singleton@colostate.edu; David Pearson, Idaho State University, peardavi@isu.edu.

T7. Neogene Tectonic Geomorphology and Landscape Evolution in the Intermountain West.
Matthew Morriss, Utah Geological Survey, mmorriss@utah.gov; Carlos Montejo, University of Idaho, mont7968@vandals.uidaho.edu; Nicolás Pérez–Consuegra, Weber State, nperezconsuegra@weber.edu; Yann Gavillot, Montana Bureau of Mines and Geology, ygavillot@mtech.edu; Nathan Toke, Utah Valley University, nathan.toke@uvu.edu.

T8. The Geology of State and National Parks of Utah and the Rocky Mountain Region.
Janae Wallace, Utah Geological Survey, janaewallace@utah.gov; Tyler Knudsen, Utah Geological Survey, tylerknudsen@utah.gov.

T9. Bonneville Basin: Geology of Pleistocene and Holocene Lakes.
Adam McKean, Utah Geological Survey, adammckean@utah.gov; Michael Vanden Berg, Utah Geological Survey, michaelvandenberg@utah.gov.

T10. Past and Present Glaciation in Western North America.
Endorsed by GSA Quaternary Geology and Geomorphology Division. Benjamin Laabs, U.S. Bureau of Reclamation, blaabs@usbr.gov; Leif Anderson, University of Utah, leif.anderson@utah.edu; David Marchetti, Western Colorado University, dmarchetti@western.edu.

T11. Alpine Hydrology in the Rocky Mountains.
Endorsed by GSA Hydrogeology Division. Greg Carling, Brigham Young University, greg.carling@byu.edu; Anna Bergstrom, Boise State University, annabergstrom@boisestate.edu; Matthew Morris, Utah Geological Survey, mmorris@utah.gov; Scott Hotaling, Utah State University, scott.hotaling@usu.edu.

T12. Advances and Applications in Water Resources of the Intermountain West.
Trevor H. Schlossnagle, Utah Geological Survey, tschlossnagle@utah.gov; Paul C. Inkenbrandt, Utah Geological Survey, paulinkenbrandt@utah.gov; Kathryn Ladig, Utah Geological Survey, kladig@utah.gov; Greg Gavin, Utah Geological Survey, greggavin@utah.gov.

T13. Geomorphology, Geoarchaeology, Soils, Surface Processes and Paleoclimate.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geochronology Division; GSA Quaternary and Geomorphology Geology Division; GSA Soils and Soil Processes Divisions. Nicolás Pérez–Consuegra, Weber State, nperezconsuegra@weber.edu; Jen Pierce, Boise State University, jenpierce@boisestate.edu; Tammy Rittenour, Utah State University, tammy.rittenour@usu.edu; Shannon Mahan, U.S. Geological Survey, smahan@usgs.gov; Tanzila Hanif, Boise State University, tanzilahanif@u.boisestate.edu.

T14. Innovative Climate Solutions and Relevant Science for Resilient Communities.
Endorsed by GSA Environmental and Engineering Geology Division; GSA Geoarchaeology Division; GSA Geochronology Division; GSA Hydrogeology; GSA Quaternary and Geomorphology Geology Division. Jen Pierce, Boise State University, jenpierce@boisestate.edu; Ashley Bosa, Boise State University, ashleybosa@boisestate.edu.

T15. Natural Hazards Risk Assessment, Communication and Reduction Associated with Seismicity in the Rocky Mountain Region and Beyond.
Ron Harris, Brigham Young University, rharris@byu.edu.

T16. Critical Minerals in the West: How to Lead a Once-in-a-Generation Crisis to the Best Possible Outcome.
Adrian Van Rythoven, Montana Bureau of Mines and Geology, avanrythoven@mtech.edu; Steven Emerman, Malach Consulting, SHEmerman@gmail.com.

T17. Drones in Geoscience: Advancements in Unmanned Aircraft System (UAS) Applications in the Geosciences.
Endorsed by Utah Geological Survey. Adam Hiscock, Utah Geological Survey, adamhiscock@utah.gov; Ben Erickson, Utah Geological Survey, benerickson@utah.gov; Christian Hardwick, Utah Geological Survey, christianhardwick@utah.gov; Kayla Smith, Utah Geological Survey, kayladsmith@utah.gov.

T18. Geologic Maps, Derivative Maps, and Mapping Workflows in the Intermountain West.
Zach Anderson, Utah Geological Survey Mapping Program, zanderson@utah.gov; Lauren Reeher, Utah Geological Survey Mapping Program, lreeher@utah.gov.

T19. Innovations in Geoscience Education: Effective Teaching, Research, and Curricula in the Earth Science Classroom.
Endorsed by GSA Geoscience Education Division. Doug Czajka, Utah Valley University, Doug.Czajka@uvu.edu; Rachel Atkins, Utah Valley University, rachel.atkins@uvu.edu.

T20. Undergraduate Research Posters.
Daniel Horns, Utah Valley University, hornsda@uva.edu; Cal Ruleman, U.S. Geological Survey, cruleman@usgs.gov.

LOCAL COMMITTEE

Meeting Chair: Daniel Horns, Utah Valley University, hornsda@uvu.edu
Technical Program Co-Chairs: Nathan Toké, Utah Valley University, Nathan.Toke@uvu.edu; Matt Olson, Utah Valley University, Matt.Olson@uvu.edu
Field Trip Co-Chairs: Patricia Garcia, Utah Valley University, pgarcia@uvu.edu; Daren Nelson, Brigham Young University–Idaho, nelsond@byui.edu
Exhibits & Sponsors Chair: David M. Pearson, Idaho State University, peardavi@isu.edu

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Scientific Division Awards

Congratulations to all 2024 GSA Division Award recipients! Learn more about GSA's Scientific Divisions at www.geosociety.org/divisions.

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Curtis-Hedberg Award
D. Randy Blood, DRB Geological Consulting

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Hashindra Kumari Herath, University of Arkansas

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Richard Hay Award
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Nagissa Mahmoudi, McGill University

Outstanding Contributions in Geobiosciences Award—Post-Tenure
Eva E. Stüeken, University of St Andrews

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M. Lee Allison Award for Outstanding Contributions in Geoinformatics
Xiaogang (Marshall) Ma, University of Idaho

GEOLOGY AND HEALTH DIVISION

Distinguished Career Award
Avner Vengosh, Duke University

Student Research Grant
Jenna Hynes, Cornell University

GEOLOGY AND SOCIETY DIVISION

E-an Zen Fund Geoscience Outreach Grant Award
Clare Mate, University of Missouri
Esther Oyedele, Virginia Polytechnic Institute and State University

GEOPHYSICS AND GEODYNAMICS DIVISION

George P. Woollard Award
Larry Douglas Brown, Cornell University

Seth and Carol Stein Early Career Award in Geophysics and Geodynamics
Alireza Bahadori, Springer Nature Group

GEOSCIENCE EDUCATION DIVISION
Iris Moreno Totten Geoscience Education Research Award
Lauren Huhn, Bowling Green State University

HISTORY AND PHILOSOPHY OF GEOLOGY DIVISION
Mary C. Rabbitt Award History of Geology Award
Silvia Fernanda de Mendonça Figueirôa, University of Campinas-UNICAMP, Brazil

History and Philosophy of Geology Student Award
Cheyenne Woodward, Juniata College

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O.E. Meinzer Award
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Birdsall-Dreiss Lectureship
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Richard R. Parizek, Penn State University

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Distinguished Geological Career Award
John Michael Rhodes, University of Massachusetts

Early Geological Career Award
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G.K. Gilbert Award
Charles "Chip" Shearer, University of New Mexico

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Driving Geoscience Policy: GSA's Position Statements in Action

Joshua Martin, GSA Science Policy Fellow, with contributions from MaryAnn Malinconico

INTRODUCTION AND BACKGROUND

Did you know that GSA has a series of Position Statements on important topics relevant to geoscience? Since 2001, the Geology and Public Policy Committee (GPPC) has developed **27 Position Statements** that cover a wide range of topics including education, data, climate change, and energy. These Position Statements are tools that members can use for any form of science policy outreach, and they are written for legislators, decision-makers, and the GSA membership.

Former GSA Director of Geoscience Policy Craig Schiffries has said the value of these Position Statements is that GSA or its individual members can respond quickly to a geoscience-related issue with a statement that is known to have the consensus endorsement of not just leadership but also the Society as a whole.

GSA's first Position Statements, approved in May 2001 and published in the October 2001 edition of *GSA Today*, were "Teaching Evolution" and "Scholarship and Professional Activity in Geoscience Public Policy and Geoscience Education." These first two statements took up a total of one page combined, but over time the Position Statements have evolved. GSA's current Position Statements each include a brief position summary, conclusions and recommendations, and a rationale, and their development requires careful thought and discussion.

PURPOSE

GSA's Position Statements provide an informed framework that guides the Society's advocacy efforts on policy issues and help ensure that the Society's views are consistent and credible when engaging with government bodies, industries, and the public. These statements also often serve as educational tools that inform the public and decision-makers about pressing geoscience issues. By offering expert insight, these statements help to clarify complex scientific topics and highlight the relevance of geology in addressing modern global challenges.

GET INVOLVED

GSA's current Position Statements can be found at **https://bit.ly/3XQwErU**. If you are interested in proposing a new Position Statement or assisting with the revision of Position Statements, please contact sciencepolicy@geosociety.org or consider serving on the Geology and Public Policy Committee!

How Position Statements Are Developed

STEP 1
RECOMMENDATION
Any GSA member, division, or Council member can recommend a new Position Statement to the Geology and Public Policy Committee (GPPC).

STEP 2
PROPOSAL DRAFTING
The GPPC drafts a proposal for the new statement, including a list of ad hoc committee members with relevant expertise, and submits it to the GSA Council for approval.

STEP 3
STATEMENT DRAFTING
Once approved by Council, the ad hoc committee drafts the Position Statement, and it is reviewed by the GPPC.

STEP 4
PUBLIC COMMENT
The draft is published in *GSA Today* for public comment, with revisions made as needed.

STEP 5
FINAL APPROVAL AND EVALUATION
After final approval by the GPPC and Council, the Position Statement is adopted by GSA and evaluated for revisions every 3–5 years.

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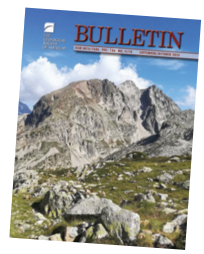

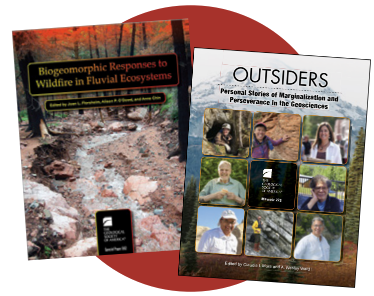

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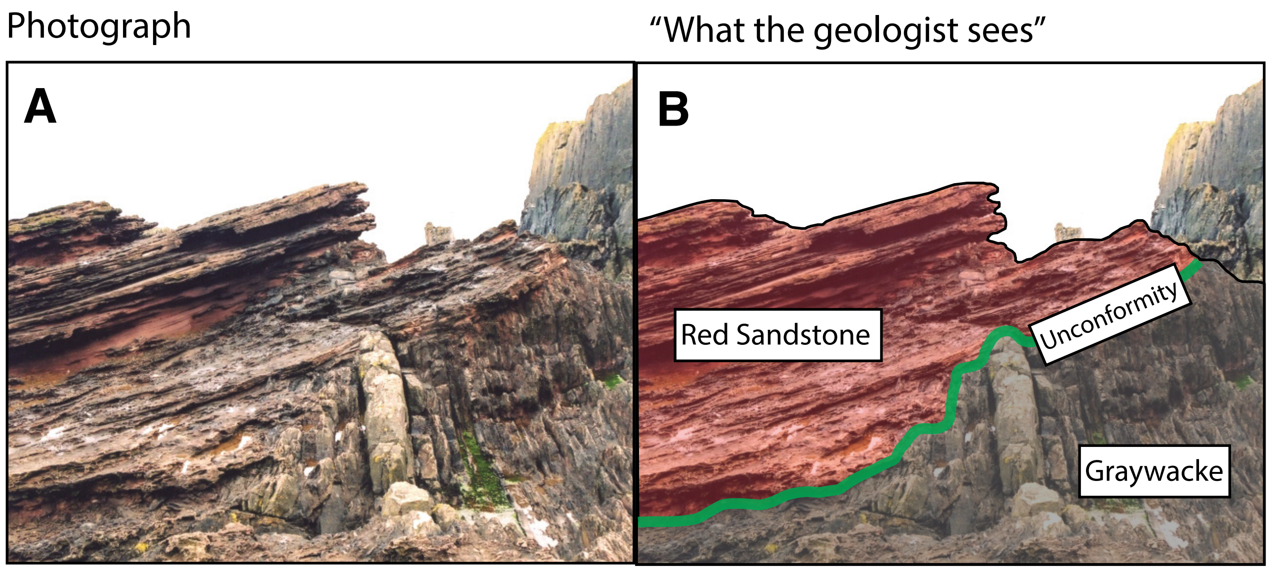

Figure 1. (A) A picture of the angular unconformity at Siccar Point, Scotland. Photo by Anne Burgess. (B) Integration of the photograph and the mental model (concept) using the approach of "what a geologist sees," adapted from Marshak (2018). This figure illustrates how professional geologists lump data ("graywacke," "red sandstone," "unconformity") to reduce cognitive load.

Siccar Point, Scotland, and the Role of Mental Models

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

"What clearer evidence could we have had of the different formation of these rocks, and of the long interval which separated their formation, had we actually seen them emerging from the bosom of the deep? We felt ourselves necessarily carried back to the time when the schistus on which we stood was yet at the bottom of the sea, and when the sandstone before us was only beginning to be deposited in the shape of sand or mud, from the waters of a superincumbent ocean. The mind seemed to grow giddy by looking so far into the abyss of time; and while we listened with earnestness and admiration to the philosopher who was now unfolding to us the order and series of these wonderful events, we became sensible how much farther reason may sometimes go than imagination can venture to follow."

—J. Playfair (1805, p. 73)

Geological logline: *The angular unconformity at Siccar Point—with its implication for significant loss of time in the stratigraphic record—is generalized into a mental model for angular unconformities.*

Cognitive science logline: *Mental models of the world incorporate knowledge about the regularities of patterns in Earth processes to identify novel cases as members of important conceptual classes.*

The angular unconformity at Siccar Point, Scotland, is iconic. Many geologists who have never been to Siccar Point can name the location when shown a picture of the angular unconformity there because they have seen the outcrop before in textbooks (Fig. 1A). Siccar Point is on the east coast of Scotland near the village of Cockburnspath, ~35 miles (56 km) east of Edinburgh. The lower, nearly vertical rocks are Silurian graywackes, a lightly metamorphosed sandstone that contains a fair amount of feldspar. The upper, shallowly dipping rocks consist of Upper Devonian red sandstones. The Silurian rocks were tilted and folded by the Caledonian orogeny, which recorded the closure of the Iapetus Ocean and construction of a mountain belt. The Devonian rocks are thought to be broadly postorogenic (colloquially called "the Old Red Sandstone") and represent an upland valley or wadi channel filled with (ephemeral) flash-flood deposits (Archer et al., 2017). The unconformity reflects 65 m.y. of time in

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which sedimentary deposition is missing from the rock record (Fig. 1B).

The unmistakable pattern of juxtaposed beddings requires an explanation: How did the different rock units get to their current position and orientation? Geologists are well aware that events leave traces, and that particular processes can lead to diagnostic patterns. What process or series of processes could have resulted in the pattern at Siccar Point? Reasoning about events that happened outside of human experience requires the mind to use analogies, drawing from the patterns of familiar events to understand the less familiar ones (see Tikoff and Shipley, 2024: *GSA Today* October issue). Sediments settling from water into horizontal beds is such an analogy, and that pattern has been codified as the "law of original horizontality."

THE UNMISTAKABLE PATTERN OF JUXTAPOSED BEDDINGS REQUIRES AN EXPLANATION: HOW DID THE DIFFERENT ROCK UNITS GET TO THEIR CURRENT POSITION AND ORIENTATION?

For sedimentary beds to be other than horizontal requires some movement to change their orientation. At Siccar Point, where events could be imagined that would change the orientation of beds, no singular event could generate beds with two different orientations. Rather, only a sequence of events that took place over time could explain this geometry: (1) The graywacke unit formed into rock; (2) the graywacke unit changed orientation; (3) there was erosion of the graywacke unit to the level of the unconformity; and (4) the red sandstone was deposited over the eroded graywacke unit. Novices and expert geologists who have engaged with this question accept that such a sequence of rock formation must have occurred over a long time.

Siccar Point is inextricably associated with James Hutton, who realized the significance of the exposure when arriving at it by boat. Hutton, aided by his field companions John Hall (chemist) and John Playfair (mathematician), understood and was first to articulate the importance of an unconformable contact. A core concept in the field of geology was born at this location: There was significant missing time represented by the unconformity surface. In an ironic twist, the term "unconformity" first appeared in a book by neptunist Robert Jameson, who opposed Hutton's plutonism. Jameson translated Abraham Werner's German phrase, which would have been literally translated as "deviating bedding." Regardless, Siccar Point expanded many minds to encompass time beyond the horizon of recorded history. With Playfair's succinct description (Playfair, 1802, 1805) and Hall's sketch of the unconformity, his companions helped Hutton convince many skeptics of an old Earth (Hutton, 1788, 1795). The argument for long time and consistent geological processes was supported by spatial logic, not by statistics or physical principles such as radioactive decay (which was not known at that time). The graywacke and red sandstone have such different orientations that they must have formed at different times. Eroded fragments of graywacke occur as angular pebbles (clasts) in the red sandstone, indicating that the graywacke was present as rock before the red sandstone became rock. We now recount these facts to students to illustrate how geological observations of the traces of past events allow confident inferences about those events. Unconformities are one of those low-level inferences that have become observations, as discussed in our first essay (Shipley and Tikoff, 2024: *GSA Today* September issue). Hutton's simple observations had the power to change minds. Why?

The question ultimately requires an answer that considers both the nature of Earth and the human mind. The only way Earth processes can form a contact with different bedding orientations is through a sequence of events in which a group of sediments was deposited, and sedimentary rocks were formed, then tilted, and then eroded; after that, another group of sediments was deposited, and sedimentary rocks were formed. This sequence of events is responsible for every angular unconformity in sedimentary rocks. The mind can mentally animate this sequence to confirm that such a sequence will result in this pattern. The pattern guides a mind to imagine events as Playfair eloquently related in the quote at the beginning of this essay. In seeing "into the abyss of time" at this outcrop, the mind has changed and can no longer believe that Earth is young (i.e., thousands of years old). Once recognized, this pattern becomes a mental model in the service of recognizing the meaning of similar patterns.

This essay highlights the important role that "mental models" play in science. Mental models are spatial abstractions of visible patterns observed in nature. The abstraction captures the key spatial properties, and the abstraction is represented in such a way that the irrelevant spatial properties are not required for recognition. Figure 1A shows a picture of Siccar Point. In contrast, Figure 2A shows a simplified sketch a geologist might make of the outcrop, and Figure 2B shows an idealized version intended to convey the abstract character of a mental model.

Although Figure 2A is arguably a more correct representation, in that it matches more of the metric spatial properties of the actual outcrop (Fig. 1A), Figure 2B is the orientation in which the processes likely occurred because it allows horizontal bedding, and it contains the unconformity (the region where there is missing time inferred from the discontinuity in bedding orientation). Thus, Figure 2B is akin to the product of mental simulation.

In the mental model of an angular unconformity, the older bedding can have any orientation. Figures 2C and 2D show different examples of angular unconformities in which the bedding in the underlying unit is variable. Despite the differences, these all fit a single mental model of an angular unconformity. Combining ("lumping") these as similar is not especially challenging, likely because the more recent sedimentary layers are in their original orientation. Figures 2E and 2F are more challenging because the younger rock sequence is no longer horizontal. Nevertheless, the expert immediately recognizes that these too are also angular unconformities. Although the configurations in Figures 2E and 2F may be less frequently observed than those in Figures 2B–2D, they do occur. Figure 3, for example, is a picture that

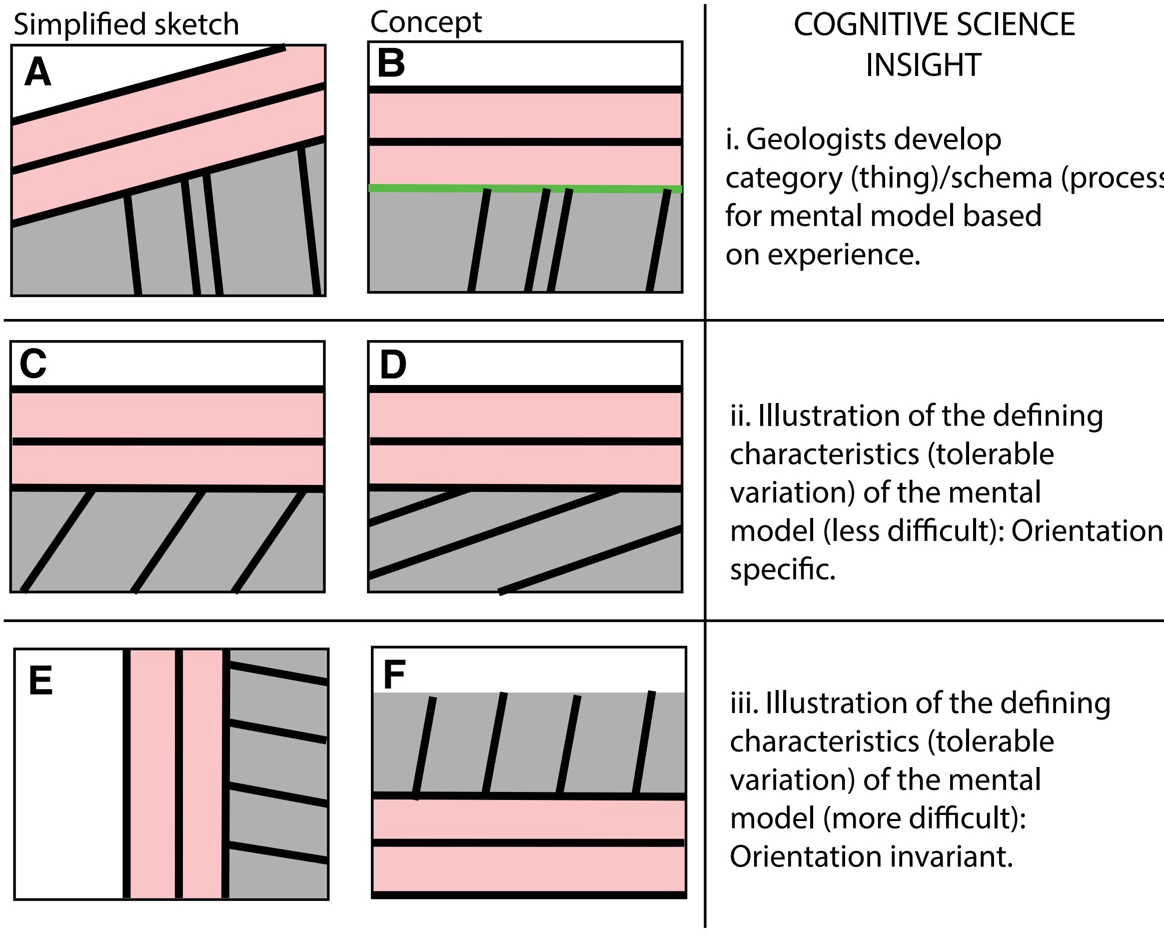

Figure 2. An attempt to illustrate the mental processing of an image from the world to arrive at an interpretation based on a mental model. We highlight three qualitatively important aspects of this process (i–iii), indicated as cognitive science insights on the right side of each of the three rows. (A) A highly simplified sketch of the outcrop. (B) The "concept" or mental model of the angular unconformity at Siccar Point, Scotland, where the green line identifies the unconformity. (C–D) Simplified sketches of different angular unconformities shown in vertical cross section, compatible with the mental model shown in B. (E) A simplified sketch of an angular unconformity in which the unconformity is vertical. (F) A simplified sketch of a different angular unconformity in which the unconformity is completely overturned.

shows overturned cross-bedding, which is a type of intraformational unconformity. Visual recognition of objects is generally orientation-dependent; it is disrupted when an object is viewed from a novel perspective. Because rocks can rotate, geoscience experts must learn to recognize important patterns, such as unconformities, in whatever orientation they appear. All of the patterns in Figure 2 fit a mental model in which some bedding ends abruptly at a contact, and the orientation of the overlying bedding matches the orientation of the contact. Thus, the mental model is flexible in some respects as to where a pattern can vary (e.g., the wide variation of the orientation of the bedding ending at a surface is permissible), whereas some aspects of a pattern are necessary conditions for a model (e.g., bedding must end at a continuous surface).

Figure 1B illustrates how the general mental model of an unconformity can be applied to this specific outcrop. When the mind begins to see the spatially separate elements as parts of a singular pattern, it is known as "unit formation." Unit formation refers to perceptually collecting separate stimuli together to experience them as a whole thing. As such, unit formation indicates statistical predictability. That is, things are treated together because doing so reflects something common to the group. In geology, parts of a formation share a common age or sequence of events that formed them, and in perception, the parts belong together in the world so that properties of each part can predict properties of other parts (as when parts of objects move together).

There is a significant body of cognitive science literature on how humans form units, beginning with the Gestalt psychologists (e.g., Wertheimer, 1923), who first recognized that a mental process grouped features, and continuing to modern accounts of object completion circuits in the brain (e.g., Weigelt et al., 2007). Shipley et al. (2013) reviewed the Gestalt principles as they apply to perception in geology. Figure 2 applies the Gestalt principles to Siccar Point. Rather than seeing a series of individual beds, experts see a package ("unit") of rocks (colored red) with a shallowly dipping orientation. Experts also see a separate package of rocks (colored gray) with a subvertical orientation. They also see the nonplanar surface between them. Note that the nonplanarity (Fig. 1) is not present in the expert's idealized mental model (Figs. 2A and 2B); it is one of the parts that is allowed to vary. Each part of the model that is fixed or variable reflects statistical regularities that arise from Earth processes. The discontinuity in bedding orientation reveals a break in time recorded in the rock. The erosional processes that caused the discontinuity do not always leave smooth surfaces, so planarity is not definitional.

Once unit formation is achieved, the model saves mental work. The owner of the model does not need to recapitulate the mental animation to confirm the meaning of the pattern. Thus, a practitioner can simply move directly from the geometrical pattern to its meaning. Evidence for this claim comes in this simple test: Look at Figure 3. Many geologists will still recognize stratigraphic up immediately, while also knowing that completely overturned stratigraphy may be relatively uncommon. In contrast, most novice geologists do not initially recognize the reoriented angular unconformities. The likely challenge for novices is that they do not treat the unconformity as a unit; before the unit formation occurs, each of the parts is processed separately. Novices first encountering Siccar Point must go beyond the properties of each part and see how they fit together as a whole. Experts may help novices to develop mental models by guiding attention to the relevant aspects of the world and being explicit about and using schematic diagrams to show which properties are definitional and which may vary from one exposure to the next.

These mental models are critical for expert geologists because they act as shortcuts that allow rapid recognition of particular phenomena. The reasoning is simple: Cognitive processing of many parts as a single package requires less cognitive work. In contrast, keeping track of separate independent things requires effort, as each additional item required to be remembered comes with a cost to the mind's ability to think about how the items might be related.

Figure 3. An upside-down stratigraphic section near Vredefort, South Africa. The cross-bedding patterns in the outcrops of the Witwatersrand quartzite, which are effectively intraformational angular unconformities, indicate that the entire section is inverted. Geologists immediately recognize the overturned stratigraphy; compare to Figure 2F. Photo by D.L. Reid (University of Cape Town).

SICCAR POINT REVEALED DEEP TIME, BUT IT ALSO REVEALS THE ROLE OF THE MIND IN ASSEMBLING EXPERIENCES INTO A WORKING MODEL THAT ENCOMPASSES GEOLOGICAL TIME.

All humans make mental models; geologists must be particularly adept at making *spatial* mental models. Basil came to realize that his field experiences had left him as a "walking library" of spatial mental models (e.g., Fig. 2B); we suspect the same is true for most field-based geologists. One's library contains unconformities, but also models of mineral habits, rock fabrics, and geological structures. Every encounter with a new outcrop can prompt a consultation of the mental library—whether conscious or not—to access relevant models tied to patterns in the data. Having a mental library of geological patterns—that come explicitly linked to a possible process or processes—is a critical resource for making geological inferences. Note that there are potential downsides to the shortcuts allowed by mental models. An important one is that with quick judgement, there is less attention to individual features as one sees what one expects to see; this situation is a visual analog of the bias engendered by a favored hypothesis (Shipley and Tikoff, 2024).

The core of Siccar Point's power to persuade is the integration of unit formation and causal processes. Although cognitive science has studied and developed accounts for how each element works in isolation, as we have discussed in this essay, the integration of these two processes in mental models is not well appreciated. This lack of attention by cognitive scientists does not reflect low frequency, as reasoning from event traces is familiar and common. For example, the sight of a crumpled bumper immediately suggests that a collision caused the deformation. One possibility is that the pattern (shape) and the process (event) are an association that is learned by rote. We find this hypothesis unsatisfactory—particularly for Siccar Point—as it does not offer an account for: (1) how Hutton, Hall, and Playfair connected pattern to process; or (2) why that connection makes a compelling argument for deep time. Cognitive science really does not offer a much better theory at this time. Yet, geologists do develop mental models to characterize patterns in terms of likely processes, in response to their minds asking, "*Why* is the world the way it is?" In this way, the geologist's scientific method complements the science of the mind by highlighting an aspect of thinking that has not been visible to cognitive science research.

Siccar Point revealed deep time, but it also reveals the role of the mind in assembling experiences into a working model that encompasses geological time. The importance of Siccar Point emerged from Hutton's deliberate search for the contact between the gray rocks he observed at St. Abb's Head to the east and the red ones he encountered in Pease Bay to the west, and then interpreting and understanding the implications of the unconformity. Humans had likely been walking past Siccar Point for a long time before one asked, “Why do those rocks look the way they do?” Once asked, a new mental model entered geologists’ libraries. A satisfactory mental model is a powerful tool, and once properly established, it functions with little effort. However, mental models adapt with the practitioner, splitting and lumping as understanding of the meanings of the patterns evolve. The challenge is to both use mental models to recognize the familiar and yet also be open to novel patterns and processes.

ACKNOWLEDGMENTS

Ellen M. Nelson is thanked for figure drafting. David Uttal first introduced Basil to the idea that he—and almost every other field geologist—carried mental models around in his mind. Reviews by J.R. Underhill and A. Egger significantly improved this manuscript.

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PERSPECTIVES

Critical Minerals Production and the Future of Mining

Gregory R. Wessel,* David H.M. Alderton, Ernesto O. Cordero, Jeffrey K. Greenberg, Etzigueri Góngora Ubeda, James A. Heller, Marli B. Miller, David K. Norman, Arthur Reis, and Tricia R. Sears†

ABSTRACT

Current projections from within and outside the mining industry highlight the need for expanded production of metals necessary to facilitate a transition to renewable energy. Mining can negatively impact Indigenous peoples, rural communities, and pristine landscapes and habitats, with harm extending far into the future. The push for critical minerals, however, provides an opportunity for mining to be part of a circular economy. A paradigm shift is necessary along with higher standards to bring all those affected together around a twenty-first-century stance that values place, people, justice, and legacy.

INTRODUCTION

Humanity is now at a unique moment in time, in which we realize that we are a destructive geologic force enabled by a reliance on fossil fuels. One solution is the acquisition of critical minerals to allow us to moderate our adverse environmental impact, but this comes with its own problems.

Pundits argue that "we need" these minerals, implying at all costs, but calling them "critical" is misleading. It is true that consumers want products constructed from these minerals, but their absolute necessity is another story. For example, a current Smithsonian exhibition on the "Cellphone: Unseen Connections" includes a display that explains, "If everyone in America uses their phone a year longer on average, it would equal the emission reduction of taking 636,000 gasoline-powered cars off the road."

Future consumer demand will determine how much of these minerals we will need. With ongoing research into the recycling of critical elements, it is foreseeable that the need for them in 10 years may be very different than projected today. For the near future, mining is necessary, but there are alternatives to contemporary mining practices.

ENHANCED STANDARDS FOR SUSTAINABILITY

Most of us are familiar with the definition of sustainability (Fig. 1). Current mining practices do not meet sustainability standards, but as we transition from a fossil fuel–based economy to one based on materials, it will be imperative for the critical minerals underpinning these future materials to be sourced and used responsibly with sustainability in mind.

Because the impacts of mining operations emanate from specific point sources, the industry is uniquely positioned to improve its performance and the public perception of its value. This can be achieved by first following the principles of responsible mining as promoted by groups like the Initiative for Responsible Mining Assurance (IRMA). From there, society can continue elevating those standards to accomplish sustainability goals.

Raising standards will increase production costs of critical minerals because we have not attempted to count the true costs of mining until now. However, corporations now realize that serving the public good is also good for the bottom line (PwC, 2023).

For mining, the general standards that industry should meet include:

- All benefits and costs must be measured using full-cost accounting.
- Activities must be consistent with the United Nations Sustainable Development Goals.
- Only temporary or reversible impacts are allowed. There shall be no permanent contamination.

Figure 1. Definitions: Sustainability vs. responsible mining. See Jarvie-Eggart (2015).

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- Mining must respect the priorities and preferences of Indigenous and other local residents.
- Mining must include restoration of habitat and topography to mimic preexisting conditions and eliminate legacy hazards that endanger humans or wildlife.
- Restoration shall include rewilding and habitat enhancement.

Implementing these standards would move the industry toward a sustainable circular economy by minimizing waste, recycling or repurposing discarded materials, and reducing the demand for new raw materials (Fig. 2). Miners can prioritize the following alternative sources of mineral resources in place of new discoveries:

(1) Mining "anthropological resources," also known as recycling. As pointed out by Sackett (2016), much if not most of the metal available to mining is already above ground, in use, in infrastructure, or in waste. For this reason, truly sustainable anthropological metabolisms must be part of a larger cycle in which waste is the first step to regenerating a future consumable.

(2) Existing wastes, tailings, or waste streams at active mine sites: The waste streams produced in various stages of ore processing present an opportunity to optimize material reutilization through a circular economic approach.

(3) Treating abandoned mine waste for the simultaneous purpose of remediation: Wastes may contain elemental concentrations that were once unappealing but are now valuable. These sites often require remediation to mitigate environmental impacts; reworking them can be part of the remediation.

(4) Reworking existing districts or previously mined deposits: With rising metal prices, deposits with uneconomic concentrations may now be economically viable, and some deposits may host minerals that we did not value until now.

(5) Exploiting virgin resources via conventional exploration and development practices is what we have always done, but this should be a last resort after exhausting the non-virgin alternatives above. When it is necessary, opening new mines in virgin areas should only be done if all impacts and costs can be fully mitigated, with no long-term impact to society or the environment.

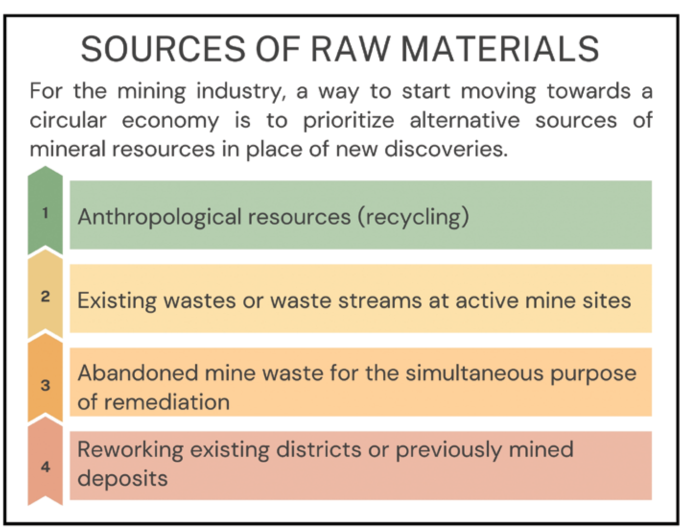

Figure 2. Sources of "ore" materials for the mining industry, ranked in the suggested order of importance.

With these considerations, let's examine three pending mining projects, including two that could become disasters and a third that might be a model for the near future.

Pebble Mine, Alaska

The Pebble Mine proposal called for an open pit in the middle of wetlands and watershed feeding into Bristol Bay, Alaska. The area is known as "America's Fish Basket" because it is home to the world's largest salmon fishery.

Developers wanted to excavate a pit 1 mile (1.6 km) wide and 0.25 miles (0.4 km) deep, destroying 3000 acres of wetlands and more than 21 miles (34 km) of salmon streams. Opposition to the project included the entire Alaska congressional delegation, a consortium of Native tribes that represent 80% of the people who live in the region, and the Environmental Protection Agency (EPA).

In 2023, the EPA issued a final determination that effectively precludes the mine's development, and in April of this year, the U.S. Army Corps of Engineers reaffirmed that it would not issue a key permit. Ordinarily, that would mean the end of a project that was poorly conceived from the start, but now the developer and the State of Alaska are suing to invalidate the EPA's findings (BBNC, 2024; Safina and Reynolds, 2023).

Oak Flat, Arizona

Discovered in 2004, the Oak Flat deposit in Arizona could not be mined unless the land was first transferred out of federal government ownership. For that reason, Resolution Copper, a joint venture of BHP Billiton and Rio Tinto, lobbied Congress to pass a law allowing a land swap. The current plan is to block-cave the deposit, creating a crater 2 miles (3.2 km) wide and 1000 ft (305 m) deep within an area sacred to the Western Apache people, including those at the neighboring San Carlos reservation. Several versions of a land-exchange bill were petitioned, but each received pushback until 2014, when proponents slipped the land exchange into a midnight rider to the National Defense Authorization Act. Few knew about it until it was unveiled after 11 p.m. the evening before the bill came up for consideration. It had been impossible for the land exchange to stand on its own feet; nevertheless, it was signed into law 2 weeks later (Redniss, 2020).

The fight is not over. The Biden administration withheld approval of the environmental impact statement but the project has also been working its way through the court system. Apache Stronghold, a 501(c)3 nonprofit dedicated to defending holy sites and freedom of religion, objected to a March 2024 appeals court ruling and they are now before the Supreme Court. A ruling there may come as early as December, 2024, but that may not decide the fate of Oak Flat (Smith, 2024).

Thacker Pass, Nevada

The Thacker Pass deposit in northern Nevada contains an estimated 3.7 million metric tons of lithium reserves. Lithium exists in unusually high concentrations (up to ~9000 ppm) within altered lake beds in the McDermitt Caldera.

Lithium Americas received authorization to begin mining after a rigorous permitting process, and it may turn out to be an example to which other operations can look for guidance. Continuous open-pit mining will occur entirely above the water table, with mined areas backfilled as the mining proceeds, allowing for a high degree of reclamation (NVDEP, 2023).

Lithium Americas is a pending member of IRMA. Thacker Pass may easily meet IRMA's standards for responsible mining and could very well surpass those standards if the enhanced standards described above are given priority.

CONCLUSION

Because the impacts of mining last for generations, society needs to plan generations ahead. This is a paradigm shift for the industry, but not an unimaginable one. What we need is a universal protocol for mining that goes beyond responsibility and that can be applied everywhere on the planet. We are forming a team to address that need, with a goal of presenting a draft framework for twenty-first-century mining within 12 months. If you are interested in participating, we invite you to contact us (info@thegngs.org).

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GEOLOGY THROUGH THE LENS

Geothermal Gem

The Grand Prismatic Spring in Yellowstone, a striking example of geothermal activity. The vibrant colors are created by thermophilic bacteria thriving in the hot, mineral-rich waters. This iconic hot spring is part of the Yellowstone Caldera, one of the largest active volcanic systems in the world.

Stephen Gao is a professor of geology and geophysics and the chair of the Earth Sciences and Engineering Department at Missouri University of Science and Technology in Rolla, Missouri.

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Celebrating Excellence in Soil and Paleosol Science: Announcing the Peter W. Birkeland Distinguished Career Award

We are excited to announce the establishment of a new fund, the Peter W. Birkeland Distinguished Career Award, named in honor of the esteemed geologist Peter Birkeland. This fund is dedicated to recognizing and celebrating individuals who have made exceptional contributions to advancing soil and paleosol science.

The creation of this fund has been a true labor of love, led by Pete's son Karl Birkeland in partnership with the GSA Foundation and scientists from the GSA Soils and Soil Processes Division. Their unwavering dedication has been pivotal in bringing this vision to life.

Pete Birkeland, enjoying a winter day in North Boulder Park, Boulder, Colorado. Photo courtesy of Karl Birkeland.

See p. 31 for inaugural award winner

Pete Birkeland's research and teaching laid a strong foundation upon which his students could build their scientific knowledge, thereby empowering them to expand their expertise and make significant contributions in their fields. These students have, in turn, become the pillars supporting future generations of geoscientists, ensuring that Pete's legacy continues to inspire and empower. This model of success reflects the mission of the GSA Foundation, your trusted partner, in nurturing the next wave of scientific leaders. Each year, as our portfolio of endowment funds expands and grows, so does our ability to support the development of emerging geoscientists.

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